# 3D Interactive Virtual Chemistry Laboratory for Simulation of High School Experiments

Numan Ali, Sehat Ullah, Aftab Alam, and Jamal Rafique*

*Abstract*—In education laboratory is the main contrivance for students' learning improvement. Therefore we developed a 3D interactive virtual chemistry laboratory (VCL) for chemistry experiments. This paper describes the potential contribution of the VCL in students' learning improvement which is based on advanced 3D interaction interface. The aim of VCL is to provide more immersive virtual environment to users by using 3D interaction with chemical items and to simulate their chemistry experiments on high school level. This will increase the learning aptitudes of students in performing chemistry laboratory work. We evaluated the VCL by high school level students, which revealed that VCL is more useful for learning enhancement in chemistry education.

*Keywords—Virtual reality environment, 3D interaction.*

## I. INTRODUCTION

IN science subjects laboratories perform an important role in students learning enhancement, particularly in chemistry education [1]. Students take more interest in learning by performing and observing the experiments in the chemistry laboratory which improve and consolidate their learning [2]. However due to financial problems and other deficient facilities in laboratories most of the institutions cannot establish a complete chemistry laboratory, particularly in developing countries. In the teaching-learning process innovative approaches have been developed by using new technologies, one of the best technologies for education is the virtual reality technology [3]. Virtual environment presents the 3D representation of the real or imaginary facts and provides to users a real time interaction [4].
Virtual chemistry laboratory is very useful for chemistry practical learning. It also fulfills the deficiency of chemical equipments which appear in the real chemistry laboratory environment [5]. It can be also used for distance learning education, because it can be used in each place and each time for virtual experiments [6]. A big advantage of virtual chemistry laboratory is that student can perform the experiment without any faltering and hazardous [7]. In addition, to improve the performance of students in virtual environment, there should be provided immersive base interaction. In virtual reality the 3D interaction is considered as a coercing component which allows the user to navigate, select, control and manipulate the objects in a virtual environment (VR) [8]. Through 3D

numan@uom.edu.pk
sehatullah@uom.edu.pk
alam@uom.edu.pk
jamal7r@yahoo.com
Department of Computer Science & IT, University of Malakand, Pakistan
*Departamento de Qumica, Universidade Federal de Santa Catarina, Brazil

interaction interface it provides to users more realism and immersion in a virtual environment where users feel their presence. It is required to propose a complete equipped virtual chemistry laboratory for students to easily perform their chemistry experiments virtually.
This paper examines the development of a VCL where the students can simulate on intermediate level chemistry experiments through 3D interaction interface.
The paper is organized as follows: Section 2 elaborates some related studies in the field of virtual system for learning. Section 3 presents our proposed VCL. Section 4 is about the experiment and evaluation results of our VCL. Finally section 5 is related with conclusion and future work.

## II. LITERATURE REVIEW

This section describes previous works which is related to virtual chemistry laboratories.
Due to deficient laboratories and scarce of equipments in laboratories at Turkey, Cengiz et al. developed a 2D virtual environment for chemistry education at school level. Various experimental groups of students performed the experiments in this environment and the results were compared with habitual methods of teaching. They found that the use of virtual laboratory had positive effects on students learning but there were no navigation techniques due to 2D environment which is less realistic environment [9].
Similarly the Model ChemLab is also a virtual environment developed by Model Science Software Incorporation Canada. Model ChemLab not only allows users to simulate some chemical reactions but also train them about the use of various apparatuses and chemicals. As the environment is 2D, so the selection of an experiment, its apparatus and chemicals and their required amount is made through menus and dialogue boxes which not only makes the interaction difficult but also lacks realism [10].
The VUOL (Virtual Unit Operational Laboratory) is a 2D virtual industrial chemical laboratory. This was developed for the chemical engineering students at Texas Tech University Lubbock. The main equipments used in this virtual environment were a double-pipe heat exchanger interface, gas absorber interface and a cooling tower interface. Using these interfaces the new chemical engineers could easily learn how to control and operate these equipments which is useful only for the new chemical engineers [11].
At Charles Sturt University a virtual chemistry laboratory has been developed. In this 3D environment the students can work collaboratively. The students can only assemble and collect the equipments to know about the procedures of the

real laboratory but there is no simulation of chemical reaction. This 3D environment is useful only for students to train them for the real laboratory [12].

