A Virtual Reality Laboratory for Distance Education in Chemistry

J. Georgiou, K. Dimitropoulos, and A. Manitsaris

Abstract—Simulations play a major role in education not only because they provide realistic models with which students can interact to acquire real world experiences, but also because they constitute safe environments in which students can repeat processes without any risk in order to perceive easier concepts and theories. Virtual reality is widely recognized as a significant technological advance that can facilitate learning process through the development of highly realistic 3D simulations supporting immersive and interactive features. The objective of this paper is to analyze the influence of virtual reality's use in chemistry instruction as well as to present an integrated web-based learning environment for the simulation of chemical experiments. The proposed application constitutes a cost-effective solution for both schools and universities without appropriate infrastructure and a valuable tool for distance learning and life-long education in chemistry. Its educational objectives are the familiarization of students with the equipment of a real chemical laboratory and the execution of virtual volumetric analysis experiments with the active participation of students.

Keywords—Chemistry, simulations, experiments, virtual reality.

I. INTRODUCTION

TEACHING chemistry either at school or at university constitutes a challenging task requiring a theoretical approach on specific chemical concepts as well as a deep study on specific phenomena through the conduction of experiments in specially equipped laboratories. However, the total number of chemical experiments carried out at a school/university laboratory is usually limited due to safety factors, lack of appropriate infrastructure and equipment, restrictions in terms of time and space availability, poor accuracy on account of significant experimental errors involved in final results etc [1].

Despite of this fact, experiments constitute an integral part of the chemistry instruction, as they play an essential role in the comprehension of theory and the acquisition of a wide range of skills and abilities [2]. Hence, an alternative educational approach is required to address the aforementioned problems

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and provide a cost-effective solution for secondary education as well as a valuable complementary or distance learning tool for university students.

Virtual reality technology has been widely proposed as a significant technological advance that can offer a novel form of education. Especially in the case of chemistry, the potentials of virtual reality technology can facilitate learning process surpassing major restrictions characterizing traditional educational methods. Its primary objective is to provide highly realistic and believable simulations of chemical procedures within a fully-immersive, interactive and three-dimensional virtual world. The educational benefit of these applications is the active participation of students in learning process, since researches have shown that humans remember only 10% of what they read, 20% of what they hear, but retain up to 90% of what they learn through active participation [3]. Moreover, students can observe or carry out virtual chemical experiments, which are either difficult or even impossible to be performed in a physical laboratory e.g. high-speed chemical activities that do not allow observation and reliable measurement of results (explosions, issues of chemical kinetics etc), extremely slow or complex chemical processes, experiments involving health risks for students and teachers (e.g. radiations), processes requiring expensive consumables or devices not available in a conventional laboratory etc [4].

Recently a lot of research efforts have been made aiming to take advantage of the potentials that virtual reality and Web technologies offer at chemistry instruction, such as CSU Chemlab [5], VRLUP [6] and Lab 3D [7], which deal with hygiene, safety and biochemistry issues respectively. Furthermore, in [8] a virtual reality application is presented aiming to familiarize post-graduate students with the facilities of a large-scale chemical plant, which are not otherwise easily accessible to students, and provide them the opportunity to conduct a series of virtual experiments. Specifically, three modules are presented: i) Vicher I dealing with industrial methods of handling the decay of catalysts and heterogeneous catalytic mechanisms, ii) Vicher II, dealing with non-isothermal effects in catalytic reactions and iii) Safety, which allows students to walk through a chemical pilot plant to evaluate the hazards and safety systems. Moreover, many applications have been recently developed using simple 3D models for the efficient teaching of chemistry in secondary education, such as VR-Assisted Chemistry Education [9], High School Chemistry Educational and Virtual Reality [10] etc.

