Virtual Nuclear Laboratory for E-Learning

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Abstract

This paper describes an online virtual nuclear lab (VNL) for fourth-year nuclear physics students. The work presents four web-based experiments: (1) plotting a Geiger Plateau; (2) inverse Square Law; (3) Absorption of gamma Particles and (4) Half-Life of Ba-137m. Each simulated experiment is programmed in full analogy with a real experiment performed in a real laboratory. The VNL is based on assumption that all results achieved during the virtual lab were the results achieved earlier in real-life experiments. The VNL enables distance students to interact with systems that would otherwise be impractical to implement in a real laboratory setting. It also helps students to increase their learning potential of course material.

Introduction

Need for Virtual Nuclear Lab (VNL)

Nuclear radiation is met in many branches of science, technology and medicine. Nuclear physics lab is an essential part of the education experience. Therefore it is very important that students, trainees and specialists are properly educated in this field. The associated expense, time, space and maintenance are major difficulties to make the teaching of this course very effective. Such labs also require highly skilled technicians in order to run and maintain its equipment. Although many universities have well-organized laboratories in nuclear physics but experiments installed in these laboratories are not commonly accessible (Abu-Mulaweh, 2009). Another problem is the restrictions of importing of radiation sources. Some western countries have put restrict regulations and constraints on exporting radiation sources to other countries, including the Middle East countries. This has created difficulties for institutions to have the radioactive sources they require.

Nuclear and radiation physics courses are compulsory courses in all physics departments. In Saudi Arabia, some new universities and colleges have lacks in the facilities and licensure to offer nuclear lab. Ideally, students are required to perform about eight to ten experiments in the nuclear and radiation lab. A lot of diverse concepts are covered in these experiments. It is always a challenge for instructors to cover these concepts in one semester and, at the same time, it is always very difficult for students to grasp the concept to the required level of understanding. The amount of work required and limited time available in order to perform a full experiment is always a problematic. From our experience, many female students are afraid of performing nuclear experiments due to the misconception of the radiation hazards that they may expose to. Expanding the nuclear and radiation laboratory to cover advanced experiments and projects would therefore be impractical.

Aspects of Virtual Nuclear Labs

The available advanced educational technologies, powered by the recent advances in the internet, provide an opportunity to present the material of nuclear and radiation laboratory in a new way where many difficult concepts can be made more tangible and easy to understand. This should have a huge impact on our students' level of comprehension whether the virtual lab is used as standalone course or as a supportive material for the traditional lab.

After learning most of the concepts in nuclear and radiation courses, usually, students have to practice a lot on different problems to master these concepts and their applications in new different settings. This is a very essential part of the learning process, not only for passing the exams, but also for applying these concepts in innovative ways in the students' future fields. Usually the lectures or recitations do not offer enough of this kind of practice. Virtual lab, on the other hand, can be designed to provide enough of practice and conduct the experiment and facilitate the process of supervising many students who do their share on their own paces(Crosier, Cobb, & Wilson, 2000).

Virtual lab (sometimes is labeled as simulation-based lab) can be designed to provide ample opportunities for students to learn from their mistakes without the embarrassment of doing it in the traditional lab. Good communications and feedback with instructors and among students themselves can also be available. This should encourage more students to have active role in the learning process(Kopp, 2011; Pechousek, 2011).

Another important aspect of the virtual nuclear lab if designed carefully is that it does not allow students to jump to a new material before mastering the old material. This is especially important in nuclear science in which many concepts are built on each other. Making sure that the knowledge base of students are solid before introducing new material usually very difficult to accomplished in traditional class stetting. Also, if it is used effectively, the online technologies should reduce the burden of managing the affairs of a large number of students(Tłaczała, Ulaczyk, Zagórski, & Zaremba, 2005).