Virtual ChemLab is a part of the Y Science laboratories which is developed by the Brigham young University. Virtual ChemLab is helpful for students improvement of cognitive imagining skills and to understand the chemical theory to improve their exams scores and the capabilities about solving problems. The user could only select the experiments in the virtual ChemLab which is then illustrated as a movie metaphor by Adobe Director [13].

The iVirtualWorld is a web-based online 3D environment, which gives end-users with domain oriented environment. In this 3D environment the students can perform the chemistry experiments virtually. In the iVirtualWorld when the user performs the virtual experiments he/she gets a positive response for learning achievements. Items and other chemical equipments are selected from 2D menus. In the iVirtualWorld when the user wants to move or rotate any objects in 3D space, first of all he/she will check on the commands from 2D menus to perform the task [14].

The above literature review stated that the previous virtual chemistry laboratories were developed in a way that the interaction with these laboratories were based on mouse and keyboard. Due to 2D interaction interface there was no immersion for users to take more interest.

## III. 3D INTERACTIVE VIRTUAL CHEMISTRY LABORATORY (VCL)

The main objective of our research work is the simulation of chemistry experiments, the ease of use and 3D interaction. Our 3D virtual chemistry laboratory provides some advantages over previous virtual chemistry laboratories:

- It provides 3D interaction interface which facilitates the users to feel more immersion in a 3D environment.

- It enables the users through 3D interaction to simulate their chemistry experiments easily and to take more interest in chemistry practical learning.

Figure 1 shows the inside scenario of the VCL. The chemicals, equipments, an experimental table and other necessary instruments are visualized inside the lab. All the chemicals are placed in the cupboard where user can easily identify them. All the apparatuses and glassware are placed on experimental table as stand, spirit lamp, digital balance, and rack for test tubes and pipette as shown in figure 1.



Fig. 1. The inside scenario of VCL

The user can freely navigate in the environment to select the chemicals and apparatuses using the simple virtual hand (SVH) technique. To perform an experiment, the user can easily identify the required chemicals according to the experiment and selects the chemicals from the cupboard and brings it to the table as shown in figure 2. Similarly user can selects the apparatuses that are already on the table as china dish, teaspoon and other apparatuses.
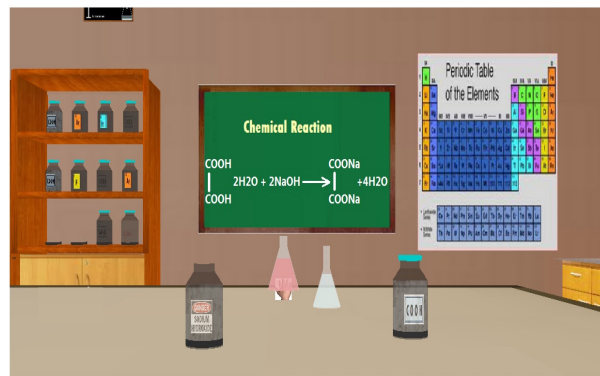


Fig. 2. Simulation of an experiment

The VCL also contains a virtual board which displays information about chemicals and apparatuses and equation about the experiments.

If user simulates the experiment successfully according to the procedure he/she also obtained a textual feedback on virtual board that "you successfully completed the experiment".

### A. User interaction with VCL

Interaction techniques are the most important in human computer interaction. Through interaction the user can presume the degree of realism in the virtual environment. The first unit of this system architecture is the user interaction unit which provides an interface between the user and VCL. Through interaction the user navigates, selects and manipulates the virtual

objects. The user interacts with VCL through wiimote and we use the wiimote controller as an input device. Interaction through wiimote controller is more realistic and gives more easiness to the users. This section contains on the following subsections.

