Virtual Chemistry Lab to Virtual Reality Chemistry Lab[*]

N. S. Sreekanth, Nobby Varghese, N. Sarat Chandra Babu

The recent Covid-19 pandemic has brought about drastic changes in the teaching-learning process. We witnessed a paradigm shift from conventional classrooms to virtual online learning. Although online learning is not a new concept, the covid-19 pandemic situation came with subsequent restrictions that shook the entire school educational system. Education has become highly uncertain for the time being, especially in India. This has been more evident in rural and village areas where the teaching-learning process does not include technology-enabled methods. Over one year, we have observed that conducting theory classes through online conferencing and virtual classroom software systems has become very common, and students are coping with it. However, in an online environment, students miss out on the practical aspects, i.e., laboratory experiments which are an essential part of science and engineering education. Software-based virtual labs are available, but they lack the real feel of performing an experiment, especially getting familiar with the laboratory apparatus. In this context, the present article proposes an innovative teaching-learning system that helps conduct chemistry volumetric experiments through a hardware-enabled platform named *avatar-shell*. The proposed system helps students develop titration skills using the actual apparatus. However, while performing experiments with the *avatar-shell*, we don't need to use real chemicals; instead, we use ordinary water. The proposed virtual reality chemistry laboratory system comprises two units—the administrator module for teachers to configure the experiment with


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appropriate molarity associated with a solution and the simulator module for students to perform the volumetric analysis. The simulator module *avatar-shell* comprises a high sensitive weight sensor, which communicates with the administrator module and verifies the correctness during every instance of titration. *avatar-shell* can connect to the administrator module via the internet, and teachers can monitor the experiment through a mobile-based application.

Keywords
Chemistry, online education, virtual learning, virutal lab, titration, experiments.

Introduction

Virtual learning or online learning has become popular and the norm of the day in schools due to the recent Covid-19 pandemic. While conventional online learning required both students and teachers to spend time in front of the computer system, the evolution of smartphones with a wide variety of sensors could avoid such monotonous interactions during online learning.

The advancements in Information and Communication Technology (ICT) has revolutionized the teaching-learning process (TLP) by embedding technologies as part of the process. Adopting a technology-driven teaching-learning environment enhances the learning experience and helps reach out to the larger population irrespective of the physical location. Virtual learning or online learning has become popular and the norm of the day in schools due to the recent Covid-19 pandemic. While conventional online learning required both students and teachers to spend time in front of the computer system, the evolution of smartphones with a wide variety of sensors could avoid such monotonous interactions during online learning. The development of IoT (Internet of Things) and sensor-enabled technologies combined with smartphone-based applications provide a higher level of freedom to learners and trainers so that TLP becomes interesting. Organizing theory classes over internet-based platforms became a common practice, and both the stakeholders have gotten used to this method over the past year. However, when it comes to science education, we observe a huge gap in online-based TLP in the context of laboratory-based practical learning. The scientific experiments carried out in the laboratory environment play a significant role in understanding the concept, and it also helps the students to explore new possibilities. Virtual laboratories are considered an affordable alternative for enabling students' laboratory experience in online learning. Nowadays, software-based, keyboard, and mouse-driven virtual lab solutions are widely available. Though this approach lacks the real feel of doing an actual experiment, it can be used as additional material for learning the experimental concept. Ensuring the sense of an actual laboratory experiment through a virtual environment is always challenging, especially when it comes to science and engineering streams, and software-based labs will definitely lack the experience of handling real apparatus and reagents.

