The Effect of Multimodal Virtual Chemistry Laboratory on Students' Learning Improvement

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Abstract. This paper presents a novel Multimodal Virtual laboratory (MMVL) for the learning of chemistry experiments. MMVL is a Virtual Reality environment where the user can perform chemistry experiments like a real world chemistry lab. The user can easily interact with MMVL through 3D interaction interface. The audio and visual information about each chemical objects are provided to its users. The system improves the learning capabilities of students in chemistry education. The analysis shows that the average learning of untrained student is 32.7% while that of trained students increased to 83.5%. Experiments reveal that confidence level in practical field of students who got training in MMVL is much better than those who did not use it.

Keywords: Virtual reality environment · 3D virtual chemistry laboratory · Multimodal

1 Introduction

Guided methods of learning process have given little opportunities for students to motivate them. The intelligence, individual abilities and innovative thinking of the students can be obtained by doing something practical by them. In this framework laboratory applications perform an important role for students motivation. In the field of science education (chemistry, physics, biology and engineering) a lot of researchers admitted that laboratory activities increase the students capabilities and interest [1,2]. Especially in chemistry education, the role of laboratory is clearly understandable [3]. Students take more interest in learning by performing and observing the experiments in the chemistry laboratory [4]. Laboratory activities enhance and stabilize students learning capabilities [7]. However due to financial problems and other several hurdle most of the institutions cannot establish and utilize chemistry laboratories, particularly in developing countries. These include the followings

- ☐ To arrange all equipments and chemicals for experiments in the laboratory are more costly for institutions.
- ☐ For a student it is difficult to perform the experiments individually.

L.T. De Paolis and A. Mongelli (Eds.): AVR 2014, LNCS 8853, pp. 65–76, 2014.
DOI: 10.1007/978-3-319-13969-2_5

- It is also difficult for teacher to check the performance and learning process of every student if the number of students is high in a class.
- Repetition of an experiment will require more time and resources.
- Consumption of chemicals and breaking of glass ware is also an issue.
- A little mistake in real laboratory environment may hurt the student or may cause damage to the laboratory.

The solution of these challenges is the use of Virtual Reality (VR) technologies in education and laboratory activities [5]. Virtual environments allow users to have real time interactions with computer generated objects and perform the desired task while getting the illusion of reality. It fulfills the deficiency of chemical items and other equipment which appear in the real chemistry laboratories. There are many benefits of virtual laboratories especially in distance learning education, because it can be accessed anywhere and anytime for experiments without any cost [6]. Virtual laboratories provide safe environment for students to simulate their experiments [9]. There is a need to design fully equipped virtual chemistry laboratory for students to easily simulate their chemistry experiments virtually. This paper examines the development of MMVL where the students can simulate their chemistry experiments like they perform a real world chemistry experiment. The paper is organized as follows: Next section will present previous studies. Section 3 presents the development of MMVL. Section 4 is about the experiment and evaluation of the MMVL. Section 5 presents the whole work. Final section 6 presents the conclusion.

2 Literature Review

This section presents the literature review which is related to the development of virtual chemistry laboratories.

The Virtual Reality Undergraduate Projects Laboratory (VRUPL) is a 3D virtual chemistry environment developed for the training purposes of undergraduate students. VRUPL enables students to learn that what apparatuses will be used and what will be their proper assembly in a particular experiment. In addition students are guided about how to take various safety measures while working in real chemistry labs both in industrial and educational settings. Although the environment is helpful for learning safety principles but not suitable for traditional teaching where it is important to learn that how a particular experiment is done in actual [8].

Similarly VRAL (Virtual Reality Accidents Laboratory) is another 3D web-based virtual chemistry lab developed for the training of undergraduate chemical engineering students to learn how to safeguard themselves from accidents in chemical laboratories setups [9].