However, it should be pointed out that the term "virtual" is

also used by a large number of applications without exclusively implying the use of virtual reality technology. In most of these cases, the term is used to indicate that experiments are not executed in a real laboratory, but in a computer. Many applications belong to this category, such as the Oxford Virtual Chemistry [11], the Model Science Software [12], the IrYdium project [13], the Crocodile Chemistry [14] etc. Nevertheless, the drawbacks of this category in comparison with virtual reality systems are: lack of immersion feeling, limitations in interaction and navigation, not realistic representations of models in three dimensions etc

This paper aims to study and underline the benefits and impacts from the use of virtual reality technology in chemical education as well as to present a novel virtual reality environment, which faithfully reproduces a real chemistry laboratory in three dimensions. The proposed system takes advantage of virtual reality potentials and recent advances in Web technologies to provide both a complementary educational tool and a distance learning application for students of chemical engineering. The fundamental goal of the application is to transfer via internet each student into an interactive virtual world, which simulates a real educational process. Initially, students can navigate in the virtual lab and interact with its equipment to acquire the required experience and familiarity with a chemical laboratory. Subsequently, the second step of the application involves the simulation of volumetric analysis experiments with the active participation of students in the experimental process. Specifically, the virtual experiments supported by the proposed system concern: i) volumetric analysis of acid from base and vice versa, ii) volumetric reduction-oxidation and iii) complexometric neutralization and water hardness estimation. The interactive features of the application allow students to conduct virtual experiments considering all the parameters that may affect the final experimental results. The main advantage of this educational approach is that students can repeat the same procedure without any limitation, study and compare the results in order to perceive easier each one of the experimental processes. Finally, the application contains relative educational material such as theory, exercises, tests etc constituting so an integrated educational tool for distance learning in chemistry.

In the next Section the role of Web in distance learning is presented, while in Section II the main educational benefits from the use of virtual reality technology in Web-based education are highlighted. The virtual laboratory application is described in Section III and the familiarization function is presented in Section IV. Finally, the volumetric analysis, volumetric reduction-oxidation and complexometric neutralization and water hardness estimation experiments are analyzed in detail in Section V, VI and VII respectively, whereas conclusions are outlined in Section VIII.

II. ONLINE DISTANCE EDUCATION

The term "distance education" is mainly used to imply the physical distance among teachers and learners. Traditional distance education practices aim at the substitution of face-to-face instruction using various communication means, such as mail, video or audio tapes, educational programs on TV, teleconferences etc and rarely, in some special cases, a limited number of meetings. The advent of the World Wide Web has changed radically the area of distance education providing a new form of learning, widely known as online education [15] (or alternatively e-learning). The main advantage of Web is that it provides a suitable platform for the development of distance learning tools, which directly connect learners with teachers and relative educational sources [16]. This form of communication involves the use of simple text as well as the transmission of voice, image and video. Specifically, the main advantages of Web-based distance education are:

- *Space independency*: Learners are able to participate in the learning process from any place, even from their own home simply using their personal computers.
- *Time independency*: The simultaneous participation of teachers and learners is not a prerequisite in online education. Learners choose when they are ready to study the educational material and determine the time needed to assimilate the learning content. That is, students can repeat processes and revise the content of an online application without any time limitations, adapting so the learning process to their personal needs.
- *Low cost*: The total cost required for the training of a large number of learners at universities, schools, enterprises and so on is significantly reduced by the use of Web-based learning applications. On the other hand, the cost corresponding to users-learners is usually limited to the price of a conventional PC.
- *Easy access*: The main advantage of online learning is free and easy accessibility via Web. Furthermore, in most cases the connection with other external educational sources (e.g. libraries) is also possible.
- *Simultaneous participation of a large number of learners*: Web allows the participation of a large number of trainees in the learning process, something that is hardly achieved with traditional distance learning methods. Considering also that Web constitutes the largest and the most powerful global network, in which millions of computers are connected to, one can easily understand its enormous potentials in distance education and the dissemination of knowledge as well.
- *Non-isolated learners*: Traditionally in distance education, learners are considered isolated from the other members of the learning community studying the learning material on their own. On the contrary, in online education, Web promotes the cooperation between learners and teachers as well as the creation of learners' groups with common educational objectives. This capability is possible due to the

synchronous or asynchronous communication [17] supported by Web technologies.

- *Equal opportunities to all participants*: As it has already been mentioned the learning process is adapted to the personal abilities of each learner. Hence, while in a real learning process it is a common phenomenon some students not to be able to follow the learning rhythm, in online education Web provides equal opportunities to all participants regardless of their abilities, as they have as much time as they really need to study the learning material.

- *Simulation of a real learning process*: Web allows the creation of learning conditions that are usually developed in a real classroom. For this purpose various pedagogical methods such as behaviourism, cognitivism, constructivism, collaborative learning etc [18][19] can be applied.