In this context, the present article proposes a hardware-based simulation platform *avatar-shell* for performing volumetric analysis in chemistry for secondary and senior secondary students. Unlike other software-based virtual labs, the proposed system helps students get familiar with the usage of various laboratory apparatus in chemistry, like a pipette, burette, conical flask, etc. Especially in chemistry, the students may have to handle hazardous chemicals for experiments; hence, it always restricts the experiments as they must be performed under the teachers' supervision, especially in schools. The proposed system will replace the use of actual chemicals with normal water, but the lab apparatus used for volumetric analysis can be retained in the proposed hardware-based virtual environment. Since we use the actual apparatus, students still feel the experience of conducting the experiments in a real environment. This model will also enable the students to do as many as hands-on to get familiar with the experimental environment without wasting chemicals. The system will also provide effective feedback to the student while doing the experiment. The proposed augmented virtual reality based laboratory environment has two major components. An administrator module for teachers to configure the experimental environment for the students and a hardware-based simulator *avatar-shell*, which enables the students to perform the experiments in an augmented virtual reality environment.

The present article proposes a hardware-based simulation platform *avatar-shell* for performing volumetric analysis in chemistry for secondary and senior secondary students. Unlike other software-based virtual labs, the proposed system helps students get familiar with the usage of various laboratory apparatus in chemistry, like a pipette, burette, conical flask, etc.

The system also has an advantage over the real environment, where the teacher may prepare two or three different concentrations of a solution, and its molarity needs to be calculated in a given lab session for a batch of students. Knowing the results well in advance, students can simply perform the titration till near the neutralizing point, after which they can carefully get the required equilibrium point for evaluating the molarity of a solution. This method may not help to develop essential titration skills, where they have to be very careful during every instance of the experiment. The advantage of this model is each experiment can be configured with a range of values so that experimenting in a known result environment can be avoided.

Virtual Labs for Science Education – Limitations

One of the popular systems in India for conducting virtual labs for school and intermediate education is OLabs. OLabs uses interactive simulations with theory, procedure, animations, videos, assessments and reference material.

In this section, let us discuss some of the popular virtual lab systems proposed for fundamental science subjects and, more specifically, for chemistry. One of the popular systems in India for conducting virtual labs for school and intermediate education is OLabs [1]. OLabs uses interactive simulations with theory, procedure, animations, videos, assessments and reference material. OLabs and all similar virtual lab environments present the 2D computer images of chemical reagents, glassware and instrumentation, which can be manipulated using a keyboard and mouse driven interface. As it is a keyboard and mouse driven interface, it lacks the real experience of performing the experiment, and may only be effective for someone familiar with the real experimental apparatus. The effectiveness of conventional software-driven and virtual lab environments has been studied empirically. It is reported that e-lab is an effective pre-physical laboratory training tool as it allows students to develop skills required for conducting hands-on experiments. There are some cases when using an e-lab is preferred or is the only possible way of teaching and learning. For example, distance learning and the impossibility of conducting a physical chemical experiment (lack of equipment, safety concerns, time constraints) [2]. There are a variety of virtual lab-based solutions for physics and mechanical streams. An ideal virtual laboratory should have the functionalities to simulate instruments' assembly and disassembly processes. The work carried out by Dongfeng Liu et al. on Game Based Intelligent Science Tutoring system (GISTS) provides instrument manual, auto assembly, assembly animation for teaching, and simulation, through which the user can design and setup his/her experiment, simulate the experimental processes, and obtain the corresponding experimental data [3]. Beach and Stone (1988) highlight that the most efficient way of chemistry education is through laboratories and that "chemistry education without laboratory is like painting without colors and canvas or learning how to ride a bike by reading its operating manual" [4]. Hence providing a virtual reality lab rather than a virtual lab is highly preferable in science and engineering. The proposed method is an effort to attempt the same.

How Avatar Works?

Consider a typical volumetric analysis experiment performed at the secondary or senior secondary level to find the concentration of Na (sodium) in a given NaOH (sodium hydroxide) solution using a known concentration of HCl (hydrochloric acid). In the conventional method, the user/student has to take a known volume of NaOH solution using a pipette in a conical flask. For example, the volume of NaOH in the conical flask is 20 ml. The burette is to be filled with HCl. One drop of indicator (phenolphthalein) is to be added to NaOH. The NaOH solution in the conical flask turns pink after adding phenolphthalein. The pink coloured NaOH solution (its molarity needs to be determined) is to be titrated against HCl (molarity will be given), which is filled in the burette. The HCl should be added drop by drop until the NaOH solution turns colourless, and the corresponding burette reading is to be noted down. The experiment should be repeated, and the average result taken for calculating the molarity of Na in the NaOH solution. For example, the average reading of burette is V_{acid}, i.e., the average reading of HCl consumed, which makes the solution in the conical flask become colourless.