At Charles Sturt University a virtual chemistry laboratory has been developed. The main objective of this environment is to make the students familiar with real laboratory environment. It allows a student to know about the procedure of an experiment and assembling of various apparatus. The main limitation of this environment is its inability to simulate any chemical reaction [10].

Virtual ChemLab is a part of Y science laboratories developed by the Brigham Young University. ChemLab allows a student to select a chemical product and see its various properties like molecule structure, color etc. In addition, movie metaphor is used to simulate a chemical reaction. Evaluation of the ChemLab showed that the environment was helpful for students to improve their exams scores and the capability of problem solving [11].

An online virtual chemistry laboratory system is developed by Oxford University England for harmonizing their first year undergraduate teaching. This system contains a number of chemical reactions experiments in the form of video clips. The user can view the video clips by selecting two reactants. In this system the user can repeat the reaction many times. The system was also suitable for users to learn about the safety rules during the experiments in the real laboratory. The system was suitable for undergraduate students and was very less interactive environment due to video clips [12].

The iVirtualWorld is a web-based environment where various 3D objects required for an experiment are selected from2D menus using traditional mouse based interaction. Similarly different properties of the selected object are also set using 2D graphical user interface (GUI), which makes the environment less realistic and hence it becomes difficult to achieve more immersion of the user [2].

The above related works stated that the previous virtual chemistry laboratories were developed in a way that user can identify and select the chemicals but there were no multimodality (textual and audio information) system to know about the physical and chemical properties of chemicals and apparatuses. Besides this interaction with previous laboratories was possible only through keyboard and mouse and resultantly they were less realistic and immersive.

3 Multimodal Virtual Laboratory (MMVL)

The objective of this research work is to study the effect of simulating chemistry experiments in a computer generated world on the learning of students. Our 3D virtual chemistry laboratory provides some advantages over previous virtual chemistry laboratories:

- It is a multimodal (visual and audio) system which provides the detail information about the physical and chemical properties of chemical objects. Through multimodality users will improve their learning capabilities about the theory of chemistry.
- Both the visual and audio information are combined in MMVL which guides users to increase their learning which is very useful for their exam score improvement.

MMVL is a 3D virtual environment like a real chemistry room/lab as shown in figure 1. All the chemical items are placed in the cupboards where user can easily identify them. The environment contains all the apparatuses, chemical and glassware that are required for the high school and college level experiments. The environment has a table in the center where experiments are performed as like the real chemistry lab. Some apparatuses like burette, spirit lamp, digital balanceetcare permanently laying on the table. Similarly the chemicals and other glassware have been placed in their respective shelves as shown in figure 1(a). In order to perform an experiment, a student can select and bring a chemical/glassware to the table. The environment also contains a virtual board on which the equation of the chemical reaction is shown. For example when the user selects the experiment of standardization of sodium hydroxide by oxalic acid the following equation is displayed as shown in figure 1(b).

$$\begin{matrix}\text{COOH} \\ | \\ \text{COOH}\end{matrix} \quad 2H_2O + 2NaOH \rightarrow \begin{matrix}\text{COONa} \\ | \\ \text{COONa}\end{matrix} \quad + 4H_2O$$

(a) (b)

Fig. 1. The inside scenario of MMVL

The user can navigate in the environment either to know about the properties of various chemical and glassware or to select an item (chemical or apparatus) to perform an experiment using the simple virtual hand (SVH) technique. He/she can identify the required chemical items and other instruments according to the experiment. In addition, the user can pick up and place the selected item on the table as shown in figure 2.

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By selecting any item in the MMVL, the student gets multimodal (textual and audio) information about the selected chemical items as shown in figure 3. This information is very useful for student learning enhancement where he/she comes to know about the properties of chemical items.

