

Virtual Chemistry Laboratory as a Chemistry Teaching Tool for the Mobile Platform

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Abstract: In the Philippines, the fight to improve science literacy is an uphill battle. This is because schools are unable to cope with the transition to K-12, an academic reform designed to improve the quality of education, as they are left behind with inadequate materials and insufficient infrastructure for the new system. Chemistry education is greatly affected because the lessons and modules in chemistry are highly conceptual and difficult to visualize. Due to this, laboratory activities are needed so that students can apply and experience concepts they have learned in the classroom. However, schools in the Philippines, especially those in the public sector, do not have the necessary equipment and space for these activities, promoting the negative feedback loop of students being disinterested in the sciences. To address this, this research aims to create a mobile-based Virtual Laboratory Application to provide chemistry educators with an easy-to-use, cost-effective, and portable substitute for laboratory activities by providing teachers and students with a virtual laboratory that can be used regardless of whether internet connection is available or not.

Key Words: Chemistry Education, Virtual Laboratory, Virtual Chemistry Laboratory, Mobile Virtual Laboratory

1. INTRODUCTION

In the Philippine educational landscape, many public high schools lack access to fully equipped science laboratories, especially for chemistry (Bete, 2020; Jaca et al., 2018). This persistent challenge has hindered the ability of students to engage in hands-on experimentation, a critical component in understanding complex chemical concepts. Although some private institutions and urban schools are able to facilitate laboratory work, a significant number of public schools rely heavily on textbooks, teacher demonstrations, or theoretical instruction alone (Jaca et al., 2018). Virtual laboratories have emerged globally as a promising solution to this gap, offering interactive simulations that

mimic real world experiments. However, in the Philippines, the integration of virtual lab technology remains limited. Existing platforms are either inaccessible due to high subscription costs, lack of localization, inability to be used or accessed without internet, or misalignment with the Department of Education's K-12 curriculum. Moreover, most of the available simulations are developed abroad, often without considering the technological constraints of local classrooms. Recognizing this, our team sought to address the absence of an accessible, curriculum-aligned digital chemistry laboratory designed for Filipino students. Our project proposes the development of a virtual chemistry lab designed specifically for senior



high school learners in public institutions that can be used offline. The platform allows students to safely conduct simulated experiments, such as neutralization, flame tests, and titration, using a modular interface that mirrors actual lab processes. This paper presents the development process of our system, covering the research background, design decisions based on interviews with high school chemistry teachers, implementation highlights, and future development goals. By showcasing sample pages and features of the application, the aim is to demonstrate the potential of our project to support equitable, high-quality science education in the Philippines.

2. RELATED WORKS

2.1 Digital Learning Environments

Jiang et al. (2024) proposed a flipped classroom learning model that aims to address monotonous classroom content and low student engagement in traditional learning. The personalized recommendation model improved some of the experimental group's attributes, such as autonomous learning ability, learning satisfaction, participation, problem-solving ability, and classroom time utilization efficiency. Lin et al. (2017) investigated the effects of digital learning on learning motivation and learning outcomes. The study revealed that digital learning presents better positive effects on learning motivation and learning outcomes than traditional teaching does. Learning motivation was also shown to have a significant positive effect on learning outcomes and learning gains. It was also stated that the integration of digital learning into classroom teaching does not only benefit students, but teachers as well.

2.2 Virtual Learning Environments

Alkhatib et al. (2023) developed a virtual laboratory that connects students to labs on campus in real-time, which allows students to remotely build virtual systems that perform experiments involving logic gate systems. The results indicated that most learners

were satisfied with the virtual laboratory, with learners averaging only 15 minutes in figuring out how the virtual laboratory worked. Dung (2020) explored the advantages and disadvantages of virtual learning, investigating students' and teachers' perceptions of this mode of learning. Overall, virtual learning was perceived positively by students, who recognized extra time for studying, new ways of learning, and ease of access to learning resources as its advantages. However, disadvantages such as exposure to screens for an extended period of time, lack of body movements, lack of development of social skills, and fear of online assessments were cited as some of the more prevalent ones. Makransky et al. (2016) proposed that simulations will enhance student learning by deepening their understanding of genetic testing methods by allowing them to interact, choose, and perform these laboratory tests. The results of the study indicate that the use of the virtual learning environment increased the students' motivation, interest, confidence, and overall understanding of concepts.

