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A chemistry laboratory platform enhanced with virtual reality for students' adaptive learning

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In recent years, virtual reality system (VRS) has become more prominent among many researchers due to its capacity of providing as close as possible to real-life experience for users from diverse fields of life, such as tourism, academics, manufacturing and medicine. In this study, we present an VRS for the titration experiment in a chemistry laboratory to enable students to learn the titration experiment in a virtual laboratory environment before proceeding to the chemistry wet lab. The virtual chemistry laboratory environment was developed using the Unity Real-Time Development Platform, and the Microsoft SQL Server was used for the database to enable easy assessment of the student performance after the experiment. To evaluate our VRS, we tested it among 50 students (25 high school and 25 first-year undergraduate chemistry students). We collate their user's experience through a structured questionnaire, and the responses from the students show that 60% agreed that it was helpful, 66% easy to interact with and 54% strongly agreed that it improved learning. Therefore, it is evidence that the proposed VR-enabled chemistry laboratory platform could be used to improve the understanding of chemistry titration practical process among students.

Keywords: virtual reality; virtual chemistry laboratory; titration; computer interaction

Introduction

Virtual laboratories (VLabs) are designed to overcome the difficulties of learning often encountered in a traditional class and the conduct of dangerous chemical experiments. VLab has been reported as a new teaching technique, which is less expensive and less challenging, but capable of maintaining students' interest during learning activities (Morozov *et al*. 2004; Peplow and Marris 2006). Moreover, according to Bortnik *et al.* (2017),VLabs are seen as a low-cost solution for laboratory experiments that would be too expensive (either in terms of cost of instrumentation or supplies). The idea behind the use of VLab is to provide students with an authentic laboratory environment, in which experiments can be carried out to solve problems, in a mimic of a typical physical laboratory (Tsovaltzi *et al.* 2010).

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In addition, VLab is enabling students to play an active role while having access to details of the experiments could be made possible through the virtual learning systems (Tatli and Ayas 2010). It thus can be said that virtual reality system (VRS) is a means for humans to visualise, manipulate and interacts with computers and extremely complex data (Shiratuddin and Zulkifli 2001). Consistent with this approach, the need for a laboratory environment, in which students can conduct hazardous experiments at their own pace, with a feeling of safety and comfortability necessitate the choice of a VLab in this study.

The VRS environments allow users to interact with objects and give an enabling environment for testing phenomena that may be too costly or too dangerous and environments that ordinarily the user will be denied access to in the physical reality (Shudayfat, Moldoeanu, and Moldoeanu 2012). Asides, some VRS environments are embellished with the use of information and communication technology for a better learning experience (Babateen 2011). The VRS environments are generally classified based on the type of technology employed in the development of the VRS. This classification ranges from 'fully immersive', in which the user is secluded from the effects of the real world, to 'non-immersive' VR environment or the desktop VR environment, in which the user is still conscious of the outside visual world (Muhamad, Zaman, and Ahmad 2012). In recent years, the field of VR has grown enormously and the practical applications of VR technology have been reported in many fields. The application of VR technology ranged from aviation training, military applications and industrial machine operations to medicine, where surgeons can be trained in surgical techniques through the VRSs (Balogun, Thompson, and Sarumi 2010; Holden 2005).

In addition, the VLab is used in varied science programs for an easy hand-on practical experience. Even though the multi-user virtual learning environment has brought about development in terms of collaboration in virtual space, multimedia VLab is still used to aid the understanding of resource material that could provide solutions as well as the restrictions of instrumentation devices in a real laboratory (Zurweni and Erwin 2017).

In this study, we proposed a VLab system that would aid the understanding of the principles and practice of chemistry titration. Besides, a mathematical model was developed for describing the chemistry titration experiment. The developed VLab would offer learners the opportunity to relate the theoretic knowledge of titration to practical situations, especially in cases of unavailability and accessibility to titration apparatus.

Materials and methods

The software development tools used to create the virtual chemistry laboratory (VCL) are as follows. Unity Real-Time Development Platform (UNITY), which runs on Microsoft Windows, Linux and macOS systems. Unity is a cross-platform game engine designed to support and develop 2D and 3D video games, simulations for computers, virtual reality, consoles and mobile devices platform (Buyuksalih *et al.* 2017). Unity3D is a 'game development ecosystem', which includes an environment for the development of an interactive 2D and 3D content. This includes the rendering and physics engine, a scripting interface to program interactive content, content exporter in many platforms (desktop, web, mobile) and a growing knowledge-sharing community (Winkler 2013).The Unity3D comprises a game engine that allows the games to be created, tested and played in different environments. The application was used to create the various objects within the virtual environment. The Hypertext Markup Language was used to create the web pages due to its numerous attributes to create a page and connect pages while Hypertext Preprocessor (PHP) was used for scripting at the server-side and to design a responsive database-driven application. The Microsoft SQL Server was used to create and manage the created database to enable easy assessment of student performance after the experiment. The Windows Apache MySQL PHP was used to test the web application on the local machine due to its adaptability to all Windows Operating Systems. The web browser was used to achieve document retrieval from the server while the bootstrap framework was used to develop the front-end of the web since it is an open-source Cascading Style Sheets (CSS) framework.