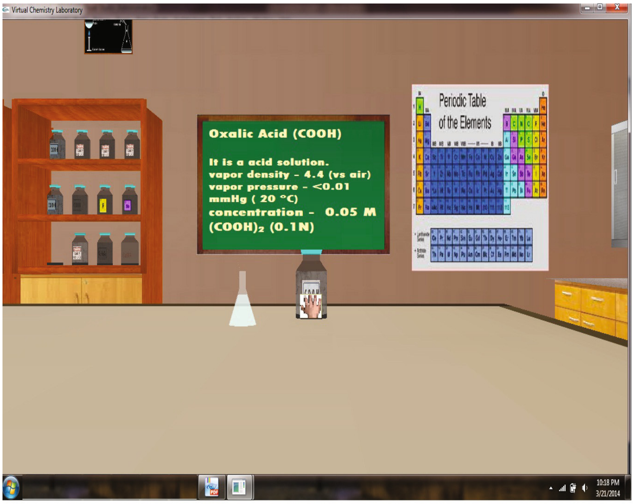


Fig. 2. Simulating virtual experiment

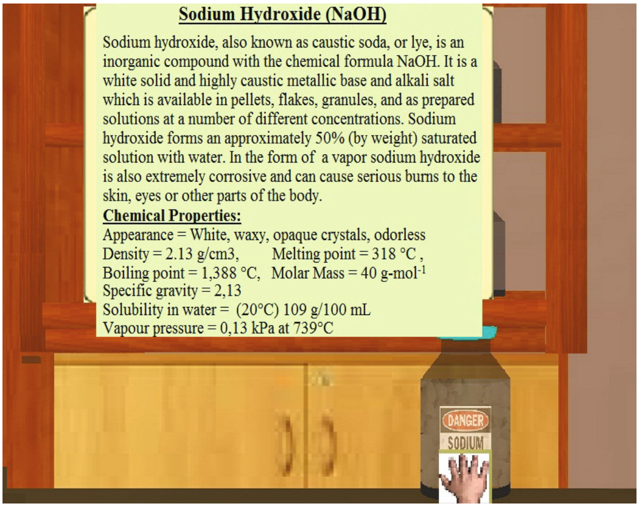


Fig. 3. Visual/audio information

3.1 Software Architecture

In this section we are going to discuss the principle components of the software architecture as shown in figure 4, on which the MMVL is based. For one-column wide figures use

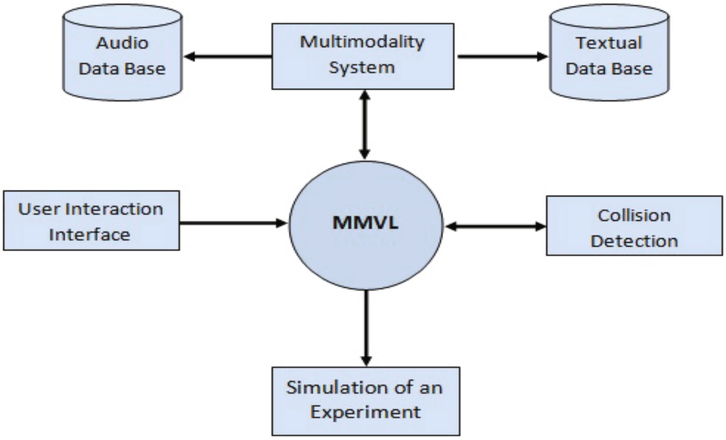


Fig. 4. Software Architecture of MMVL

User Interaction. The first module of this model/architecture is the user interaction module. This provides an interface between the user and MMVL enabling the user to navigate and select/manipulate virtual objects. In order to make the interaction more realistic and give more freedom to users, we use wiimote controller as an input device.

Wiimote's Interface. Wiimotes Interface. There are many devices for 3D interaction like kinect, leap, wiimote, ?ystick, joystick etc. In our MMVL we have used wiimote for 3D interaction because it is a cost e?ective device than other 3D interaction devices, it can also provide haptic sensation in the form of vibration. Wiimote is a video game controller that contains on two accelerometers, multiple buttons, a small speaker and a vibrator. For connection with the system it uses Bluetooth technology (see in figure 5). Its workspace is quite large and allows the interaction from a distance of 18 meters. The user in MMVL is represented by a virtual hand which is controlled via wiimote.