*1) Interface of wiimote:* Wiimote is a 3D wireless game controller which allows the user to interact with the virtual environment through gesture recognition [15]. It contain on multiple buttons, two accelerometers, a vibrator and a small speaker as shown in figure 3. It uses Bluetooth technology for connection with the system and has the capability for interaction from the distance of 18 meters.
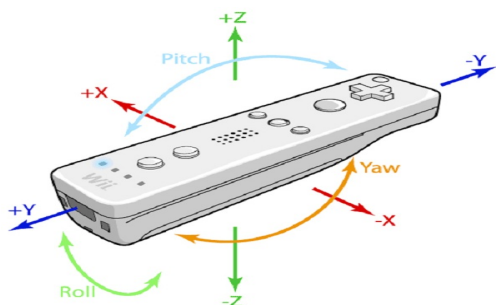


Fig. 3.   Wiimote Motion Sensing [16]

A simple virtual hand is used for interaction with objects which represents the user in VCL and it is controlled through wiimote.

*2) Navigation:* In the VCL the user can freely move in all directions through a simple virtual hand and can study the whole environment. The position of Wiimote is directly mapped to the simple virtual hand by calculating its 3D position in the VCL. In the real world environment when the user moves the wiimote, the simple virtual hand follows the motion of the wiimote in the VCL. To move (navigate) the virtual hand along X-axis (left and right side) the user presses the left and right buttons of the wiimote. Similarly to move the virtual hand along Z-axis the user presses the up and down buttons of the wiimote. The buttons of wiimote is shown in figure 4.
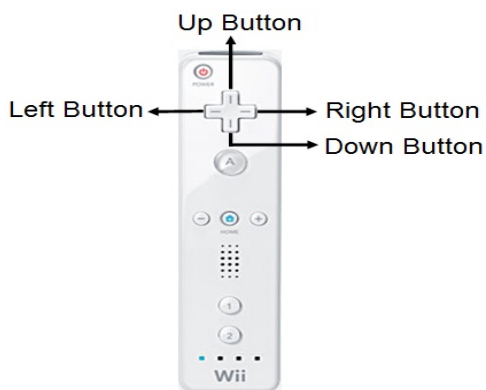


Fig. 4.   Wiimote's buttons

To move the virtual hand along Y-axis (up and down side) the user rotates the wiimote along its X-axis as shown in figure 5(a). Similarly to move the virtual hand along Z-axis the user rotates the wiimote along its Y-axis as shown in figure 5(b).
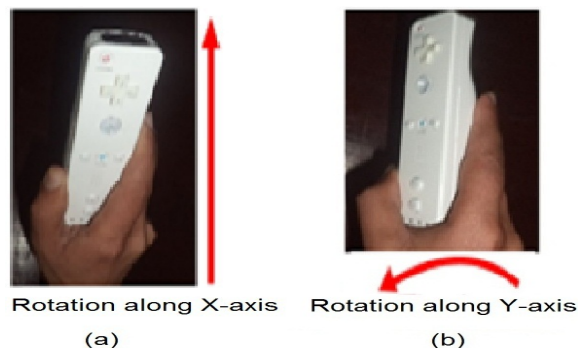


Fig. 5.   Wiimote's rotation

*3) Selection and manipulation:* In real world we identify the targeted object then we select or pick up the object, similarly in the virtual environment first we identify the object then we select the object. When an object is selected, through navigation user can bring it from one place to another in the virtual environment. In VCL if the virtual hand is in collision with an object and wiimote's button "A" is pressed the latter is selected. Similarly the selected object will be released if the same button "A" is pressed again.