Architecture of the virtual chemistry laboratory

The VRS for our VCL is divided into five components, which include the access module, data collection module, VCL system, database and the users, as shown in Figure 1.

The access module is the first phase in the VCL. The access module controlled the user's navigation and the interpretation of actions. It is responsible for the human–computer interaction and the generation of appropriate data that are transferred to the VCL system. The data collection module is the bridge between the user and the virtual environment. This phase helps in the collection of the user's (student) biodata into the VCL environment. The VCL system is a visual representation of the titration process. The conduct of the experiment and the behaviour of the virtual objects were controlled in this phase. The virtual environment allows the users to actively participate and interact with the object using the interface. The user experiences the virtual environment through the access module with the input/output device and receives a

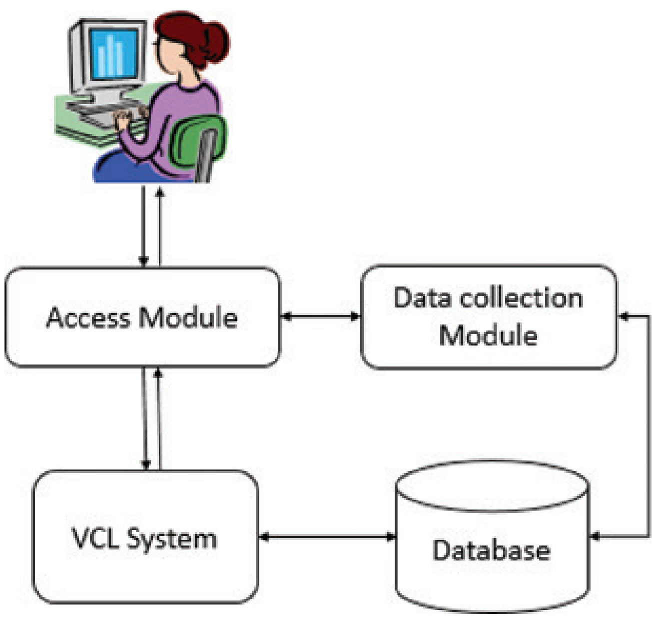

Figure 1. System architecture.

sense of immersion through the visual component. Whenever the user starts the system, the navigation and action command is sent to the access module. However, when an action is performed, the access module sends data to the database and immediately the output is displayed to the user. The instructor and the student are represented as users during interaction within the virtual environment.

Mathematical model

The mathematical model for the titration process was developed following the titration process conditions. The process of obtaining quantitative chemistry analysis involves the use of a fast chemical reaction that is made up of reactants of known concentrations and products. The reactants used in this study were the chemicals solvents: acid (A_i) and base (B_j) as represented in equations (1) and (2).

The apparatus (E) such as burette, pipette, funnel, beaker, white tile, conical flask and bowls are needed for the titration process and were represented as: $\{E \mid 0 < E \leq 10\}$, where the set of all apparatus (E) is such that E is greater than 0 but less than or equals 10. The conditions of acid and base reaction to give a product at an endpoint were chosen from the following categories, as shown in equations (3)–(5). The categories were denoted by C_k, where $k = 1, 2, 3$. C_k is a function of the pH of the solvent used in the experiment. Furthermore, satisfying the conditions stated in equations (3)–(6), the titration experiment could proceed as denoted by T in equation (7).

$$A_i = \begin{cases} A_1 = \text{strong if pH} \leq 3 \\ A_2 = \text{weak if } 3 < \text{pH} < 7 \end{cases} \tag{1}$$

$$B_j = \begin{cases} B_1 = \text{strong if } 12 < \text{pH} < 15 \\ B_2 = \text{weak if } 7 < \text{pH} \leq 12 \end{cases} \tag{2}$$

where A_i represents the acid; B_j represents the base; $i = 1, 2$; and $i = 1$.