Navigation. The virtual hand representing the user can move (navigate) freely in all directions in the MMVL. The position of the wiimote is mapped onto the virtual hand and whenever the user moves the wiimote in the real world environment, the virtual hand follows its motion in the MMVL. The navigation of virtual hand along X-axis is achieved through the rotation of wiimote along its Y-axis as shown in figure 6(c). Similarly the movement of virtual hand along Y-axis is controlled through the rotation of wiimote along its X-axis as shown in figure 6(a). The Z-axis movement of virtual hand is controlled through the up and down buttons of wiimote. Figure 6 shows the 3D coordinates of MMVL.

Selection & manipulation. Selection and manipulation are the important activities in any virtual environment. For the manipulation of an object it needs to

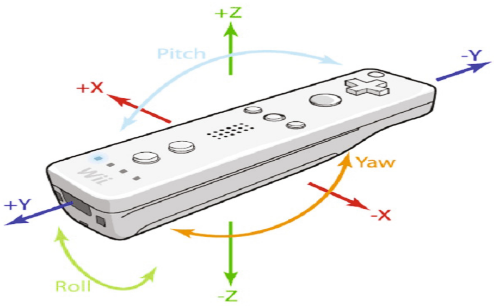


Fig. 5. Wiimote Motion Sensing [13]

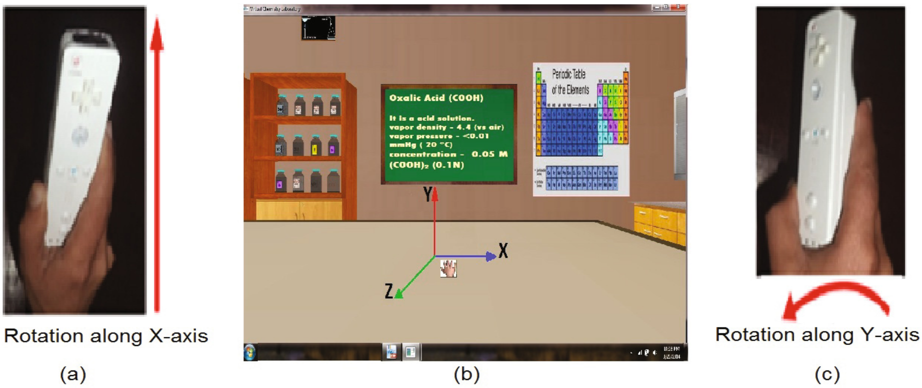


Fig. 6. 3D Coordinates of MMVL

be selected first. In MMVL an object becomes selectable when the virtual hand collides with it. After collision if the user presses the button "A" of the wiimote, the object is selected. After selection the user is able to manipulate it i.e. to change its position or orientation and other attributes. For example he/she can bring the selected chemical or glassware to the table and can place it anywhere by just pressing the wiimote "A" button again.

Collision Detection. It is a natural matter that one solid object cannot inhabit the space of another solid object. In a simulated virtual environment an object needs realistic responding collision with other objects to show solidity [14]. In MMVL the collision detection module is responsible to check the collision of the virtual hand with all other objects such as chemical and apparatuses. The system performs different actions when the collision occurs. If the virtual hand collides with an object, the audio/visual information related to the object is provided by the system or the object is selected. If a selected object collides with any other object in the environment, the former stops moving further.

Multimodality. The MMVL is a multimodal virtual environment when the virtual hand collides with an object (chemicals, apparatuses etc) its information (such as physical and chemical properties of chemicals and function of glassware etc) is given to the user in the form of multimodal feedback. The multimodal feedback works as cognitive aids for users while performing an experiment.

Simulation of an Experiment. After the successful performance of an experiment the user obtains the simulated reaction and the equation of the resultant products is also displayed on the virtual board in the MMVL.