2.3 Virtual Laboratory Environments

Herga et al. (2016) presented a way of effectively using virtual chemistry laboratories by implementing dynamic visualization techniques. The research highlights the macroscopic level, the symbolic level, and the level of particles – sub-microscopic level, which are the three levels students need to consider when dealing with chemistry. The results imply that using the virtual laboratory increased students' knowledge retention, understanding of concepts, and cognitive performance. Jagodzinski and Wolski (2014) explored how natural user interfaces could be used in education. The researchers specifically tackled how a Kinect could be used in a virtual chemistry laboratory designed for middle and high school students. The study concluded that students who worked using the virtual laboratory were more engaged in the activity when they moved on to working in a real laboratory setup. The virtual laboratory also improved the students' ability to solve laboratory problems and design new laboratory



experiments. Peechapol (2021) investigated the effect of virtual chemistry laboratory simulations on first-year undergraduate students' learning achievement, self-efficacy, and learning experience. The study tested a control group that used traditional learning methods (lectures) against the experimental group that used a virtual laboratory to learn. The results showed that the virtual laboratory positively affects learning achievement, self-efficacy, and learning experience. The study also highlighted that students who used the virtual laboratory to supplement the lecture had a higher knowledge and self-efficacy score than those who only learned through the lecture. The virtual lab also positively affected students as it encouraged learning motivation, made it easy to understand the concept through visualization and practice, learned with theory and quiz questions, and received progress feedback.

3. METHODOLOGY

3.1 Data Gathering

To develop the application, the needs of the target demographic must be evaluated through inquiry, which will be chemistry educators for junior high school. Then, based on the requirements of the target demographic, an application will be designed and developed based on these requirements. After development, a limited real-world test of the application with a small group of students and educators will be conducted in order to gather feedback and evaluate the success of the application. A school that will benefit heavily from the application, which is the target demographic, will be searched for. Ideally, this school should have inadequate laboratory facilities with a junior high school department. Once a school has been identified, the request for approval and consent from the appropriate offices and personnel to conduct requirements gathering, application testing, and surveys and interviews in the school will be done. Currently, there are two prospective schools that are being taken into consideration, both of which are located in Santa Rosa, Laguna. Three to five chemistry educators teaching junior high school students will then be asked to be interviewed about issues with the application, and insights into the teaching experience. Their perception

of an application that could simulate laboratories and how it could possibly improve or affect teaching will also be asked.

3.2 Software Design Implementation

Based on the answers of the educators, the designing of the interface and features of the application will begin. There are multiple tools and programs that could be used to develop the software. Unity was chosen as the game engine as it suits the needs for the development of the application. The program will be developed on PC and will be loaded into mobile devices for testing. Each laboratory activity will be defined as a dictionary data-structure to store individual aspects of the activity such as the description, the laboratory procedure, instruments to use, and chemicals involved, and their respective values. As mentioned in the scopes and limitations, to reduce storage requirements and offer great extensibility, chemical interactions will not be accurately simulated, but their interactions will be defined as a set of tags in their properties. An educator creating a custom activity would only need to define these properties for chemicals that will be used in the experiment. Additionally, to ensure the accuracy of the chemical reactions and simulations, the application will be evaluated by chemistry educators and chemists during the design and development phases. The software will be developed and pre-packaged with at least one laboratory activity that the educators in the chosen school currently teaches to serve as an acceptance criterion of a minimum viable product. To ensure accessibility in environments where internet connectivity is limited or unreliable, the application will be designed to operate offline. All necessary data, including pre-packaged laboratory activities, chemical properties, and interaction rules will be stored locally on the device. This will allow full functionality of the application without the need for an active internet connection and can be used seamlessly in any classroom setting.