The molarity of NaOH, i.e. M_{base} is determined using the equation given below

[Molarity × Volume] of acid = [Molarity × Volume] of base

$$M_{\text{acid}} \times V_{\text{acid}} = M_{\text{base}} \times 20$$

$$M_{\text{base}} = (M_{\text{acid}} \times V_{\text{acid}})/20$$

The proposed augmented virtual reality-based system imitates the conventional method using water instead of chemicals to perform the experiment. In the virtual reality environment, students have to use the apparatus pipette, burette and conical flask and also have to carry out the procedure as if they are experimenting in the real environment. Students will be provided with a highly sensitive weight sensor (load cell) mounted platform *avatar-shell* to perform the experiment. The conical flask will be placed over the highly sensitive weight sensor platform *avatar-shell*. During the titration process, while adding the solution (water) from the burette, the weight of the solution in the conical flask will be calculated and checked for the breakeven point (neutralizing point), which is equivalent to the colour change in the conventional experimental scenario. Through the administrator/configuration module, a teacher can virtually set the molarity (concentration) of both the solutions, i.e., water (known molarity) and other unknown solution, with respect to each student who is connected to the administrator module. In a virtual reality chemistry lab scenario, virtually configuring the molarity of the solution is done by the teacher through administrator module by configuring the student lab *avatar–shell* to respond to a given volume of water dropping from the burette during the titration process. The response for the breakeven point from *avatar–shell* will be indicated as a LED glow/dim corresponding to the colour change of the solution in a conventional lab scenario. In a given configured environment, the student may take, e.g., 20 ml of water in a conical flask using a pipette. The flask can be kept on the *avatar-shell* as shown in *Figure* 1.

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In *Figure* 1, the communication between the avatar shell and the administrator module can be established over WiFi or Bluetooth channel in local laboratory environment. In the above setup, the teacher configures the property of the shell to which the system should respond during the titration process. The user can press

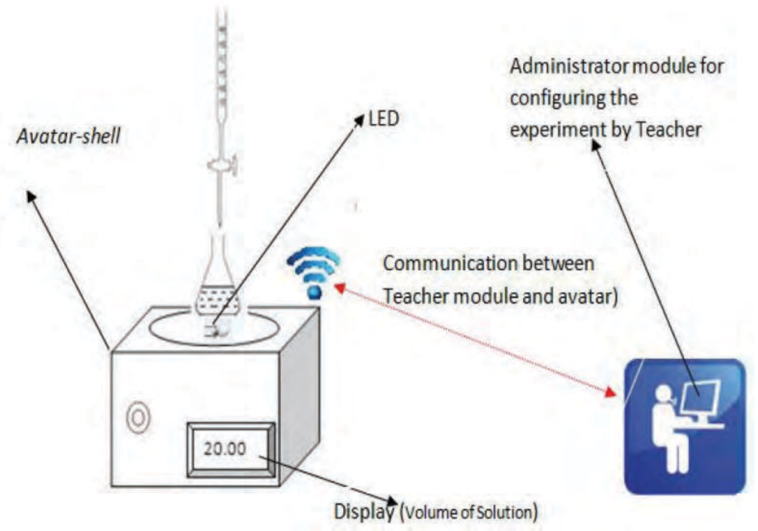

Figure 1. The virtual reality lab environment.

the button to indicate his readiness for conducting the experiment. The load sensor attached to the *avatar* cube will help to measure the quantity of solution in the conical flask. In this context, the user has taken a known volume of water (20 ml) instead of NaOH, and the molarities of Na need to be evaluated, which is configured by the teacher. Upon pressing the button, LED will turn on (pink colour), representing adding the phenolphthalein to the solution in the conical flask as shown in *Figure* 2.