4 Experiments and Evaluations

4.1 Experimental Setup

This section describes the experiment and evaluation of MMVL. Our MMVL has been implemented in MS Visual Studio 2010 using OpenGL on HP Corei3 Laptop having specification 2.4GHz processor, 2GB RAM and Intel(R) HD Graphics card. The Nintendo wiimote was used as interfacing device. Similarly, a LED screen of 40 inches was used for display during experimentation.

4.2 Experimental Protocol and Task

In order to evaluate the MMVL, fourteen students participated in the experiments. They were the 10th class students of government high school. They were in the same class and had ages from 16 to 18 years. We selected one of their course experiments The Standardization of Sodium Hydroxide. They were taught using the traditional classroom method by the same teacher. These students were divided into two groups (i.e. G1, G2) each containing seven participants. The students in G1 used the MMVL while those in G2 did not. As all the participants had no prior experience of VR systems, therefore, they were briefed with the help of 20 minutes demonstration about the use of the MMVL. For example, they were taught that how they will navigate in the environments. Similarly, they were also guided about the selection and manipulation of chemicals and apparatuses. Then each participant was asked to work in the MMVL. One of a participant performs the virtual experiment as shown in figure 7. Each participant filled a questionnaire after getting experience in MMVL. Then both G1 and G2 were taken to a chemistry laboratory where they had to perform the simulation of experiment. Here the data of the students performance were collected again through a questionnaire.

Fig. 7. Simulation of an experiment by one of the participants in MMVL

4.3 Analysis

This section describes the data analysis accumulated from the evaluation. The analysis of the questionnaire filled by students in G1 (group 1). There were seven questions in this questionnaire. The objective of these questions was to evaluate the following aspects of MMVL:

- ☐ The effect of MMVL on students learning in chemistry education.
- ☐ Realism of the system.
- ☐ Ease of interaction in MMVL.

The students had to answer these questions on a scale of 1 to 5. Where 1= low and 5 = very high level. The analysis of these responses is given below.

Statistical and Subjective Assessment. This subsection presents the statistical results of the MMVL which we obtained from participants. By using MMVL all of the participants completed their virtual experiments in an average time of 12 minutes.
The first question which are related to learning for which 75% students selected the highest level as shown in figure 8(a).

For question 2 which are related to realism of MMVL, 68% students selected for the very highly real option as shown in figure 8(b).

The next question which was related to the easiness of interaction in MMVL got the vote 67% students for the highest option as shown in Figure 9.

Similarly 75% students selected the highest level for usefulness and 67% students selected the highest level of confidence they feel after performing the experiment in MMVL as shown in figure 10(a) and 10(b) respectively.