Tiftikci developed a software with a capability of creating experimental setup that is suitable for a specific virtual radiation lab with minimum cost and to speed up the training in radiation physics for students(Tiftikci & Kocar, 2010). The results obtained can then be analyzed by multichannel analyzer (MCA). Several academic institutions have successfully implemented interactive computerized laboratories with software such as LabVIEW and MATLAB (Crosier, et al., 2000; TLACZAŁA, ZAGÓRSKI, & ZAREMBA, 2006). In Clemson University, remote radiation detection and measurements lab was developed in LabVIEW environment. Distance students are allowed to control physical instruments and acquire and analyze actual data in real-time (Kopp, 2011). Park (2005) proposed web-based nuclear physics laboratory and used HTTP, HTML and CGI program to construct the remote control lab (Park, Lee, Yuk, & Lee, 2005).

This project is a compromise between two conflict demands, reducing the cost of establishing and running nuclear and radiation lab and making them available to all students and instructors wherever and whenever they are. Teachers and students in the General Education sector would also benefit from such a project.

The Virtual Labs Project has been initiated at physics department at Taif University. A major goal of the Virtual Labs Project is to increase scientific literacy by using interactive multimedia to educate the fundamental concepts of physics, and to contribute those resources through Internet. The Virtual Labs objects are presently hosted on a password-protected site and are generously accessible to concerned parties for educational exercise

A wise individual once said that a picture is worth a thousand words; with Virtual Labs we use not just pictures, but also animations and interactive simulations. Students will be able to think about and interact with dynamic methods in the body. We have urbanized learning modules. The ideas in these modules place the groundwork for different experiment of physics.

Research Objectives

The aim of this project is to create an interactive online virtual nuclear and radiation laboratory for science and engineering students. It is specifically focused on the lab and associated experiments conducted in the course titled Nuclear Physics (203460-4) offered at Taif University. The project is designed to help students to learn about radiation concepts and the basic of gas-filled detectors without the need to experience a physical laboratory environment. All the experimental data in this proposed virtual laboratory will be based on results obtained in real measurements performed by the authors earlier in the nuclear lab.

Materials and Methods

The physics department at most Saudi universities offer 3-credit nuclear physics course with 1 credit (3 hours) undergraduate level lab on the fundamentals of radiation detection and measurements. This lab features 10 laboratory experiments centered around gas-filled and scintillation detectors. In this project, four basic experiments were chosen for simulation:

1. Plotting a Geiger Plateau
2. Inverse Square Law.
3. Absorption of gamma Particles.

4. Half-Life of Ba-137m.

In this lab, the student is allowed to fully control the simulated functions of the experiment (Figure 1). Each experiment is designed with software controls that represent real instrument controls, which control experiment parameters that, in one way or another, affect the outcome of the experiment. Using these controls, students are able to interact with the experiment in varying degrees, depending on the type of lab. Well-designed and realistic controls, such as dials, buttons, and slides, can give students the impression that they are actually turning a dial, pressing a button, or sliding a slide. The results obtained from the physical lab are mathematically modeled to represent the expected results. The simulation-based lab can be used in class education and distance education. The equipment, tools and radioactive sources used in the nuclear lab are provided by Spectrum Techniques(Spectrum Techniques, 2002). Each physical experiment was conducted according to the lab's manual(Spectrum Techniques, 2002). All experimental data, variables and results are fed to the simulation-based lab to perform the exact function as the actual experiment.