The burette will be filled with water which virtually represents HCl, whose molarity is known. Students can start the titration, i.e., adding the water drop by drop. When it comes to the neutralizing point, the LED will be turned off, which is equivalent to the solution becoming colourless as shown in *Figure* 3.

The experiment can be repeated multiple times to get the average burette reading corresponding to the equilibrium point, i.e., the colour change. We can perform the calculations for finding the molarity of an unknown solution using the average burette reading corresponding to the equilibrium point as discussed at the beginning of this section. Since the experiment is performed with water while calculating the molarity corresponding to a representative solution, say HCl, we may have to consider the spe-

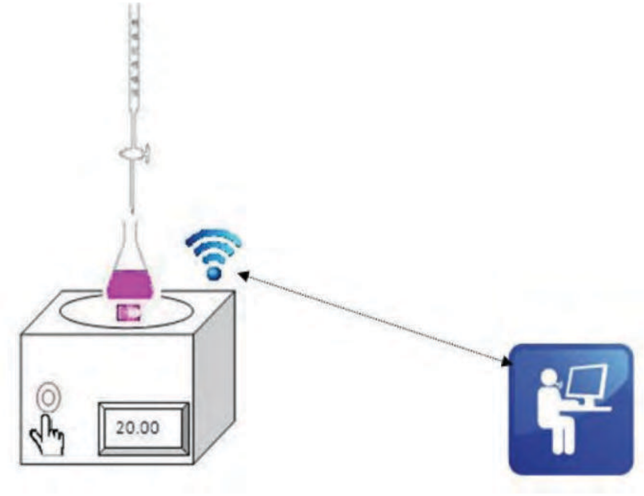

Figure 2. Starting the experiment: Virtually adding phenolphthalein (the user can press the button to turn on the LED).

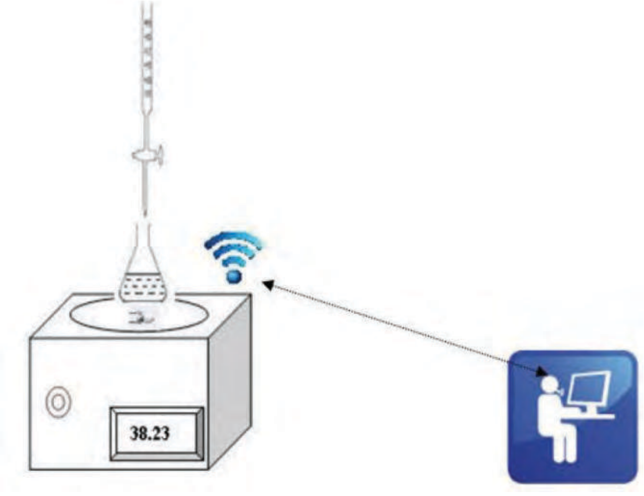

Figure 3. While adding solution from the burette, when it attains the desired proportion, the solution becomes colourless (LED turned off).

cific gravity with respect to the solution under consideration. So the burette reading should be multiplied by the specific gravity of the solution under consideration (For e.g. HCl) equivalent to consumed water. (One drop of water from the burette is approximately 0.05 ml, and its weight will be 0.05 g, i.e., the specific gravity of water is 1 kg/m^3). So the equation becomes