- *Attractive environment*: The use of multimedia technology (video, sounds, 3D graphics etc) engages students attention and creates a pleasant learning environment [20].

In general, the potentials of Web shift the centre of learning process from teachers to learners. This simply means that learners acquire an active role and determine the development of the learning process. These features are further enhanced by the use of virtual reality technology in online education as described in the next section.

III. Virtual Reality In Distance Education

Virtual reality has introduced a new form of education allowing students to experience situations, instead of simply reading or hearing about them [21]. Its use in online distance education set the base for the implementation of interactive systems offering to students the ability to broad their knowledge without any help from their teachers [22]. The interactive functionalities supporting virtual reality environments reinforce the active participation of students and thus they are not any more regarded as simple passive observers, but as active members of the learning process, in which they can either discover or even produce new knowledge.

An educational virtual environment can be defined as one or more virtual worlds that offer multiple educational functionalities to each user-student [23]. Within these virtual worlds, students can navigate, interact with virtual objects and study the educational material, which can be either a 3D model or even text, image, sound or video. Besides, it is widely recognized that virtual reality technology engages students' attention and turns learning into pleasant and entertaining process. In short, three are considered to be the main features of these applications: immersion, interactivity and representation in three dimensions.

Generally, the use of virtual reality technology in Web provides a new framework for distance education, since it can be regarded as the extension of internet in third dimension. This capability allows the development of Web-based virtual learning environments, which are approachable by all internet users. The most practical use of virtual reality is in training and simulations. However, there are many applications aiming to reproduce a learning process of a real classroom. These applications allow students to interact with information in a physical sense beyond the conventional interaction supported by typical two-dimensional Web pages. In the next section a Web-based virtual reality application for the simulation of chemical experiments is presented.

IV. The Virtual Laboratory

The virtual lab constitutes a combination of hypermedia and virtual reality features. For the development of Web-pages, the Microsoft FrontPage software was used, whereas virtual worlds were created using VRML and 3D Studio Max software. The proposed system is, in essence, a hypermedia application and, thus, it is a collection of HTML pages, which constitute the base of the application. A common prototype was followed for the designing of all HTML pages, while the VRML worlds are embedded and presented always at the centre of the HTML pages. In order to present virtual worlds properly, the installation of a plug-in, the Cortona VRML of Parallel Graphics, at the user's browser is a prerequisite. The virtual lab has been designed for a resolution of 1280x1024 and a 32 bit depth of color. These are the minimum specifications of the application, which requires only the existence of conventional equipment without any support from peripheral virtual reality devices that increase the cost of the application and, consequently, restrict the number of potential users.
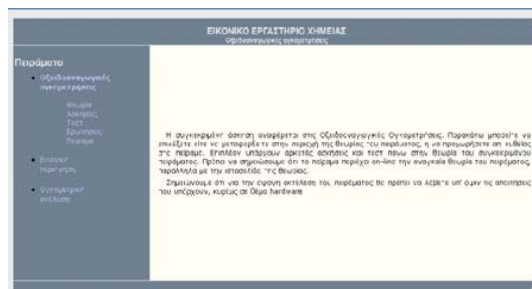

Fig 1. The main page of the application.

Apart from the virtual worlds of the lab, the main page (Fig. 1) of the application contains links that allow trainees to have access to relevant theory issues, solved and unsolved exercises, diagnostic tests as well as questions answered or not based on [24] [25]. This educational material has been used so that the application can play an integrated educational role by helping trainees-users to acquire the required theoretical background, raise questions and give answers or interpretation about the experimental results and phenomena. Moreover, the virtual worlds of the proposed application provide the following educational functionalities:

• Familiarization with the equipment of a chemical laboratory

• Execution of virtual experiments

V. THE FAMILIARIZATION FUNCTION

One of the fundamental objectives of the proposed application is the familiarization of users-students with the equipment of a real chemical laboratory. This function is of great importance especially for students without any previous experience in a real chemical laboratory, due to the reasons described in the introduction of this paper. To this end, the first function supported by the system allows students to navigate within the virtual world and manipulate its equipment through the interactive functionalities of VRML language. This function should be always performed before the execution of virtual experiments, as the familiarization of students with the lab's equipment is a prerequisite for the next stage of the application i.e. the correct execution of virtual experiments.