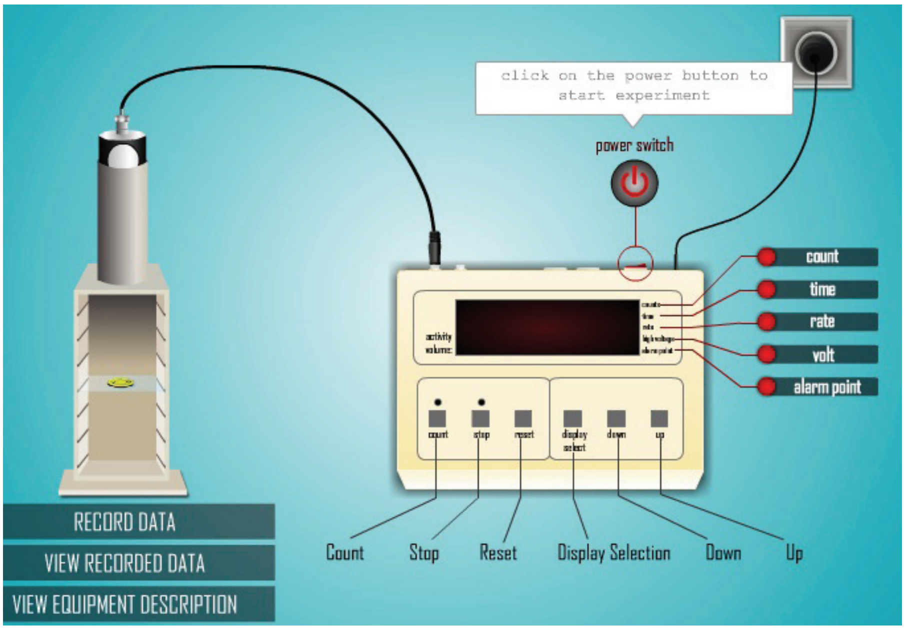

Figure 1: The Simulation-based lab. The lab replicates actual experiments shown in Figure 3.

The structure of the virtual nuclear laboratory

Figure 2 shows the structure of each experiment. This includes:

Student Information: this section includes student's profile (name, university ID, lab section, date, contact... etc.).

Introduction: this section is intended to be a descriptive of the theory underlying the laboratory to be performed, particularly describing the equations, the variables to be measured and the quantities to be determined from the measurements. In addition to the text and pictures, there will some video (animation with voice) explaining these information so that the student can fully understand this subject.

Objectives: this section explains briefly the purpose and the learning outcomes of the experiment.

Equipment: A list of the equipment needed to perform the laboratory and a picture of each equipment/tool with some explanation of what is it for, its functions, precautions…etc.

Experimental Procedure: The procedure will be very detailed. It attempts to give very explicit instructions on how to perform the measurements. The data tables provided include the units in which the measurements are to be recorded. Measurements can be repeated again and again. This is the simulation section of the experiment through which the student will virtually conduct his/her experiment and be able to change values and record results.

Analysis: Student would be able to see/view the recorded data taken from the virtual equipment and perform calculations such us calculate the unknown quantity, determine the mean and the standard error. A graph is required in most of the experiments. The student would first plot his/her data in a spread sheet, determine the slop and calculate the unknown quantity.

Laboratory Assignment: Each laboratory (experiment) would include assignment that is based upon the laboratory description and results. The student should answer a series of questions about the theory and working numerical problems related to the calculations in the laboratory. The purpose of this section is to evaluate the student's understanding.

Laboratory Report: The student should be able to print a summary report of the experiment including the data, graphs and calculation data, his/her answers. This report can then be sent electronically to the lab's instructor.

Feedback: The student may send a question/comment/feedback to the lab's instructor.

Appendices: Physical constants, radiation terms, conversion factors, abbreviations.

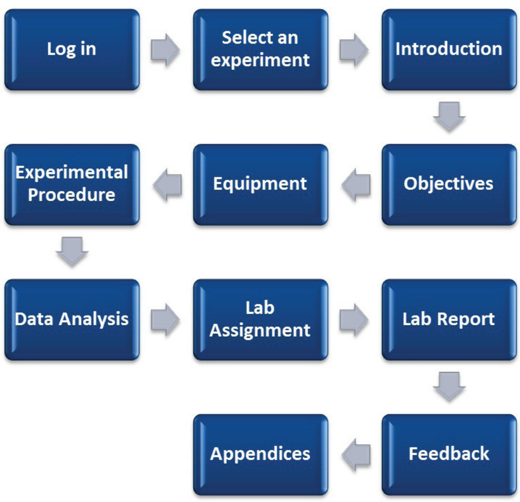

Figure 2: The general structure of the virtual nuclear lab.

In the VNL, four labs were developed: (1) Plotting a Geiger Plateau; (2) Inverse Square Law; (3) Absorption of gamma radiation; (4) Half-Life of Ba-137m. Each lab contains theory, objectives, equipment, procedures, data analysis, lab assignment and lab report. Details of these sections are explained above. All four labs are using almost the same equipment and tools (Figure 3). This includes: GM counter, GM tube, power supply, shelf stand, source holder, aluminum and lead absorbers and radioactive sources (Cs-137 and Co-60).