*4) Experiments selection and procedure:* First of all user selects the experiment from the experiments list that which experiment he/she will perform. After selection of an experiment user can select the objects that which chemicals and apparatuses will be used for the selected experiment to perform it? Every experiment contains its own step by step procedure. Figure 6 represents an experimental model which is a class diagram that summarizes experimental objects. For example, the relation between beaker and spirit lamp is that a spirit lamp can heat a beaker.
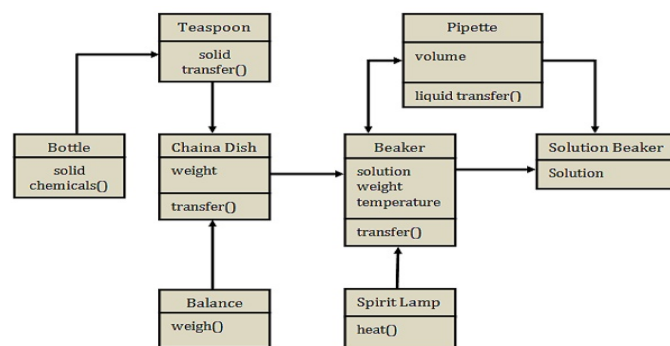


Fig. 6.   A class diagram about objects

Pipette transfers the liquid into the beakers. The solution beaker contains the chemicals and solutions. The beaker also

contains the chemical solution and the spirit lamp heats the beaker. A teaspoon takes the solid chemicals and transfers it into china dish for weighting. The balance weighs the china dish and through china dish the user transfers the solid chemicals into the beaker for chemicals reaction. Similarly beakers contain on different chemicals reactions and pipette transfers these chemicals from beakers into solution beaker for final solution reaction.

*5) Simulation of an experiment:* After successful experiment performing the user obtains the simulation of an experiment and the resultant chemical equation of an experiment which is displayed on the virtual board in the VCL. Similarly the user can perform next experiment.

## IV. EXPERIMENTS AND EVALUATIONS

This section describes the features of the experiment evaluation of VCL. Our VCL has been implemented in Ms. Visual Studio 2010 using OpenGL on HP Corei3 Laptop and wiimote. The specification of the system was 2.4GHz processor, 2GB RAM and Intel(R) HD Graphics card. All the chemistry experiments were performed in a teaching classroom through using a laptops and wiimote. We performed the experiments by participants, including high schools students and their chemistry teachers. We also used LED Samsung screen of 40 inches for demonstration. The following sections presents the detail of evaluation, including participants and the results of evaluation. The results of evaluation were analyzed using Microsoft Excel 2007.

### A. Experimental protocol

In order to evaluate the VCL, we invited students of different high schools and their teachers to University of Malakand after their schools hours. All these students had ages between 15 and 17. There were twenty one participants who attended the evaluation from different high schools. We performed the evaluations in the separate groups. We collected all the background information of participants, including gender, work experience in computer and virtual 3D games experience. The participants contained on eight female and thirteen male. Most of participants had no experience about 3D virtual worlds even some of them had not heard about 3D virtual worlds, only four of them had experienced about 3D virtual games. All of them were briefed about the VCL and about the use of wiimote with the help of demonstration. Most of the participants feel that it is complicated for them but they expressed their enthusiasm to gain knowledge of chemistry because it was very helpful for their chemistry learning.

### B. The task session

This subsection describes the user study method which contains task session. This task session was achieved in four steps. In the first step, we filled out all the background information of each participant such as gender, knowledge about chemistry education, experience in computer and 3D virtual worlds.

In the second step, with the help of 20 minutes demonstration by using 40 inches LED Samsung screen we briefed all of them, including the VCL complete environment, use of wiimote and other basic functions. The basic functions stated in the demonstration that how to simulate the virtual chemistry experiment, identifying chemicals and other instruments, dragging and putting of chemicals and instruments onto the table and assembling of an instruments for virtual experiments. The demonstration also included navigation, selection and manipulation of 3D objects through wiimote.

In the third step the participants had to perform the task. The task was to select the experiment from their chemistry practical notebook and to simulate this selected experiment in VCL. Every task of experiment was performed according to their procedure. The participant required to find out the chemicals and instruments that could be used to perform the 3D virtual experiment in VCL. The participant easily identified all the objects in VCL which he/she required. He/she assembled all the objects together on the virtual table and simulated the virtual experiment using VCL. After simulating the virtual experiment each participant tested his/her experiments result. The last step contained questionnaire session to find out the subjective feedbacks of each participant about VCL. The questions contained yes/no options and also contained on five different points, which are strongly disagree, disagree, neutral, agree and strongly agree. When all participants finished their task, they were invited for 15 mints questionnaire interview to find their personal feelings about VCL, table 1 presents the questions about VCL. Each participants feedback was audio recorded for future analysis.