Fig. 2. The virtual laboratory.

More specifically, students are routed to the virtual lab through the main page of the application. The Web-page containing the virtual environment is divided in three parts, each of which performs a different role in the learning process. The first part contains the title of the applications and hyperlinks, which allow users to either return to the main page or approach the help manual of the application. The goal of this manual is to make the use of the application easier and to provide sufficient guidance for the execution of experiments. The existence of a help manual is considered a prerequisite for the development of a user-friendly application.

The second part of the page contains the virtual world (Fig. 2), in which students are able to navigate in order to learn the equipment of the lab and the use of each one of the chemical instruments. Through this function students will also learn how to navigate within the virtual world using the keyboard or the mouse of their computer. This supported function is of great importance especially for students who are not experienced with 3D technology and virtual reality environments in general.

Every time students locate the cursor of their mouse on a

virtual object, the shape of the cursor changes inciting them to select the object. The result of this selection is the appearance of a brief description of the object, which explains its function, and a smaller 3D model corresponding to the selected object so that learners observe it from different angles of view. The description of the object as well as its 3D model appears at the third part of the screen, which is always located at the bottom of the page (Fig. 3).
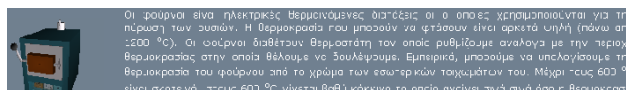

Fig. 3. The third part of the page contains the 3D model of the model and a brief description explaining the use of the chemical instrument.

The virtual lab appearing during this function is exactly the same with the labs used for the simulation of the chemical experiments. However, each experiment is executed in different virtual workbenches and requires the use of different chemical instruments. The main advantage of this designing approach is that students have access to all the equipment that is to be used for the conduction of virtual experiments and thus students are already familiar with their function. The next stage is the simulation of the experiments. Specifically, the application supports the simulation of three chemical experiments:

i) volumetric analysis of acid from base and vice versa,
ii) complexometric neutralization and hardness estimation,
iii) volumetric reduction-oxidation.

VI. THE VOLUMETRIC ANALYSIS EXPERIMENT

The main goal of this virtual experiment is the concentration estimation of an unknown solution of acid or base through a neutralization reaction. Specifically, the application supports two different methods for the estimation of the final point of the process (Fig. 4):

• Using a pH-meter
• Observing the color change of an index.

At first, students should prepare the lab, before the execution of the experiment. With this function, the application aims to simulate all the experimental process reinforcing so the feeling of presence within the chemical lab. The workbench includes the burette's base, the burette itself, the pH-meter, several conic bottles, washing bottles and other chemical instruments. Above the workbench, there are five bottles containing solution of acetic, sulphuric, phosphoric, hydrochloric and oxalic acid. Additionally, there are five more bottles containing solution of ammonia, calcium hydroxide, sodium bicarbonate, sodium hydroxide and sodium acetate. At the edge of the workbench there are also five small bottles containing various indices, such as thymole blue (base), thymole blue (acid), blue bromothymole, methyl red and phenolpthalane.

In the next stage, students should form the topologic arrangement for the execution of the experiment. During the experimental process students follow well-defined instructions and specific steps, while results can be observed either

visually through the change of the index's color or using the pH-meter. The chemical instruments needed for the experiment are a conic bottle, a burette, a mixer and a pH-meter. Firstly, students should place the burette and then the electric mixer exactly under the burette. Subsequently, the conic bottle is placed above the mixer and under the burette, so that the solution contained in the burette to be easily added.