Specific gravity of liquid under consideration × [Molarity × Vol-

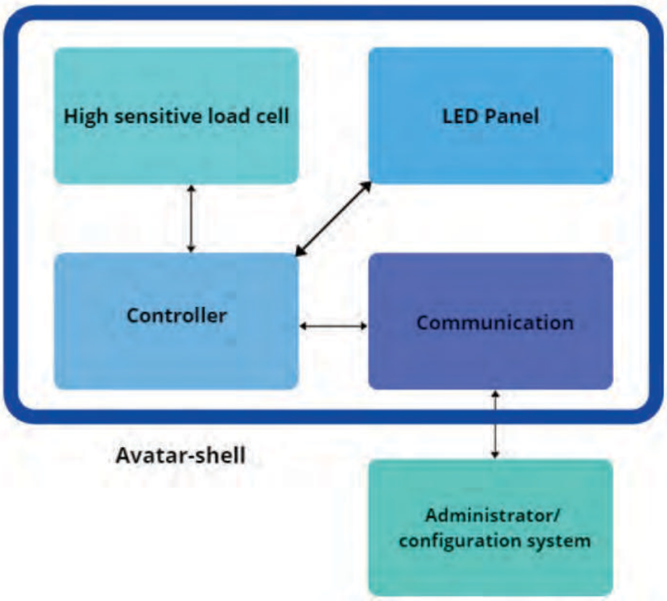

Figure 4. Avatar-Shell System.

ume] of solution in the burette = [Molarity × Volume] solution the conical flask

$$SG \times M_{\text{burette}} \times V_{\text{burette}} = M_{\text{conicalflask}} \times 20$$

$$M = (M_{\text{burette}} \times V_{\text{burette}}) \times SG/20$$

System Architecture Details

The overall generic architecture of virtual reality chemistry lab is shown in *Figure* 4.

The most prominent component of the avatar module is the highly sensitive load cell with the capacity to measure the weight at 0.01 mg level, i.e., the weight of a single drop of water. The controller module continuously listens to the load cell to monitor the weight change during titration. When it reaches the equilibrium point, the controller sends the signal to the LED panel to prompt the LED to glow/dim. The administrator module is the web server system and student module *avatar-shell* can be connected to administrator module via WiFi or Bluetooth in a normal labora-

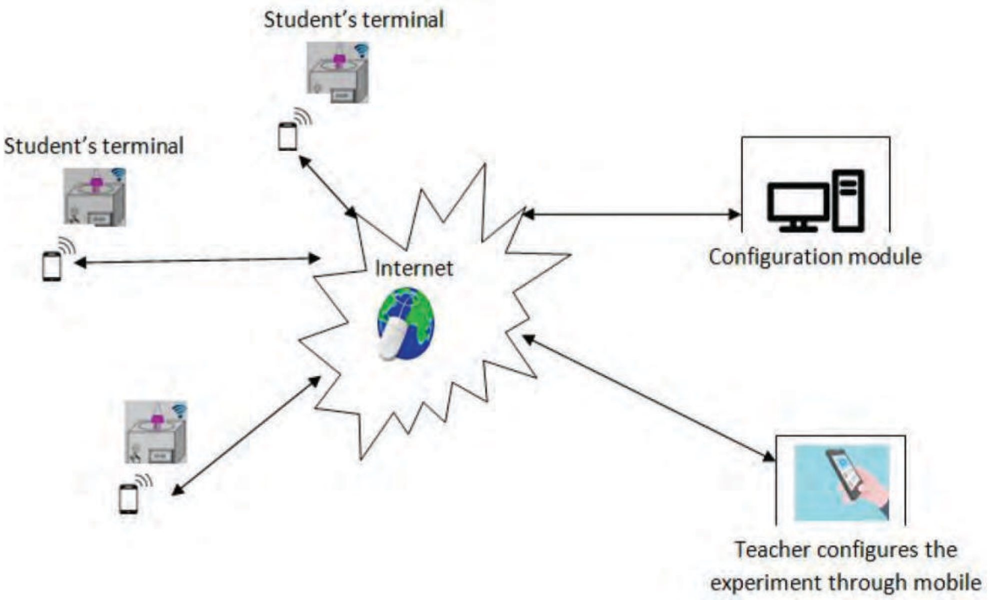

Figure 5. Virtual chemistry lab: Distance learning mode topology.

tory environment. Teachers can access the administrator system through the mobile-based app or the desktop-based environment. If the virtual reality environment needs to be operated in distance learning mode, an additional mobile application is required at the student side to connect the *avatar-shell* to the administrator module, which is located at the far site. The mobile application at the student's side can sync the *avatar-shell* with the administrator module via the internet. A typical internet-driven virtual laboratory environment topology is shown in *Figure* 5.

