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The Effect of Multimodalityand 3D Interaction in a Virtual Laboratory on Students' Learning in Chemistry Education

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Abstract: Virtual reality is the emerging technology in the field of education and many researchers have been attracted by the concept of virtual laboratory in which the students can perform their practical work the way they do in the actual laboratory. We developed a 3D interactive multimodal virtual chemistry laboratory (MMVCL) for high school level students. This paper describes the potential contribution of the MMVCL for the students' learning improvement which is based on advanced 3D interaction interface and multimodality (audio and text information). The aim of MMVCL is to provide to students the detail information about the physical and chemical properties of chemical items and to simulate their chemistry experiments in a virtual environment. The system enhances the learning skill of students in chemistry education which is very useful for their exam scores improving. We evaluated the MMVCL by high school level students in two groups, which shows that the average learning of untrained student is 29.4% while that of trained students increased to 81.2%.

Keywords: Virtual Laboratory, 3D Interaction, Multimodal

1. INTRODUCTION

In science education (physics, biology, chemistry and engineering) laboratories are the core contrivance for students' learning enhancement and awareness, particularly in chemistry which is entirely a practical field of science, the role of laboratory in teaching is clearly understandable (Bryant *et al*., 1987; Zhong *et al*., 2013; Bruner, 1990). In chemistry laboratory, students take more interest in learning by performing and observing the experiment which enhances and stabilizes their learning (Temel *et al*., 2000). However there are several difficulties and constraints in establishing and utilizing real chemistry laboratories in schools and colleges, particularly in developing countries. These include the high cost of establishing real world labs, difficulty in checking the performance and learning process of students, inability of students to perform the experiment individually, cost and time associated with experiment repetition and danger to human health.

It is inevitable if we take these problems and limitations into deliberation to search out the suitable solution. So one of the solutions may be the use of Virtual Reality (VR) technologies in education in general and laboratory activities in particular (Cengiz, 2010). This enables us to develop 3D virtual environments allowing users to have real time interaction with computer generated objects and perform the desired task while getting the illusion of reality. Virtual chemistry laboratories provide momentous benefits especially for the distance education, because it can be used anywhere and anytime for virtual experiments (Nils *et al*., 2004). Virtual chemistry laboratories facilitate the students to perform the experiments many times without any uncertainty and accidents (Kearney *et al*.,). In addition, the performance and learning capabilities of students in virtual environment can be improved by using visual, audio and haptic feedback in a virtual environment. In virtual learning environment students can significantly enhance their learning capabilities through the use of multimodality (visual and audio feedback) (Fadel, 2008). In a multimodal virtual environment user can easily understand the environment and can perform the require task easily and successfully in less time. Therefore, it is required to propose a complete equipped virtual chemistry laboratory for students to perform their chemistry experiments virtually and to improve their learning capabilities.

The paper is organized as: Next section will present previous studies. Section 3 presents the development of MMVCL. Section 4 is about the experiment and evaluation of the MMVCL. Section 5 presents the whole work. Final section 6 presents the conclusion and future work.

2. RELATED WORK

Due to deficient laboratories and scarce of equipments in laboratories, (Cengiz *et al.* 2010) developed a 2D virtual environment for chemistry education at school level. Various experimental groups

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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 make it less realistic environment (Cengiz, 2010). The VLab is another web based 2D collaborative environment for chemistry education. This enables two students to collaboratively select the equipments and chemicals to be used in a particular experiment; here the collaboration is achieved through simple chat. The VLab is suitable for the learning improvement of students but the environment is less realistic due to two dimensional (Dimitra *et al*., 2010). Similarly the 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 (MSS, 2014). The VUOL (Virtual Unit Operational Laboratory) is a 2D virtual industrial chemical laboratory where the main equipment 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 equipment which is useful only for the new chemical engineers (Sreeram *et al*., 2007).