Figure 3: ST-350 Counter with GM Tube and stand (Counter box, power supply – transformer, GM Tube, shelf stand, serial cable, and a source holder for the stand) from Spectrum Techniques (USA).

Virtual Lab research data are automatically inserted into database, a simple data analysis tool built into provided Graphical User Interface (GUI). On the basis of their information of the research design they formed, students must select the suitable data analyses. A virtual private server is used to host the program. This project has been developed in php programming language, flash and mysql database.

Results and Discussion

Before conducting any lab, description and explanation on how gamma radiation interacts with GM tube, what kinds of interactions occur and how signal is collected (Figure 4). These are some basics that are essential for students to understand the experiments and correctly analyzed the results.

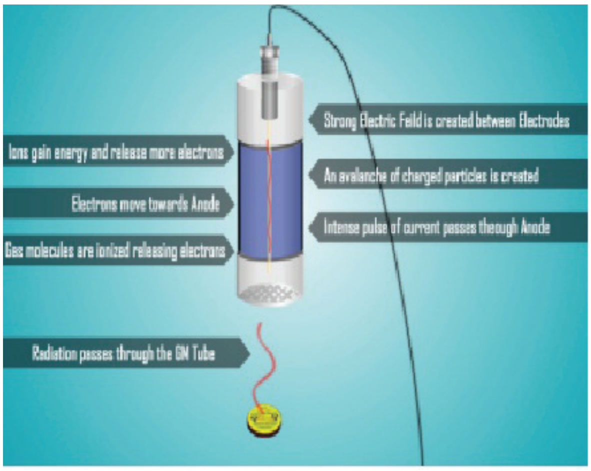

Figure 4: Animation of how radiation interacts with GM counter.

For demonstration, two labs are presented below.

1 - Plotting a Geiger Plateau experiment

The purpose of this lab is to determine the plateau and optimal operating voltage of a Geiger-Muller counter. It is a straightforward experiment, no mathematical model was used. A radioactive source was placed at a depth in the source holder. The actual count was set to 30 seconds. Actual counts versus voltage were collected. This step was repeated three times, average count is calculated and saved in a file. This data was used by the VNL. If the user selects counting other than 30 seconds, the new calculated count is calculated from the following equation:

$$C2 = C1 \times T2/30$$

Equation 1

where C1 is the actual total count

C2 is the new total count obtained when the counting time is T2 (sec.).

2 - Absorption of Gamma Rays

The purpose of this lab is to investigate the attenuation of radiation via absorption of gamma rays. The user will find the attenuation coefficients for aluminum and lead and the half thickness (X1/2) at which the gamma radiation is cut in half.

The data were modeled to conduct the experiment based on the following equation:

$$I = I_o \exp(-\mu x)$$

Equation 2

where I is the intensity of the beam after passing through x amount of absorbing material, Io is the original intensity, μ (cm2/g) is the mass attenuation coefficient, and X (g/cm2) is the mass thickness. Aluminum and lead were used as absorbers. The X1/2 is calculated from the following equation:

$X1/2 = \ln(2)/\mu$

Equation 3

In this lab the user first selects the absorber (Al or Pb). Then he measures the Io. Then he adds an absorber of a known thickness and run the experiment and records I (this is done by pressing record data). The experiment is repeated to a certain number of absorbers (thickness). Details of the experimental procedures and data analysis are written in details for the student to read before he starts the lab. The student can browse between different sections of the experiment whenever he likes. The results obtained from the VNL produce the same effect (but not the same figures) as the actual real-time data. The student would also be able to see the effect of changing other parameters on the measured count such as: no radioactive source, changing the radioactive source, changing the position of the radioactive source, changing the activity of the source, changing the operating voltage.

The Virtual Nuclear Lab helps students to get engaged in scientific innovation processes by giving them the condensed experience of building efficient experimental strategy decisions with the goal of determining the principles of a difficult virtual reality.

Conclusion

In this paper, four labs have been simulated. While conducting the lab, students are able to change parameters and observe the effect of changing variables or to the mathematical model. The designed VNL provides students with a firm grasp of reality concerning the experiments. However, the VNL cannot replace the hands-on laboratory experience.

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