### C. Analysis

This section describes the quantitative and qualitative data analysis accumulated from the evaluation. By using VCL, overall the results which were obtained from the participants were very positive and constructive. The following subsections describe the analysis results.

*a) Statistical assessment:* This subsection presents the statistical and subjective results of the VCL which we obtained from participants. By using VCL all of the participants simulated their virtual chemistry experiments and the average simulated time is 15 minutes. The virtual chemistry experiment which simulated by one of the participant is shown in Figure 7. We obtained positive responses from each participant by using VCL.
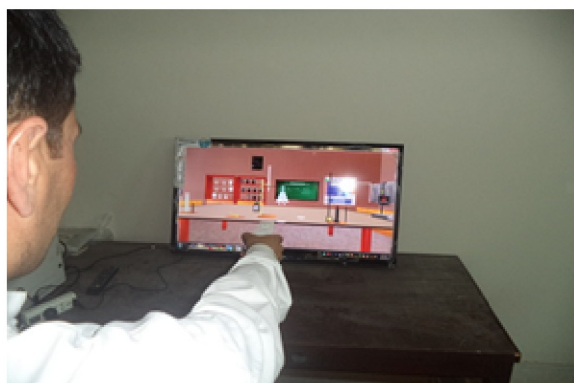
Fig. 7. Simulation of an experiment by one of the participants in VCL

Table 2 summarizes the statistical assessment of each participant by using the 5 points scale about the VCL. Twelve (57.1%) participants were agreed and nine (42.9%) participants were strongly agreed that the environment of VCL is easily understandable. Eleven (52.4%) participants were agreed and seven (33.3%) participants were strongly agreed that in VCL the identification of chemicals and apparatuses is easy. Ten (47.6%) participants were agreed and seven (33.3%) participants were strongly agreed that in VCL the interaction with items is easy however only two participants were disagreed because they had no experience of computer and the interaction through wiimote with VCL was difficult for them. Ten (47.6%) participants were agreed and nine (42.9%) participants were strongly agreed that they felt more immersion in VCL during experiment performing in VCL. Twelve (57.1%) participants were agreed and five (23.8%) participants were strongly agreed that they could easily finish the task according to their knowledge of chemistry by using VCL. Eleven (52.4%) participants were satisfied and eight (38.0%) participants were strongly satisfied with VCL, overall they also agreed that it is easy to use and useful for chemistry practical learning. On the basis of statistical result overall the VCL is an effective and an excellent system for chemistry practical learning.

TABLE I.        QUESTIONS ABOUT VCL

| No: | Questions |
|---|---|
| (1) | The environment of VCL is easily understandable. |
| (2) | The identification of chemicals and apparatuses in VCL is easy. |
| (3) | In VCL the interaction with items is easy. |
| (4) | During experiment performing I feel more immersion in VCL. |
| (5) | By using VCL I can finish my task easily with my knowledge of chemistry. |
| (6) | Overall, I am satisfied with VCL. |

## V.    CONCLUSION AND FUTURE WORK

In this paper we presented a VCL which we have developed for high schools. In most of the education institutions there are not so much laboratory facilities due to financial problems. Our developed VCL is very helpful for education institutions where students can simulate their chemistry experiments like a real world chemistry laboratory. We conducted different experiments through students to find the usefulness and efficiency of the VCL. Overall evaluations prove that the VCL is very useful and efficient for chemistry practical learning and the user can easily understand and use the system. Compared to previous works of researchers our system is very easy and flexible in using and understanding the environment. Our future work is to develop a collaborative interactive VCL where more than one users will be able to interact with each element of VCL and they will perform their chemistry practical work collaboratively. Furthermore we have made our mind to make this system more flexible and realistic for chemistry learning in future.