The Virtual Reality Undergraduate Projects Laboratory (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 was not so much suitable for the traditional teaching because there were no chemicals simulations to perform the actual chemistry experiments (Bell *et al*., 2004). 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 (Bell *et al*., 1999). The virtual chemistry laboratory of Barney *et al*., 2003 allows students 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. The Virtual Reality Interactive Learning Environment (ViRILE) developed for the training of undergraduate chemical engineering students. It allows users to know various components of a chemical plant and the procedure of its operation for a chemical reaction by simulating an experiment reaction in it (Schfield *et al*., 2010). Virtual 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 (Woodfield, 2005). An online virtual chemistry laboratory 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 (OUVCL, 2014).The iVirtualWorld is a web-based environment where various 3D objects required for an experiment are selected from 2D 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 (Zhong *et al*., 2013).

The above related works stated that the previous virtual chemistry laboratories were developed in a way that the user could identify and select the chemicals but there were no multimodality (textual and audio information) to know about the chemical properties. Beside this, interaction with these environments was mainly done through mouse and keyboard.

3. PROPOSED SYSTEM

MMVCL is a 3D virtual environment like a real chemistry room/lab as shown in **(Fig. 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 balance etc are permanently laying on the table. Similarly the chemicals and other glassware have been placed in their respective shelves as shown in **(Fig. 1).** 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 **(Fig. 2).**

Fig. 1 The inside scenario of MMVL

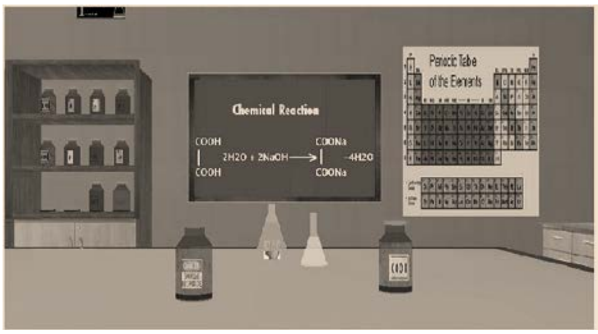

Fig. 2 Chemical equation on board

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 **(Fig. 2)**.

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

3.1 System architecture model

This section describes the main components of the system architecture as shown in **(Fig. 4)**, that how user can perform the chemistry experiments virtually in MMVCL.

3.1.1 User interaction with MMVCL

The first unit of this system architecture is the user interaction unit which provides an interface between the user and MMVCL. Through interaction the user navigates, selects and manipulates the virtual objects. The user interacts with MMVCL 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 subsection contains on the following categories.

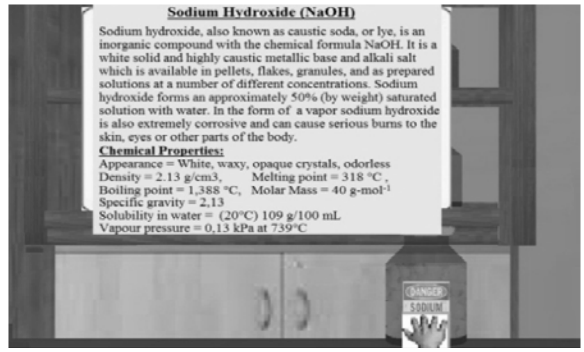

Fig. 3 Audio and visual information (Multimodality)in MMVCL

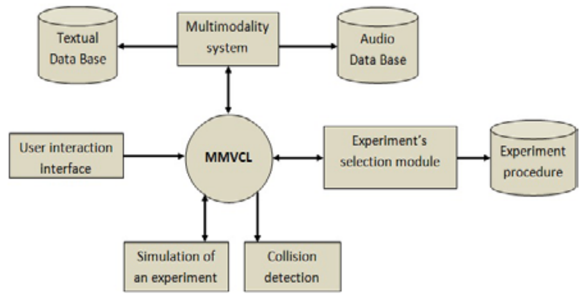

Fig. 4 System architecture model of MMVCL

Interface of wiimote

There are many devices for 3D interaction like Microsoft kinect, leap, phantom, wiimote, flystick, joystick etc. In our MMVCL we have used wiimote for 3D interaction because it is a cost effective device than other 3D interaction devices, it can also provide haptic sensation in the form of vibration. Wiimote is a 3D video game controller device which allows the user to interact with the virtual environment through gesture recognition. It contains on multiple buttons, three accelerometers, a vibrator and a small speaker as shown in **(Fig. 5)**. It uses Bluetooth technology for connection with the system and has the capability for interaction from the distance of 18 meters.