4. THE SYSTEM

The Virtual Chemistry Laboratory is a mobile-based educational platform using Unity as the primary game engine, designed specifically for Junior High School chemistry instruction in the Philippines. Designed for Android devices, the application is built with a combination of C# scripting, local and cloud

database support, and a game-based educational structure to simulate high school chemistry lab experiments in under-resourced settings. Its design and core features were shaped by extensive consultations with chemistry educators, focusing on classroom realities such as a lack of lab facilities, limited resources, and the need for engaging, low-cost tools.

4.1 Design Rationale

Interviews with chemistry educators, provided key insights that helped shape the system. Most public schools in the country struggle with functional laboratory spaces and materials, causing teachers to rely on improvisation with household items. Although existing tools like Labster and PHET were used, they were found to be too technical or too data-intensive for the students. The teachers noted that students respond most positively to simulations that are visual, interactive, and, most importantly, safe. Additionally, teachers expressed a strong desire for tools that allow for customization, offline access, and the integration of student assessments. In response to these needs, the system was designed with the following key features:

- Accessibility on Android smartphones,
- Full offline functionality, with internet access required only for syncing or downloading new experiments,
- Activity customization options for teachers,
- A 3D interactive lab environment, designed with simplified controls, ideal for younger learners.

4.2 Application Overview

The system consists of a single mobile app that can be used by both students and teachers, with different login options for each role. Upon logging in, the app adapts to the user's needs based on their role, providing tailored features for both groups.

For Students, the app offers a virtual lab environment where they can perform simulated experiments, shown in Figure 1. It includes pre-packaged modules such as the flame test, gas laws, and acid-base reactions. The app provides visual and text-based prompts, built-in safety notes, and immediate feedback on the students' actions.

For Educators, the app allows teachers to assign, customize, and preview experiments. It features a drag-and-drop activity builder, a student performance tracker, and classroom dashboards for monitoring

progress. Teachers can also export and share lab activities via small files, facilitating collaboration and resource sharing.



Fig. 1: The application's laboratory interface

4.3 Application Flow and Design

The system is structured around a gamified user flow to enhance student engagement while preserving educational rigor. Upon launch, users encounter a login screen that determines their access level: student or teacher. Students are brought to an Activity Menu, where they can select from ready-made experiments such as flame tests or acid-base reactions. Teachers, on the other hand, can assign existing experiments or create new ones using a drag-and-drop Activity Builder. Once an activity is selected, the user enters the 3D lab environment, where virtual tools and substances can be manipulated through intuitive controls.

Within each simulation, students receive real-time guidance through text prompts and safety notices. After completion, a quiz automatically follows to assess comprehension using multiple-choice or short-answer formats. Student responses are saved locally and optionally synced to a cloud database, allowing teachers to review class performance through a dashboard.

4.4 Technical Implementation

The application is built using Unity for its lightweight deployment on Android and flexible support for 3D interaction. All scripts are written in C#, handling user input, simulation logic, and dynamic content loading. To manage user data and activities, the system integrates Supabase. A local database stores student

progress, quiz scores, and offline-created activities and the cloud database allows activity sharing, teacher account syncing, and centralized performance tracking. This hybrid model allows the application to function without consistent internet access—critical for classrooms with unreliable connectivity—while enabling cloud-based collaboration and data management when possible.

4.5 Key Features

- **Virtual Laboratory:** Students explore a 3D lab environment with interactive tools and guided simulations. For example, the Flame Test module lets students select salts and observe resulting flame colors, which can be seen in figure 2, in a controlled setting.
- **Custom Activity Builder:** Teachers can create new experiments by selecting glassware, reagents, instructions, and quizzes. The builder includes form-based input fields and live previews for each step. Figure 3 shows the screen for defining the instruction in the activity.
- **Student Assessment and Feedback:** Each experiment ends with a quiz tailored to the activity, the quiz creation interface is shown in Figure 4. Formats include multiple choice, fill-in-the-blank, and short answers. Feedback is provided immediately, helping reinforce learning.
- **Performance Visualization:** Teachers have access to visual analytics of class performance, enabling them to track student activity and identify learning gaps. Figure 5 shows the timeline of a student conducting an activity, where progression is marked with green and mistakes made by the student in performing the activity are marked in red.
- **Offline-first Design:** All core features work without internet access. Synchronization to the cloud occurs only when a connection is available, preventing reliance on continuous connectivity.