(1) A strong acid reacts with a strong base to form salt and water at a neutral pH = 7.

$$C_1 = A_1 + B_1 \tag{3}$$

(2) A strong acid reacts with a weak base to form an acidic product at pH < 7.

$$C_2 = A_1 + B_2 \tag{4}$$

(3) A weak acid reacts with a strong base to form an alkaline product at pH > 7.

$$C_3 = A_2 + B_1 \tag{5}$$

$$\forall\, E \neq \varnothing, \in\left(E\right) \leq 10 \tag{6}$$

for all 'E' not empty and set of 'E' less than or equals to 10

$$T = C_1 V C_2 V C_3$$

$$\{T \mid T = C_1 \text{ or } T = C_2 \text{ or } T = C_3\} \tag{7}$$

Result and discussion

Virtual chemistry laboratory system procedures

Methods of interaction are important applications within the human–computer interaction environment. The user interaction within the VCL is expected to create a user experience that provides a degree of reality within the environment. The first stage of the system is the 'user interface', which provides an interface between the user and environment and the student's registration page and enables a biometric capture of the user. The second stage is the 'task selection page', which is designed to assist in the selection of the type of titration experiment to be carried out. The third stage is the actual 'virtual chemistry laboratory' environment where the titration process takes place. The user interacts with the VCL environment through the keyboard and the mouse as an input device. The input devices give access to the environment for input and selection purposes. Besides, the students and the VCL environment are represented as avatars as shown in Figures 2 and 3, respectively.

The set-up for the titration experiment is shown in Figure 4. The right-side contains the list of variable for titrant and titrate while below the variable was the result for the end-point. To perform the titration experiment, the user selects from the list of variables (acid, base, indicator types and normality). Figure 5 shows the endpoint of the titration process when there is a colour change in the experiment. The student monitors the flow of the titrant from the start point and clicks on the stop button immediately the titrant colour changes.

Figure 2. Student as an avatar.

Figure 3. Student performing titration.

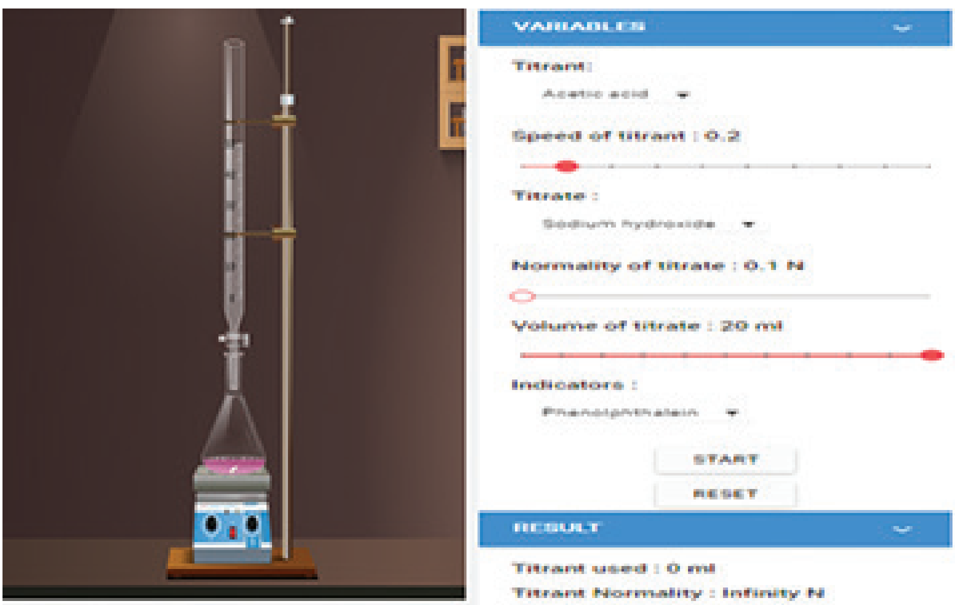

Figure 4. Titration experiment setup.

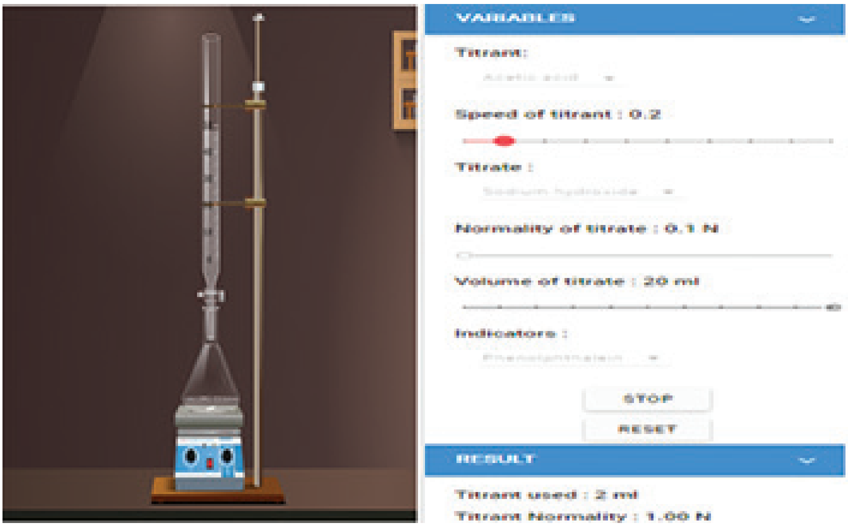

Figure 5. The end-point of titration.