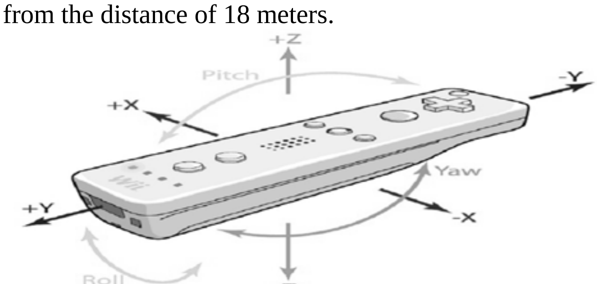

Fig. 5 Wiimote Motion Sensing (Wiimote, 2014)

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

Navigation

In the MMVCL 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 MMVCL. In the real world environment when the user moves the wiimote, the simple virtual hand follows the motion of the wiimote in the MMVCL. To move (navigate) the virtual hand along X-axis (left and right side) the user presses the left and right buttons of the wiimote as shown in **Fig. 6(b)**. Similarly to move the virtual hand along Z-axis the user presses the up and down buttons of the wiimote. To move the virtual hand along Y-axis (up and down side) the user rotates the wiimote along its X-axis as shown in **Fig. 6(a)**.

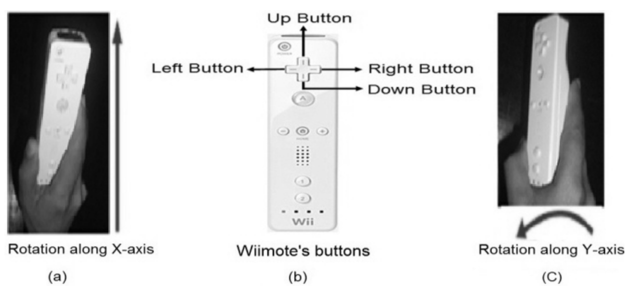

Fig. 6 Wiimote's buttons and rotations

Similarly the rotation of the virtual hand along Z-axis is achieved when the user rotates the wiimote along its Y-axis as shown in **Fig. 6(c)**. The 3D coordinates of MMVCL are also shown in **Fig. 6**.

Selection and manipulation

In a 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 selected, through navigation user can bring it from one place to another in the virtual environment.

In MMVCL selection and releasing of an object through simple virtual hand is controlled through pressing button 'A'. An object is selected by pressing button 'A' and again by pressing button 'A' the selected object is released. The liquid solution from a beaker is placed in the pipette by pressing 'Plus' button and released by pressing 'Minus' button, on this method user transfer the liquid solution from one beaker into another. In MMVCL after selection and navigation of an object, the user can manipulate an object's current position according to the user point of view.

Collision with items

Collision detection is an important task in a simulated virtual environment. In MMVCL different action are performed when the collision occurs. All the chemicals and apparatuses are selected by the collision of simple virtual hand with chemical or apparatus and the feedback is given to the user in the form of audio and textual information. If user selects an object by the virtual hand and this time the virtual hand collides with another object in the environment, the current movement stops and as a feedback the sound of collision detection is given to user.

Multimodality

The MMVCL is a multimodal virtual environment when the simple virtual hand collides with an object (chemicals, apparatuses etc) its information (such as physical and chemical properties of chemicals and function of glass ware etc) is given to the user in the form of textual and audio feedback. Through multimodality students get detail information about the chemical objects which improve learning of students. The multi-modal feedback also works as cognitive aid for users while performing an experiment.

Simulation of an experiment

After a 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 MMVCL. Similarly the user can perform next experiment.

4. EXPERIMENT AND EVALUATIONS

4.1 Experimental setup

This section describes the experiment and evaluation of MMVCL. Our MMVCL 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 MMVCL, twenty four 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 two of their course experiments "The Standardization of Sodium Hydroxide" and "Purification of Commercial NaCl (Common ion effect)". 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 twelve participants. The students in G1 used the MMVCL 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 MMVCL. 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 MMVCL. Each participant filled a questionnaire after getting experience in MMVCL. Then both G1 and G2 were taken to a real chemistry laboratory where they performed the experiments in actual. Here the data of the students' performance were collected again through a questionnaire. There were seven questions in this questionnaire. The objective of these questions was to evaluate the following aspects of MMVCL:

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

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.