Fig. 2: Simulated Flame Test Activity inside the virtual lab

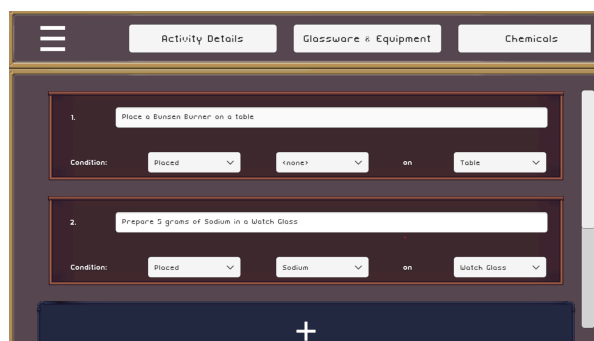


Fig. 3: Making instructions in the Activity Builder

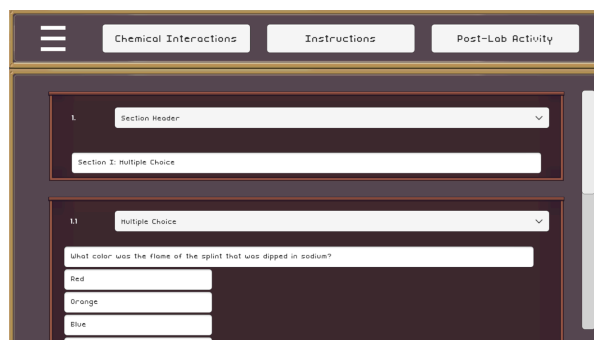


Fig. 4: Sample-post-lab quiz creatopm interface

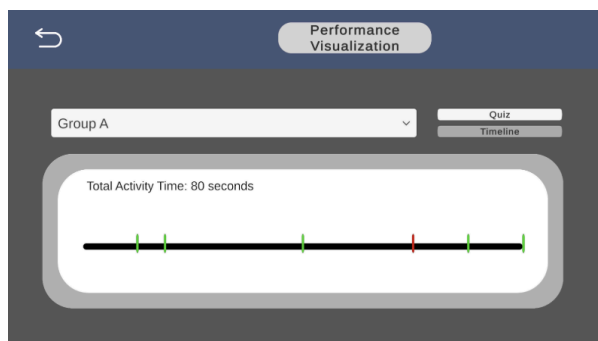


Fig. 5: Teacher dashboard displaying student activity and scores

5. FUTURE WORK

As of writing, the Virtual Chemistry Laboratory remains under active development and has not yet been deployed in classroom settings. While several of the core features—such as the virtual laboratory environment, offline functionality, and activity customization—have been internally tested, there are key areas identified for enhancement and expansion based on feedback from educators and development goals. A primary direction for future work is the implementation of structured pilot testing in partnership with public schools. These field tests will allow the research team to gather data on student learning gains, user engagement, and usability. At present, most features of the system remain in partial development, with core functionalities such as experiment simulation and quiz integration nearing completion. A major focus lies in refining the user interface and improving the visual design of the application. Current prototypes rely on placeholder assets available within the Unity Engine, and future versions are expected to incorporate custom-designed graphics and animations to enhance engagement.

To manage development scope and ensure quality, it was also suggested to focus on the full implementation of a single laboratory activity - specifically, the flame test - as a showcase of the application's core capabilities. This will allow the team to refine all elements of the activity, including 3D interaction, instructions, quiz integration, and teacher customization, serving as a proof of concept for the broader system. The project will focus on deploying this working prototype in a partner local high school, where it will be tested in a real classroom environment with

student and teacher participants. This final phase will serve as the foundation for collecting user-driven insights to further refine the system and prepare it for broader use.

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