TABLE II.        RESPONSES AND STATISTICAL ASSESSMENT OF VCL (PARTICIPANTS= 21)

| Question No: | Strongly disagree | disagree | Neutral | Agree | Strongly agree |
|---|---|---|---|---|---|
| (1) | (0.0%) | (0.0%) | (0.0%) | (57.1%) | (42.9%) |
| (2) | (0.0%) | (0.0%) | (14.3%) | (52.4%) | (33.3%) |
| (3) | (0.0%) | (9.5%) | (0.0%) | (47.6%) | (33.3%) |
| (4) | (0.0%) | (0.0%) | (9.5%) | (47.6%) | (42.9%) |
| (5) | (0.0%) | (0.0%) | (19.1%) | (57.1%) | (23.8%) |
| (6) | (0.0%) | (0.0%) | (9.5%) | (52.4%) | (38%) |

## REFERENCES

[1] K. Josephsen, *Simulation of laboratory assignments to support students' learning of introductory inorganic chemistry.*, Chemistry Education Research and Practice., 7(4), 266-279., 2006.

[2] H. Temel, B. Oral, and Y., *Avanoglu, Kimya ogrencilerinin deneye yonelik tutumlari ile titrimetri deneylerini planlama ve uygulamaya iliskin bilgi ve becerileri arasndaki liskinin degerlendirilmesi.*, Cagdas Egitim Dergisi., 264, 32-38., 2000.

[3] D.P. Sandra, M.P. Liliana, A. S. P., *Virtual reality is a tool in the education.*, In IADIS International Conference on Cognition and Exploratory Learning in Digital Age., pages 295–298., 2012.

[4] M. Hachet, *Interaction avec des environnements virtuels affiches au moyend' interfaces de visualisation collective.* PhD thesis, Universit'e Bordeaux I., 2003.

[5] N. Ali, S. Ullah, I. Rabbi, M. Javed, and K. Zen, *Multimodal Virtual Laboratory for the Students Learning Enhancement in Chemistry Education.*, International Conference of Recent Trends in Information and Communication Technology. (IRICT-2014, Malaysia), 2014.

[6] S. Olbrich, N. Jensen, *Development of a virtual laboratory system for science education and the study of collaborative action.*, Proceedings of World Conference on Educational Multimedia, Hypermedia and Telecommunications., 2004.

[7] M. Kearney, and D.F. Treagust, *Constructivism as a referent in the design and development of a computer program which uses interactive digital video to enhance learning in physics.*, Australian Journal of Educational Technology., 17(1), 6479., 2001.

[8] S. Ullah, *Multi-modal Assistance for Collaborative 3D Interaction: Study and analysis of performance in collaborative work.*, PhD Thesis, University of Evry France., (2011).

[9]    C. TYSZ, *The Effect of the Virtual Laboratory on Students Achievement and Attitude in Chemistry.*, International Online Journal of Educational Sciences., 2 (1), 37-53., 2010.

[10]   Model Science Software. http://modelscience.com/chemedu.html?ref=home&link=chemed., Accessed 25 January 2014.

[11]   S. Vaidyanath, J. Williams, M. H. T. W., *The development and deployment of a virtual unit operations laboratory.* In Chemical Engineering Education., pages 144–152., 2007.

[12]   B. Dalgarno, A.G. Bishop, and D.R.B. Jr., *The potential of virtual laboratories for distance education science teaching: reflections from the development and evaluation of a virtual chemistry laboratory.*, UniServe Science Conference proceedings., 2003.

[13]   B.F. Woodfield, *The virtual ChemLab project: a realistic and sophisticated simulation of organic synthesis and organic qualitative analysis.*, Journal of Chemical Education., 82: p. 1728  1735, 2005.

[14]   Y. Zhong, and C. Liu., *A domain-oriented end-user design environment for generating interactive 3D virtual chemistry experiments.*, Springer Science+Business Media New York., 2013.

[15]   A. Holzinger, Nintendo Wii Remote Controller in for Higher Education: Development and Evaluation of a Demonstrator Kit for e-Teaching Computing and Informatics, 2010. 29, 4.

[16]   http://embeddedcode.wordpress.com/2010/12/07/wiimote-and-glovepie/ Accessed on 02 March 2014.