Evaluation results

The evaluation of the virtual reality laboratory for the acid–base titration process in a chemistry laboratory was carried out using a structured questionnaire among high school students and first-year university undergraduate students of the Federal University of Technology, Akure, Nigeria. The questionnaire was designed on a five-point hedonic scale: Strongly Disagree (1), Disagree (2), Neutral (3), Agree (4) and Strongly Agree (5). Questions were asked about how interactive, realistic, improvement in learning, friendliness to users and how understandable and acceptability. A total of 50 students, 25 high school students and 25 first-year undergraduate students of the Federal University of Technology Akure, Nigeria, were participated as the respondent in this study. The majority of the student group was between the ages of 13 and 21. Figure 6 shows the result of the student's responses to each question. The first question is related to how it will be helpful in their academics, for which 60% of the students selected agree and 40% selected strongly agree.

The second question is related to how friendly the environment is, for which 58% of the students selected agree, 34% selected strongly agree, only 2% selected disagree and 6% selected neutral because they have no experience in the VLab. The third question is to determine if the VLab has a more realistic environment, for which 20% of the students selected agree and 12% selected strongly agree, 10% selected neutral because they never work with virtual reality on titration, 3% selected strongly disagree and 5% selected disagree because they have no experience in virtual reality. The fourth question is related to how easy to understand is the virtual lab, for which 66% of the students selected agree and 26% selected strongly agree, while 8% selected neutral. The fifth question is related to how easily accessible the virtual lab can be to the student, for which 60% of the students selected agree and 32% selected strongly disagree, while 8% selected neutral. The sixth question is related to if it will improve learning, for which 46% of the students selected agree and 54% selected strongly agree. The last question is to know if they enjoyed using the virtual lab, for which 54% of the students selected strongly agree and 46% selected agree.

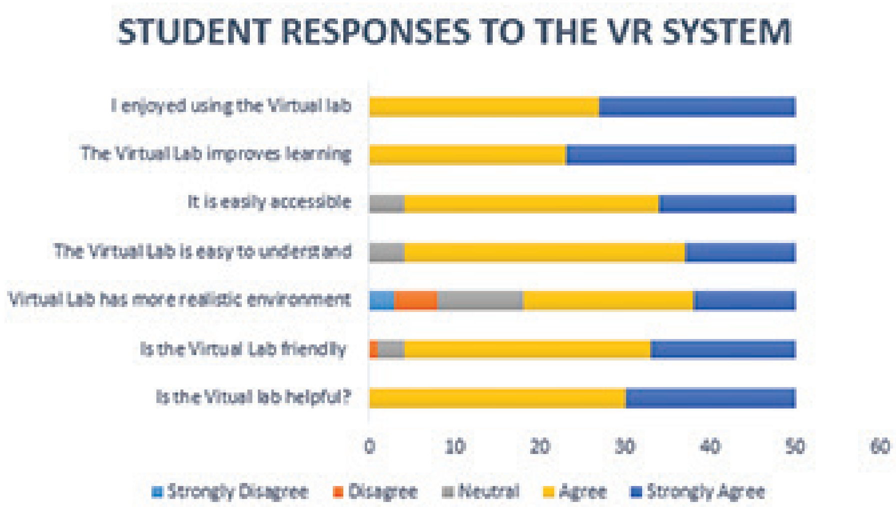

Figure 6. Analysis of the student responses to the VLab system.

Conclusion

The VRS has been a proven alternative to real-life systems in my many fields, such as architecture, tourism, medicine, education and engineering. In this study, we presented an VCL for acid–base titration processes, which could be a useful alternative to the physical laboratory, especially where there is a lack of some laboratory equipments or inadequate reagents to aid learning. The chemistry VLab provides as close as possible to real-life experience for student adaptive learning and training in chemistry titration practical procedure. Evaluation results show that our chemistry VLab system is useful in helping students to learn and understand the acid–base titration process before proceeding to the real-life wet laboratory for the experiment. In the future work, we plan to compare the performance of the students who used both the VR titration learning tool and the wet lab with those who used only the wet lab, and to evaluate if all the desired learning outcomes were achieved.

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