Implementation Guidelines

Arduino Uno microcontroller board can be used as the controller module to implement the *avatar-shell.*

Arduino Uno microcontroller board can be used as the controller module to implement the *avatar-shell*, i.e., student terminal. HX711 load cell with amplifier can be used to build the highly sensitive load cell [5]. Developers may use the circuit mentioned in reference [6–8]. The HC 05/06 Bluetooth module can be used [9, 10] to establish communication between *avatar-shell* and administrator module if both administrator and *avatar-shell* are located in the same laboratory room. For distance learning mode, *avatar-*

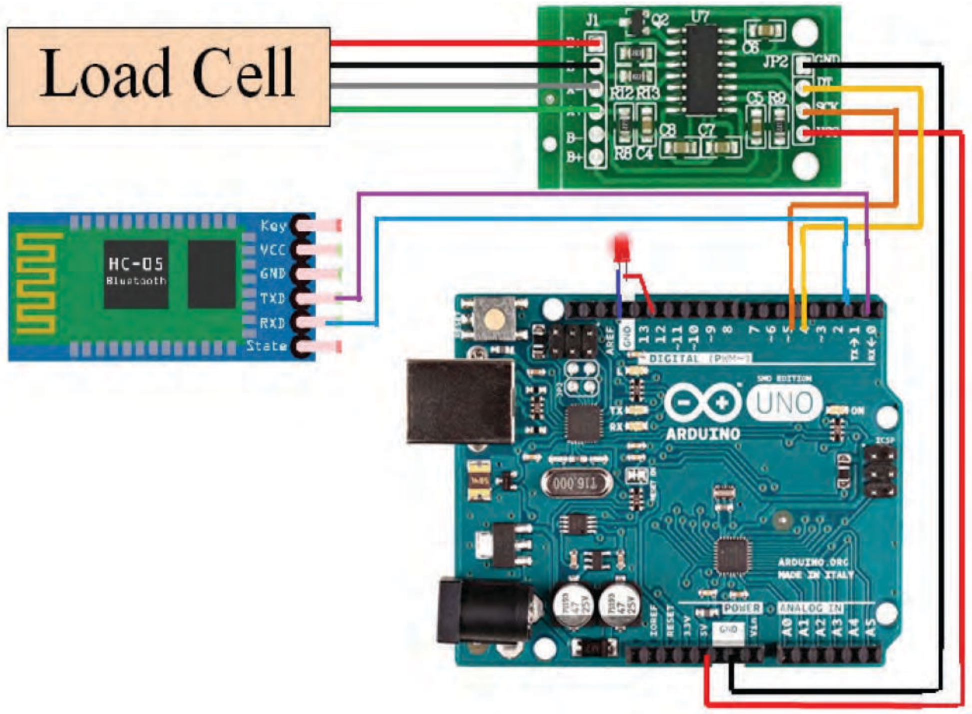

Figure 6. *avatar-shell* schema diagram.

shell can be connected through a mobile application to communicate with the administrator module for performing the experiment over the internet. The connection schema for *avatar-shell* is shown in *Figure* 6.

Configuration module can be a web-based application in which students are registered with the corresponding *avatar shell* (virtual reality lab apparatus). A mobile application or a simple web-based application can be offered to the teachers to virtually configure each student's module *avatar shell* with appropriate molarity for a given titration experiment. A mobile application can also be provided for students to connect the *avatar-shell* to the administrator module via the internet if the lab is provided through a distant learning environment. The workflow of the system is represented as shown in *Figure* 7.

