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Virtual Nuclear Laboratory for Undergraduate Students

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Abstract: This study aims at creating an interactive online virtual nuclear and radiation laboratory for experiments conducted in the nuclear physics course. The work presents three web-based experiments: (1) Plotting a Geiger Plateau, (2) Inverse Square Law and (3) Absorption of gamma radiation. Each experiment has been designed and programmed in a way that simulates the real experiment performed in the physical lab. The Virtual Nuclear Laboratory (VNL) is based on results that have been achieved earlier in real-life experiments. The project is a compromise between two conflicting demands, reducing the cost of establishing and running nuclear and radiation lab and making them available to physics students and instructors. The VNL grants distance students the ability to interact with systems and boost their knowledge of course materials that would otherwise be impractical to implement in a real laboratory setting.

Key words: Virtual nuclear lab, nuclear radiations, gamma radiations

INTRODUCTION

Nuclear radiation techniques have become powerful testing tools in many disciplines including Science, engineering 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 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 (Tiftikci and Kocar, 2010). Because of some misuse of radioactive sources and the fear of losing radioactive sources, the nuclear national regulatory in some countries have imposed restrictions in importing certain radioactive sources. This has created additional 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 lack in the facilities and licensure needed to offer a nuclear lab. Ideally, students are required to perform about eight to ten experiments in the nuclear and radiation lab. Many 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 to perform a full experiment is always problematic. In addition, many female students are afraid of performing nuclear experiments because of the misconception of the radiation hazards that they may be exposed to. Expanding the nuclear and radiation laboratory to cover advanced experiments and projects would therefore be impractical.

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 students' level of comprehension whether the virtual lab is used as a 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 great deal on different problems to master these concepts and their applications in new different settings. This is an essential part of the learning process, not only for passing

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the examinations 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. A virtual lab, on the other hand, can be designed to provide enough practice and conduct the experiment and facilitate the process of supervising many students who do their share on their own paces (Crosier *et al*., 2000).

A 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 also can be available. This should encourage more students to have an 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 for students is solid before introducing new material because this is usually very difficult to accomplish in a traditional class setting. Also, if it is used effectively, the online technologies should reduce the burden of managing the affairs of a large number of students (Tlaczala *et al*., 2005).

Tiftikci and Kocar (2010) developed a software with a capability of creating experimental setup that is suitable for a specific virtual radiation lab with minimum cost and to accelerate the training in radiation physics for students. The results obtained can 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; Tlaczala *et al*., 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 *et al*. (2005) proposed web-based nuclear physics laboratory and used HTTP, HTML and CGI program to construct the remote control lab.

This project is a compromise between two conflicting demands; reducing the cost of establishing and running nuclear and radiation lab and making such lab available to all physics students and instructors wherever they are and whenever they need. The number of physics departments in Saudi Arabia that may benefit from such project exceeds 100 departments. This would include both boys and girls sections. Teachers and students in the General Education sector would also benefit from such a project.

The Virtual Labs Project has been initiated at the physics department at Taif University. A major goal of this project is to increase scientific literacy by using interactive multimedia to educate the fundamental concepts of physics and to contribute those resources through the Internet. The Virtual Labs objects are presently hosted on a password-protected site and are generously accessible to concerned parties for educational exercise. Students will be able to think about and interact with dynamic methods in the body. The learning modules have been urbanized. The ideas in these modules place the groundwork for different experiment of physics.

The aim of this project is to create a number of online and interactive virtual nuclear experiments for physics 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. The Virtual Nuclear Laboratory (VNL) is based on results that have been achieved earlier in real-life experiments.

MATERIALS AND METHODS

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

- Plotting a geiger plateau
- Inverse square law
- Absorption of gamma particles

Each simulated experiment is equipped with controls that represent real instrument controls. Student can change parameters, such as counting time and voltage which, would enable the user to interact with the experiment in varying degrees, depending on the type of lab. 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 3 radioactive sources used in the nuclear lab are provided

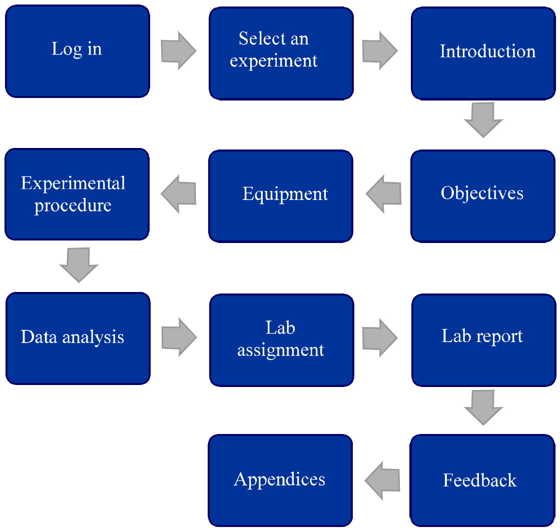

Fig. 1: General structure of the virtual nuclear lab

by 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.

The structure of the virtual nuclear laboratory: Figure 1 shows the structure of each experiment.