4.3 Statistical and subjective assessment

This subsection presents the statistical results of the MMVCL which we obtained from participants. By using MMVCL all of the participants completed their virtual experiments in an average time of 12 minutes.
The first question which is related to learning for which 47.4% students selected the higher level and 36.9 students selected the highest level (see **Fig. 7**).

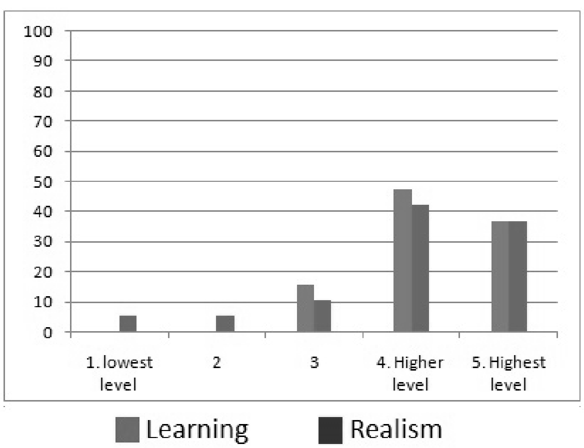

Fig. 7 Learning and realism in MMVCL

For question 2 which are related to realism of MMVCL, 42.1% students selected for the higher real option and 36.9% students selected for the highest real option only one participant selected the lowest level option and one participant selected the lower level option because they had never heard about virtual worlds (see **Fig. 7**).

The next question which was related to the easiness of interaction in MMVCL got the vote 52.6% students for the higher option and 36.9% students for the highest option as shown in (**Fig. 8)**. The next question which was related to the usefulness of MMVCL, 52.6% students selected the higher level and 42.1% selected the highest level for usefulness as shown in (**Fig. 9)**. Similarly 63.1% students selected the higher option and 26.3% students selected the highest option of confidence that they feel after performing the experiment in MMVCL as shown in (**Fig. 9,10)**.

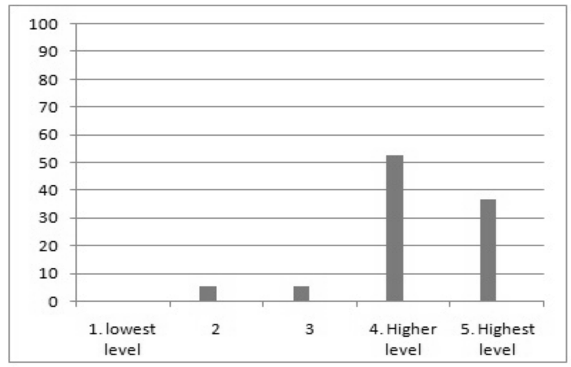

Fig. 8 Easiness of interaction in MMVCL

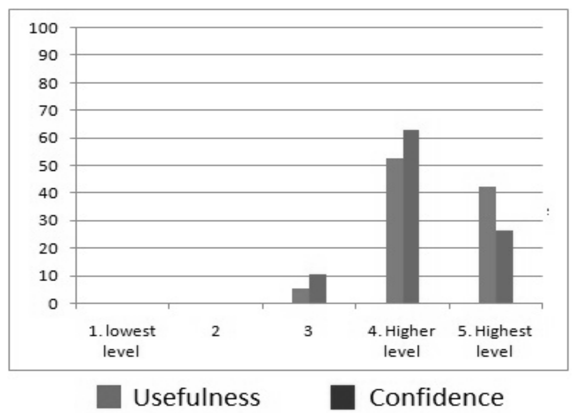

Fig. 9 Usefulness and confidence in MMVCL

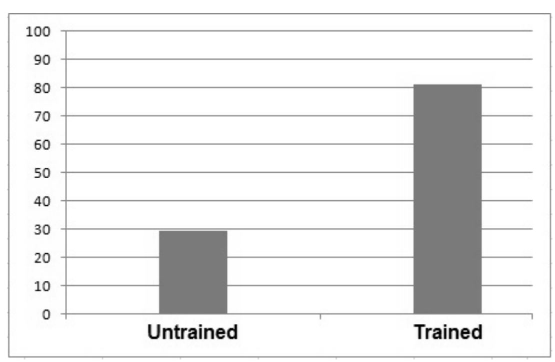

Fig. 10 Comparison of trained vs. untrained students

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 experiment in the real environment in the correct manner. Comparing the MMVCL trained group (G1) with untrained group (G2) we observed a great difference in their success rate (**see Fig.10**).Here the mean success rate of G1 is 81.2% while that of G2 is only 29.4%.