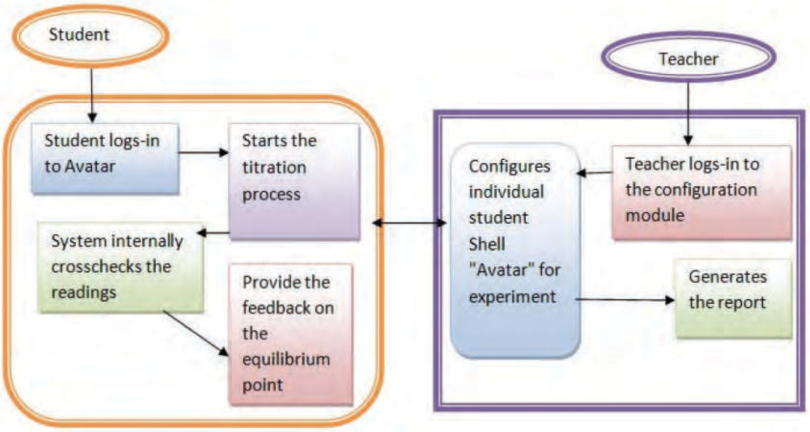

Figure 7. Overall workflow of the augmented reality based chemistry virtual lab.

Discussions and Future Enhancement

The present article introduces the concept of augmented virtual reality chemistry lab through which students can really experience and learn the actual way of performing experiments even in a distant learning environment. Let us now compare a sample titration experiment, for example, NaOH titration with HCl using phenolphthalein indicator in the context of conventional method and proposed virtual reality system environment as shown in *Table* 1.

In the intermediate-level school experiments, the burette reading is generally measured in single digit accuracy, for, e.g. 15.7 ml. The volume of one drop of water is approximately 0.05 ml; hence the error due to weight measurement using electronic sensors will be negligible.

A sample experiment, 20 ml of NaOH titrated against HCl in a conventional method, reports 15.5 ml as the average burette reading, which is the measure of HCl solution used, i.e. the measurement at which colour change happened. It is given that the molarity of HCl is 3.7 g/L. Using the conventional method, the molarity of NaOH is obtained as 3.14 g/L. Due to the error in the electronic sensor the worse case error for a peak load of 100 g is 0.90 g reported for the HX711 load cell-based circuit [5]. If

Parameter	**Conventional Method**	**Proposed system - Avatar Shell**
Chemical usage	Necessary. Can be done only with required chemicals.	Not required. Water is used instead of chemicals.
Electric power	Not required	Required
Usage of lab apparatus	Yes	Yes
User experience of performing the experiment	Yes	Yes
Reaction time	Time taken for color change and other related aspects depends on the reaction.	Not based on the actual property of chemical substances which are virtually considered for the experiment. The reaction time which is the time for color change in the conventional context is represented through an LED display, and this can be configured based on the experiment.
Usage of indicator solution	Yes	No. It is represented through LED glow.
Delay in response due to apparatus	No	800 ms to 1200 ms of delay can be expected for weight sensor stabilizing.
Configuration for wide range of concentration of solution for conducting laboratory sessions in schools/colleges	Practically difficult	Easily configurable through the software interface.
Frequent calibration of apparatus	Not required	Required
Error due to apparatus (damage in burette stopcock is not considered)	N/A	± 0.90 g for peak load of 100 g, which may cause negligible deviation in the result.

Table 1. Comparison between the conventional method and the proposed system.

this worse case error was considered for the said volume, which is highly unlikely, this error might contribute to a deviation of 18 drops which may change the reading to 16.4 ml or 14.6 ml. In this case, the corresponding calculated morality of NaOH will be 3.32 g/L and 2.96 g/L. In such cases, the deviation in the result will be ± 0.18 g/L for worst case error for HX711 based high precision load cell circuit.

The proposed system *avatar-shell* combined with the associated software module can provide the virtual reality environment for setting up a chemistry lab online. The system can also have a power backup with a lithium battery to avoid interruption due to power failure. One of the shortfalls in the present system is the fluctuation in the weight sensor reading during the titration process. It is expected to have nearly 800 ms to 1200 ms delay in stabilizing the weight while adding the solution drop by drop during the titration [11]. To overcome the fluctuation error, a system stabilizing time must be set internally before performing the calculation. This delay may cause the user to intentionally slow down the process of titration than performing in the real environment. This issue needs to be investigated and rectified in order to reduce the response time of *avatar-shell*. The present device may be enhanced by extending with more actuators and sensors for offering experiments in physics as well.

Suggested Reading

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