A. Using pH-meter for the estimation of the final point

Firstly, sufficient volume of the solution (acid or base) is introduced in the conic bottle. This means that students should choose one of the bottles containing these solutions, using their mouse, and add a specific amount of solution in the conic bottle. Specifically, each click on the bottle of the solution corresponds to 1ml. Subsequently, 50ml of acid or base are introduced into the burette and the electric mixer is used (students should turn on the mixer clicking on it) for the efficient mixing of the solution in the conic bottle. Students then click on the virtual pH-meter to introduce its electrode in the conic bottle. Each time they click on the burette, 1ml of the solution is added in the conic bottle and at the same time the corresponding value of pH is presented on the screen of the pH-meter.
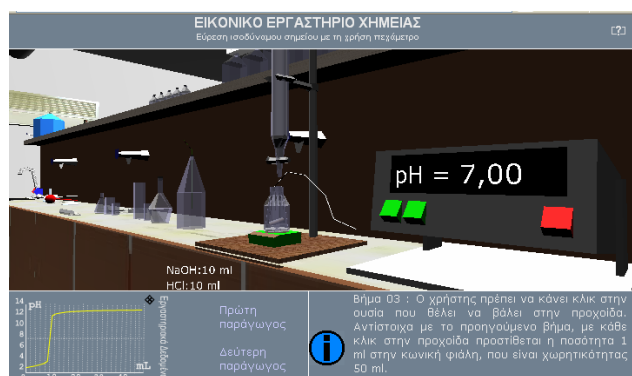
Fig. 4. The pH is presented on the screen of the pH-meter. The process completes when the pH value remains almost constant at the equivalent point

The whole process involves a gradual introduction of the acid or base solution from the burette to the conic bottle. The titration process (volumetric analysis) has been completed when the pH value remains almost constant, after its sudden change to the equivalent point (Fig. 4). The equivalent point can be graphically estimated by the titration curve, as shown in Fig. 5. These graphs are presented in the third part of the HTML page and they present the change of pH with regards to the added volume. The use of these graphs allows the accurate estimation of the equivalent point.
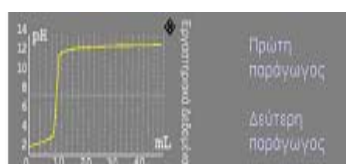
(a)
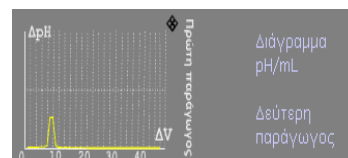
(b)
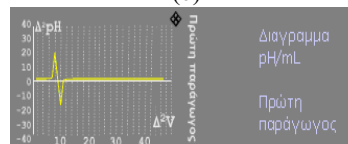
(c)

Fig. 5. The equivalent point can be graphically estimated by the graphs shown in the third part of the HTML page.

B. Using index for the estimation of the final point

In this case the estimation of the equivalent point is based on the change of the solution's color in the conic bottle. The equipment needed for this experiment (the conic bottle, the burette and the mixer) is placed appropriately, as described in the previous section. Again, the solution contained in the burette is gradually introduced into the conic bottle, while the resultant solution is mixed during the whole process. Clicking on the bottle of the index, we add the appropriate amount of index to the solution. The process is completed when the color of the solution (Fig. 6), within the conic bottle, has changed (the color depends on the index used).
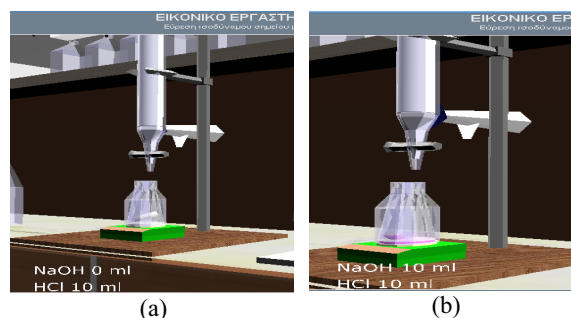
(a)   (b)

Fig. 6. The process is completed when the color of the solution has changed

Fig. 7. The equation of gram-equivalent, as shown in the third part of the HTML page.

Based on the equation of Fig. 7 and knowing the initial volume and the normality of the solution of acid or base, as well as the volume of the solution consumed (burette's indication), we can estimate the normality of the unknown solution of acid or base.