5. CONCLUSION

In this paper we presented a MMVCL which we have developed for high schools. Our developed MMVCL 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 MMVCL. Overall evaluations prove that the MMVCL 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.

RFFERENCES:

Bryant, R. and A. Edmunt, (1987)They like lab centered science. The Science Teacher, Vol. 54 (8): 42-45.

Bell, J. T., and H. S. Fogler, (2004). The VRUPL lab-serving education on two fronts. Proceedings of the Special Interest Group on Computer Science Education Annual Conference: Norfolk, VA.

Bell, J. T., and H. S. Fogler, (1999). Virtual laboratory accidents designed to increase safety awareness. Proceedings of the 1999 American Society for Engineering Education Annual Conference, Charlotte.

Barney, D., G. B. Andrea, R. B. Danny, and A. William, (2003). The potential of virtual laboratories for distance education science teaching: reactions from the development and evaluation of a virtual chemistry laboratory. Universe Science Improving Learning Outcomes Symposium Proceedings, 90-95.

Bruner, J. (1990) Acts of meaning. MA: Harvard University Press, Cambridge.

Cengiz, T. (2010). The effect of the virtual laboratory on students achievement and attitude in chemistry. *International Online Journal of Educational Sciences*, Vol. 365, 2 (1): 37-53.

Dimitra, T., R. Nikol, M. M. Bruce, P. Niels, S. Oliver, H. Andreas, and B. Isabel, (2010). Extending a virtual chemistry laboratory with a collaboration script to promote conceptual learning. *International Journal of Technology Enhanced Learning*, Vol. (2): 91-110.

Fadel, C. (2008). Multimodal learning through media: What the research says. San Jose, CA: Cisco Systems.

Kearney, M., and D. Treagust (2006) “Constructivism as 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*, Vol. 17 (1): 64-79.

Model Science Software (MSS). http://modelscience.com/chemedu.html?ref=home&link=chemed. Accessed 25 January 2014.

Nils, J., V. V. Gabriele, N., Wolfgang, & O. Stephan, (2004). 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. Association for the Advancement of Computing in Education (AACE). 2148-2153

Oxford University Virtual Chemistry Laboratory (OUVCL). http://www.chem.ox.ac.uk/vrchemistry., Accessed on 05 February 2014. Wiimote. http://embeddedcode.wordpress.com/2010/12/07/wiimote-and-glovepie/. Accessed on 02 March 2014.

Sreeram, V., W. Jason, H. Marcus, & W. Theodore, (2007). The Development and Deployment of a Virtual Unit Operations Laboratory. *Chemical Engineering Education*, Vol. 41(2): 144-152.

Schfield, D., and E. Lester, (2010). Virtual chemical engineering: Guidelines for e-learning in engineering education. *Seminar.net - International journal of media, technology and lifelong learning*, Vol. (6): 76-93.

Temel, B. O. H., and Y. Avanoglu, (2000). Kimya ogrencilerinin deneye yonelik tutumlari ile titrimetri deneylerini planlama ve uygulamaya iliskin bilgi ve becerileri arasndaki likening degerlendirilmesi. *Journal of Contemporary Education*, Vol. (264): 32-38.

Woodfield, B. (2005). The virtual chemlab project: a realistic and sophisticated simulation of organic synthesis and organic qualitative analysis. *Journal of Chemical Education*, Vol. (82): 1728-1735.

Zhong, Y., and C. Liu, (2013). A domain-oriented end-user design environment for generating interactive 3rd virtual chemistry experiments. *springer Science + Business Media New York*, doi:10.1007/s11042-013-1554-1.