Student information: This section includes student's profile (name, university, 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 be 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 it is for, its functions, precautions... etc.

Experimental procedure: The procedure is written details. 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 conduct virtually the assigned 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 as 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 the obtained data in a spread sheet, determine the slope and calculate the unknown quantity.

Laboratory assignment: Each laboratory (experiment) would include an assignment 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, answers. This report can 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.

In the VNL, three labs were developed: (1) Plotting a geiger plateau, (2) Inverse square law and (3) Absorption of gamma radiation. 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. This includes: GM counter, GM tube, power supply, shelf stand, source holder, aluminum and lead absorbers and radioactive sources (Cs-137 and Co-60).

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 analysis. 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

Figure 2 shows the VNL user interface (homepage) where the admin can view student's activities. The VNL have been designed to give the student a control to the simulated functions of the experiment (Fig. 3).

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

Fig. 2: Homepage of the Virtual Nuclear Laboratory (VNL) which contains student's login and Admin login

Fig. 3: A snapshot of the plotting a Geiger Plateau screen, the user will follow a detailed description to run the experiment

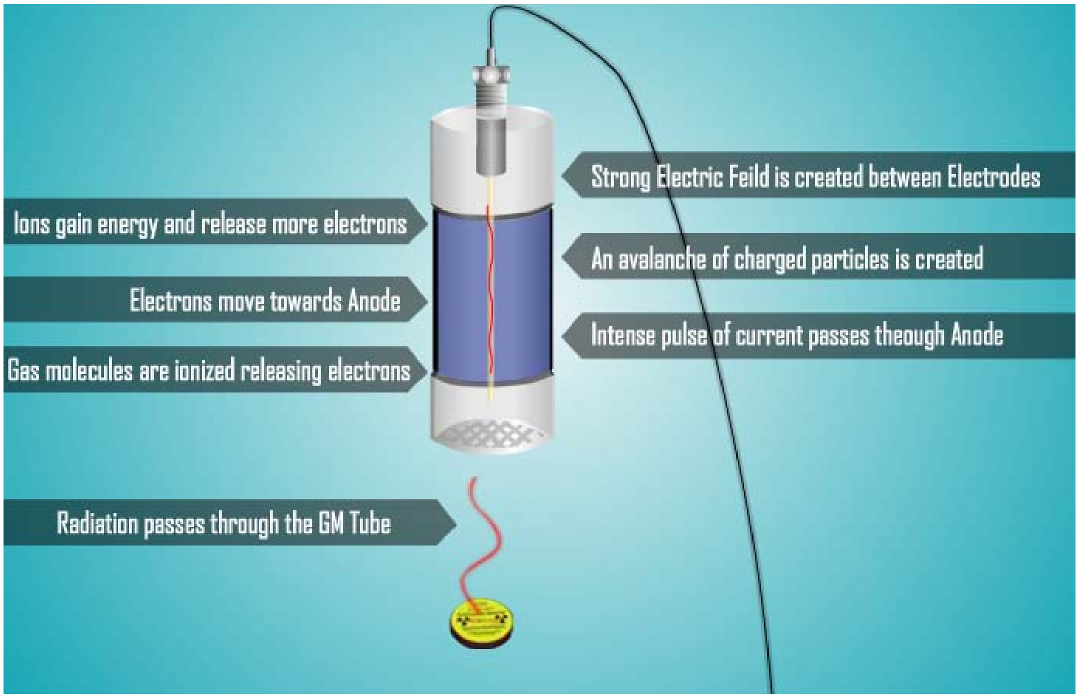

Fig. 4: Animation of how radiation interacts with GM counter

For demonstration, two labs are presented below:

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 sec. Actual counts versus voltage were collected. This step can be repeated three times, average count is calculated and saved in a file. This data was used by the VNL. If the user selects counting time other than 30 sec, the new calculated count is calculated from the following Eq. 1:

$$C_2 = \frac{C_1 \times T_2}{30} \quad (1)$$

where, C_1 is the actual total count. C_2 is the new total count obtained when the counting time is T_2 (sec).

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 ($X_{1/2}$) at which the gamma radiation is cut in half. The data were modeled to conduct the experiment based on the following Eq. 2:

$$I = I_o \exp(-\mu x) \quad (2)$$

where, I is the intensity of the beam after passing through x amount of absorbing material, I_o is the original intensity, μ (cm^2 g^{-1}) is the mass attenuation coefficient and X (g cm^{-2}) is the mass thickness. Aluminum and lead were used as absorbers. The $X_{1/2}$ is calculated from the following Eq. 3:

$$X_{\frac{1}{2}} = \frac{\ln(2)}{\mu} \quad (3)$$

In this lab the user first measures the I_o. Then selects the absorber (Al or Pb) 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 analyses are written in details. The student can browse between different sections of the experiment whenever he likes. The VNL produce the similar results 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 study, the importance and benefits of virtual nuclear lab have been highlighted and three experiments have been simulated. While conducting the lab, students can 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. Student comprehension on using VNL how this differs from the real life experiments is outside the scope of this project.

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