VII. COMPLEXOMETRIC NEUTRALIZATION AND WATER HARDNESS ESTIMATION

The objective of this experiment is the measurement of Ca^{2+}

and Mg^{2+} concentration and the final estimation of water hardness. This can be achieved through the conduction of three experiments. The EDTA is not a standardized substance, thus, in the first experiment, the concentration of EDTA solution (N_{EDTA}) is titrated with a standardized Ca^{2+} solution, which is produced by dissolving $CaCO_3$ in HCl, using as index Calcon, with pH=12, and adding 4F of NαOH. In the second experiment, water is titrated with EDTA in the presence of Calcon index (pH=12) with NaOH. From this process the Ca^{2+} concentration in the water (eqCa2+/L) is estimated. In the third experiment, water is titrated with EDTA, in the presence of EBT index, with pH=10,5 adding NH_3-NH_4Cl buffer solution. From this process the (eqCa^{2+}+ eqMg^{2+})/L concentration in the water is accumulatively estimated and, consequently, the concentration of Mg in water (eq Mg2+)/L can be found by simply subtracting the resultant concentration of Ca^{2+} estimated in the second experiment.

The learner executes the experiments following faithfully the experimental process performed in a real laboratory. Hence, the workbench should be prepared appropriately before the execution of the experiments. Above the workbench, there are bottles containing various agents. Specifically, the large bottles contain EDTA solution, $MgCL_2$ solution, standardized calcium solution ($CaCl_2$) and water, whereas the small bottles contain NaOH, EBT index, Calcon index and NH_3-NH_4Cl buffer solution. Subsequently, students should form the topologic arrangement and execute the experiments following specific steps provided by the application. The final result can be observed either visually or numerically. At first the burette, the mixer and a conic bottle are placed at the workbench exactly as described in the previous section and shown in Fig. 8.
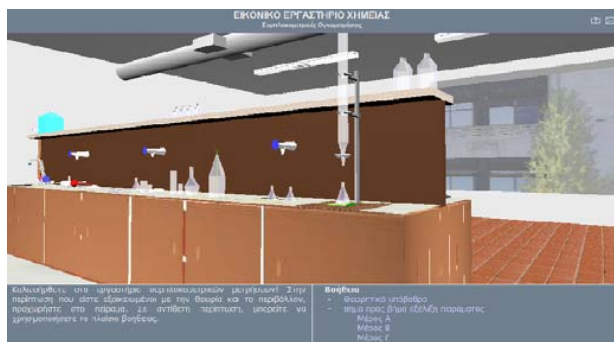

Fig. 8. The chemical apparatus used for the experiment

A. The fist experiment

Sufficient amount of Ca^{2+} solution ($CaCl_2$) is introduced into the conic bottle by clicking on the corresponding bottle (each mouse click corresponds to 1ml of $CaCl_2$). For the attainment of the final reaction, the presence of an alkaline environment is considered as a prerequisite. To this end, the addition of 5ml NaOH 4N is also required. Subsequently, students should click on the Calcon's bottle to add this index to the solution so that the completion of the reaction to be

easily perceptible by the change of the color (from red-violet to blue). Furthermore, 50ml of EDTA are introduced in the burette and the electric mixer is turned on for the efficient mixing of the solution in the conic bottle.
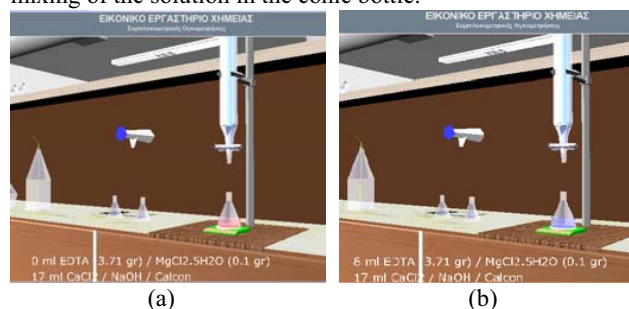

(a)   (b)

Fig 9. a) The color of the solution before the reaction and b) the color has changed from red to blue indicating the completion of the process.

The titration process is performed with gradual addition of EDTA from the burette to the conic bottle. After the completion of the process the color of the solution has changed to blue as shown in Fig 9. The experimental process can be repeated introducing different amounts of standardized Ca^{2+} ($CaCl_2$) solution.

Based on the equivalent equation (Fig 7) of the reacting solutions and knowing the volume and the normality of the Ca^{2+} solution used as well as the volume of the EDTA solution consumed, we can estimate the normality of the EDTA.