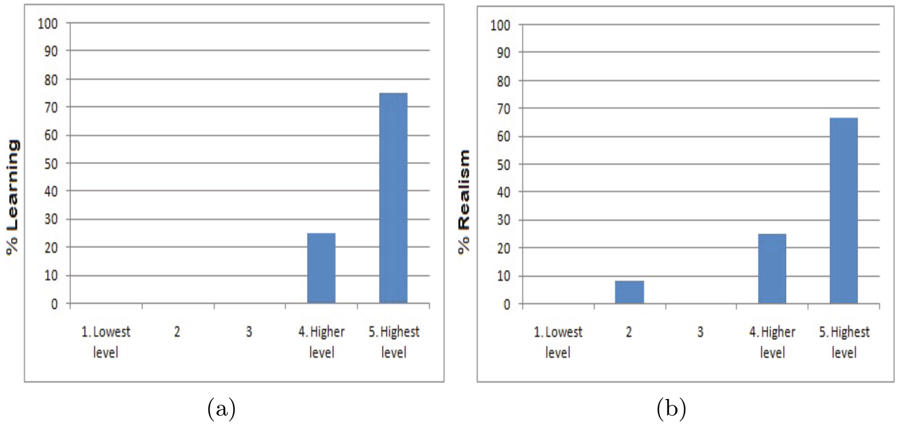


Fig. 8. Learning and realism in MMVL

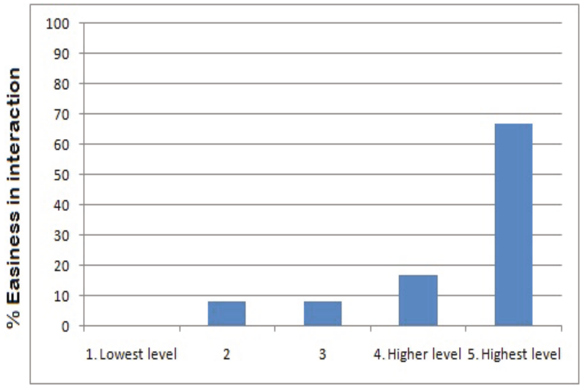
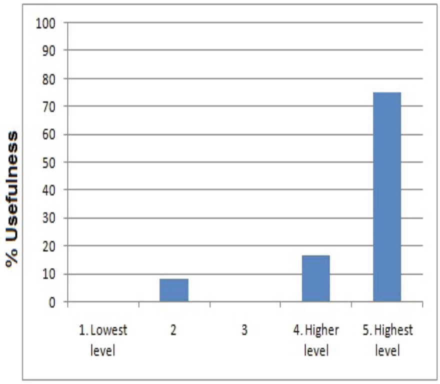
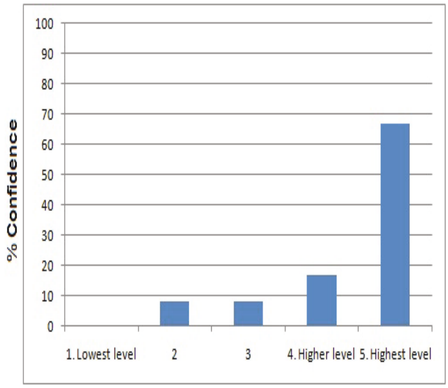


Fig. 9. Easiness of interaction in MMVL

The second part of the questionnaire was filled by both the groups (G1 and G2) during their session in the laboratory (real situation). The data recorded in the second section were consisting of their ability to identify various chemicals, apparatuses and their function and to perform the experimentin the real environment in the correct manner. Comparing the MMVL trained group (G1) with untrained group (G2) we observed a great difference in their success rate (see Fig.11). Here the mean success rate of G1 is 83.5% while that of G2 is only 32.7%.



(a)



(b)

Fig. 10. Usefulness and confidence of MMVL

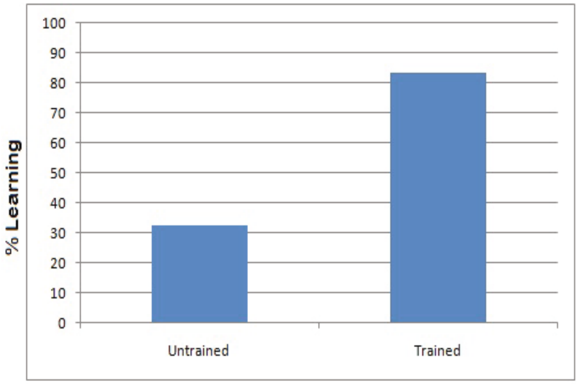


Fig. 11. Comparison of trained vs. untrained students

5 Conclusion

In this paper we presented Multimodal Virtual Laboratory 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 MMVL is very helpful for educational institutions where students can simulate their chemistry experiments like the real chemistry laboratory and to improve their learning which is very useful for exam score improvement. We evaluated the MMVL through students to find the usefulness and efficiency of the MMVL. Overall evaluations prove that the MMVL is very useful and efficient for chemistry practical learning and for students learning improvement. 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.

Furthermore we have made our mind to make this system more flexible and realistic for chemistry learning in future.

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