B. The second experiment

Clicking on the second bottle, we can place it on the mixer (under the burette) removing at the same time the first one used in the previous experiment. 50ml of water (by clicking on the tap) and appropriate amount of 4F NaOH are added so that the value of pH to be increased to 12. Moreover, Calcon index is added to the solution by clicking on the corresponding bottle as well as EDTA from the burette, while the solution is mixed at the same time. The color changes from red to blue indicating the completion of the reaction. The experimental process is finished with the cleaning of the workbench.

Similarly with the previous experiments, the volume and the normality of the EDTA solution are known as well as the corresponding volume (50ml) of the water. Hence, it is straightforward that the normality of NCa [eqCa^{2+} /L] in the water can be easily estimated from the equation of Fig. 7.

C. The third experiment

In this experiment, the gram equivalent equation of Fig. 7 is used for the estimation of the water's normality in Ca and Mg, and consequently the accumulative concentration of [eqCa^{2+}eqMg^{2+}] / L. By subtracting the concentration of Ca estimated in the previous experiment, we can find the concentration of magnesium (eq Mg^{2+} / L).

D. Water hardness estimation

For the water hardness estimation the accumulative concentration of $[eqCa^{2+} eqMg^{2+}]$ / L is considered equal to $eqCaCO_3/L$. The equivalent concentration of $CaCO_3$ and consequently the hardness of water is given by the following equation:

$$(gr/L\ CaCO_3)=(eq\ CaCO_3/L)xX.I_{CaCO3}=(eq\ CaCO_3/\ L)x50= 50\ ([eqCa^{2+}\ eqMg^{2+}]/L \qquad (1)$$
$$or$$
$$50x10^3\ ([eqCa^{2+}\ eqMg^{2+}]/L\ )\ mg/L\ CaCO_3 \qquad (2)$$

However, $1^oF = 10$ mg/L $CaCO_3$. Hence the water hardness can be defined as:

$$5x\ 10^3\ ([eqCa^{2+}\ eqMg^{2+}]/L\ )\ ^oF \qquad (3)$$

VIII. VOLUMETRIC REDUCTION-OXIDATION

In this experiment, the unknown amount of Fe^{2+} is estimated according to the volumetric reduction oxidation technique. The lab contains the burette and its base, water bottles and other chemical apparatus. Above the workbench there are four bottles containing $KMnO_4$, H_2SO_4, Fe_2SO_4 and oxalic acid respectively, as shown in Fig 10.

Fig 10. Four bottles are placed above the workbench

The equipment needed for this experiment is: two conic bottles, a burette and a mixer. After their placement at the workbench, the lab is ready for the execution of the experiment. Initially, the titration of oxalic acid (standardized solution) with $KMnO_4$ solution is carried out and then performing new titration we can estimate the concentration of Fe^{2+} in a $FeSO_4$ solution. The final point is estimated by the color change of $FeSO_4$ from the redundancy of $KMnO_4$, which is used as an index.

Firstly, $KMnO_4$ of unknown quantity is introduced in the burette and then a known quantity of oxalic acid is added to the conic bottle located under the burette. For the execution of the reaction, the addition of specific amount of H_2SO_4 2M as well as the heating of the solution is required. The titration takes place while the solution is heated up and moved circularly until its color to become constantly violet. The volume of $KMnO_4$ consumed is estimated using burette's indication. The normality of $KMnO_4$ can be estimated using the equation of Fig. 7.

Subsequently, unknown quantity of $FeSO_4$ is introduced in the second conic bottle, which is placed under the burette. Moreover, certain quantity of H_2SO_4 2M is added and the solution is heated up. The same process is followed until the color of the solution to become violet. The volume of $KMnO_4$ consumed in titration is calculated and knowing its normality we can estimate the quantity (mgram) of Fe using the equation of Fig.11.

Fig 11. The equation, shown in the third part of the HTML page, gives the mgrams of Fe.

IX. CONCLUSION

In this paper a novel Web-based virtual learning environment for the simulation of volumetric analysis experiments was presented. The proposed application takes advantage of the recent advances on Web and virtual reality technologies in order to reproduce conditions of a real learning process in a chemical laboratory and enhance learning through a real-time interactive simulation of volumetric analysis experiments. The virtual laboratory presented in this paper constitutes a cost-effective solution for both schools and universities without appropriate infrastructure and a valuable tool for distance learning and life-long education in chemistry. The use of virtual reality technology turns learning into an entertaining and easily comprehensible process, while Web provides free access and use to all internet users with a complete time and place independency. Finally, the application allows the familiarization of non-experienced students with the equipment of a chemical laboratory and the execution of virtual experiments without the need of teacher's presence. In other words, students have the main role in the learning process as they can repeat each experiment as many times as they really need in order to perceive better the chemical procedure, adopting so the learning process to their personal abilities and needs.

REFERENCES

[1] D. Sokoutis, "Simulation of thermo chemistry experiments", *Proceedings of 2nd Conference Information and Communication Technologies in Education*, 2003, Syros.
[2] A. Papas, *Student-Centric Instruction*, 1998, 4th Edition, Gutengerg, Athens.
[3] E. Dale, *Audio-Visual Methods in Teaching*, 3rd Edition", Holt, Rinehart, and Winston, 1969.
[4] N. Kalogeropoulos, and X. Karatzas, "Real or virtual laboratory ? The case of volumetric analysis in chemistry", *2nd Meeting in Intra-School Education on Information and Communication Technologies*, 2002, Thessaloniki.
[5] CSU Chemlab, [Online], Available: http://farrer.riv.csu.edu.au/chemistry/release/
[6] VRLUP, [Online], Available: http://www.vrupl.evl.uic.edu/
[7] Lab 3D, [Online], 2002 Available: http://www.frontiernet.net/~imaging/virtual_chemistry_lab.html

[8]   D. Schofield, E. Lester, and J.A. Wilson, "Virtual reality interactive learning environments", I*nternational Engineering Education Conference*, 2004, Wolverhampton.

[9]   VR-Assisted Chemistry Education, [Online], 2003 Available: http://www.vrmedialab.dk/pr/studerende/projekter/rapport 9sem1022.pdf

[10] High school chemistry educational and virtual reality, [Online], 1996 Available:http://www.hitl.washington edu/projects/learning_center/

[11] Oxford Virtual Chemistry, [Online], 1996 Available: http://www.chem.ox.ac.uk/vrchemistry

[12] Model Science Software [Online], 1997 Available: http://modelscience.com/

[13] The Irydium project virtual lab [Online], 2000, Available: http://ir.chem.cmu.edu/ irproject/

[14] Crocodile Chemistry [Online], 2006 Available: http://www.crocodile-clips.com/chem.htm

[15] L. Harasim, *Shift Happens Online Education as a New Paradigm in Learning, Internet and Higher Education*, No. 3, 2000, pp.41-61,

[16] K. Papanikolaou, M. Grigoriadou and E. Gouli "The contribution of Web in the renewal of educational practices in education", *Issues in Education*, Vol. 6, No. 1, 2005, pp. 23-57

[17] V. Steiner, "What is distance education?", Far West Laboratory for Educational Research and Development", [Online], 1996 Available: http://www.fwl.org/edtech /distance.html

[18] F. Modritscher, "eLearning theories in practice: A comparison of three methods", *Journal of Universal Science and Technology of Learning*, 2006, pp.3-18.

[19] O. Conlan, "The multi-model, metadata driven approach to personalized eLearning services", Phd Thesis, *Department of Computer Science*, University of Dublin.

[20] A. Kokkos, A. Liontarakis, X. Matralis and X. Panagiotakopoulos, "The educational material and the new technologies", Hellenic Open University, Open and distance learning, Vol. 3, Patra, 1999.

[21] J.E. Rudin, "Using virtual reality in education", *In Proceedings of STC, Education, Training and Research*, 1995, pp. 55-58.

[22] A. Manitsaris, T. Kargidis and K. Barbatsis, "Design and development of a dynamic hypermedia educational system", *Journal of Information Technology Impact*, Vol 2, Issue 3, 2001, pp.105-116

[23] C. Bouras, and T. Tsiatsos, T., "Building educational virtual environments". *In Proceedings of the Second IEEE International Conference on Advanced Learning Technologies*, 2002, pp.547-548

[24] S. Liodakis, *Analytical Chemistry: Issues and Problems*, Papasotiriou, Athens, 2001.

[25] P. Tzimou-Tsitouridou, *Laboratorial Exercises for Qualitative Analytical Chemistry*, AUTH, Thessaloniki, 2000.