Improving Perception of Invisible Phenomena in Undergraduate Physics Education using ICT

Krishnashree Achuthan[1&2], Lakshmi S Bose[2] , Saneesh Francis[2], K. S. Sreelatha[2], C. O. Sreekala[2], Prema Nedungadi[3], Raghu Raman[3]

[1]Amrita Center for Cybersecurity Systems and Networks
[2]Virtual Amrita Labs Universalizing Education
Amritapuri, Amrita Vishwa Vidyapeetham, Kollam, India
{krishna@amrita.edu, lakshmisb@am.amrita.edu, saneeshpf@am.amrita.edu}
[3]Center for Research in Advanced Technologies for Education
Amritapuri, Amrita Vishwa Vidyapeetham, Kollam, India
{raghu@amrita.edu}

***Abstract*—: Experimental learning plays paramount role in Physics education. Experimental physics requires phenomenological investigations in several cases and this includes understanding visible and invisible heuristic procedures to discern underlying concepts. This study investigates the invisible yet evident occurrences of physical phenomena that are difficult to grasp from a learner's perspective. In this work the contribution of compounded effects of using computational techniques, multimedia enhanced simulations and interactive animations to draw the learner's attention to those physically undiscernable aspects of physics experiments is presented. The study has investigated three physics experiments by engineering students (N= 42) and the methodology focused on differentiating the learning outcomes between classroom teaching, laboratory experimentation and virtual laboratories. The students were divided into two batches. Visual and conceptual understanding was quantified by assessments that included their visual and conceptual understanding. Our study not only revealed severe limitations in learning invisible phenomena based on traditional classroom methods but also empirically validated the positive impact on learning outcomes when the classroom method is combined with Virtual Labs approach.**

Keywords — Virtual Labs; Conceptual Learning; Complex phenomena; Physics; Simulations;

I. Introduction

Science learning, in particular physics learning, is considered challenging due to the involvement of extensive understanding of concepts and principles. Research has shown that conventional or traditional teaching methods have negative effects on the ability of learning physics for a majority of students [1]. Physics laboratories have played a significant role in providing a first hand experience of governing laws in physics through hands-on experimentation. Demonstrations and practical work in the laboratory have long been accepted as an integral part of learning physics [2,3] and no curriculum in physics exists without supplemental experimental or laboratory work. The American Association of Physics teachers defines the primary goals of a physics laboratory to be [4]: assisting with development of an aptitude for experimental physics, provide broad understanding of experimental procedures, data analysis, grasp physics concepts and distinguish between theoretical inferences and experimental outcomes. Although laboratory experience would improve scientific understanding of concepts, the prohibitive cost in building the necessary infrastructure causes most teaching institutions to opt for classroom teaching using textbooks. Beside the complex nature of certain phenomena, an additional issue in physics education is that even text books cannot rely for sound interpretation of information. Bohren [5] explains the how Doppler Effect, refractive indices, and several other physics concepts are incorrectly explained in common references.

The focus of this paper revolves around phenomena that are critical for fundamental understanding of physics concepts that remain obscure after theory oriented and physical laboratory experimentations. The elements of physics topics in experiments that are part of this study are applicable to those that are complex or highly theoretical and where conceptual visualization is important. Many times while learning complex concepts taught using traditional teaching techniques, the learners continue to remain incognizant. This study includes impact of perception of physics phenomena such as charges, spin, emission, absorption, interference etc. Additionally there are specific aspects of experiments that are retained in black boxes either due to its sophisticated requirements or physically harmful effects it may cause on the experimentalists. This induces a level of complexity in the learner's mind and perceiving the impact of errors and precautions becomes challenging.

II. Virtual Laboratories

In the past four decades since the advent of computers and programming languages, using animations and basic interactivity, grasp of concepts have dramatically impacted their understanding compared to what was previously presented to them as part of textbooks. The graphical representations and simulated environments have enhanced the visualization of fundamental phenomena in science education [6,7]. This is primarily due to creation of situations that cause visually appeal to the students thereby facilitating their active participation. Wasfy et. al [8] proposes how virtual reality technologies when integrated in an online environment could serve as a powerful substitute to classroom education in STEM learning.

A. *Virtual Laboratories - A supplemental tool to Physics Education*

Virtual laboratories (VL) are a set of online teaching tools supplemented with rich multimedia content to teach physics concepts that are presented to the students in an experimental format. This paper is based on the VL developed by Amrita University as part of eleven member consortia. The entire project included development of over 150 VLs and 1500 experiments [9,10,15,16]. These VLs1 mimic the laboratory set up graphically in terms of equipments that are drawn to scale and present parameters that could be modulated to better understand the phenomena. Some of the unique features of VL include 1) ability to work with the online environment anytime and anywhere, 2) ability to experiment with more parameters than what one could in the real world as in a physical laboratory 3) storing and analyzing data easily and so on. Not only normal students, but those with learning disabilities and have difficulties understanding abstract concepts can benefit from using VL. VL provides students with a variety of tools that allow them create representations of their experiments and a screen design that displays videos of experiments, magnified views of the experiment, graphic representations. Hence students can visualize multiple representations of the same experiment.

B. *Invisible Physical Phenomena Perceived in Virtual Laboratories*

Huppert et. al [11] describe the primary challenges in student understanding of physical concepts is due to lack of visualization pertinent to those concepts and lack of ability to control the influential parameters of a phenomena. Pyatt [12] indicate that conceptual understanding is directly influenced by the explorative and manipulative aspects of naturally occurring phenomena. Virtual laboratories thus help students visualize processes that might be difficult to conceptualize otherwise. Barnett et. al [13] point out that one of the important aspects of scientific learning is the ability to mentally transform 2-D objects into dynamic 3-D objects. Some of the concrete examples that are the focus of this study are given below:

i) Doppler Effect (DOP) – This phenomenon involves understanding the change in frequency of electromagnetic waves due to the relative motion between source and observer. In a traditional classroom, some of the common examples referred to are the changing perceived frequencies of ambulance sirens or car horns as they pass by the observer. To comprehend the underlying phenomena, students are asked to calculate the frequency shifts for various source velocities. When a source of frequency is given; for a range of velocities, the shifted frequencies are calculated.

Virtual lab based learning: Using VL simulations of Doppler Effect (Figure 1), several visual components are added to deepen their understanding. As an e.g. 1) student are taught to look at the two key entities i.e. the source of the sound and the detector, which could be a human observer 2) they are able to control the change in motion of the source and detector and see them in real-time and observe the frequency shift 3) using a slider, the source and detector velocities can be independently varied to mimic reality 4) in addition, the wave profiles of the source and detector due to changes in velocities are simultaneously displayed and 5) the dampening of the source frequency as detected by the detector and the parameters impacting it and 5) to portray the importance of the environment and its impact on the sound waves, a change of media from air to water or glass or steel is provided. Almost all of the above features are impossible to visualize without the aid of the VL tool.

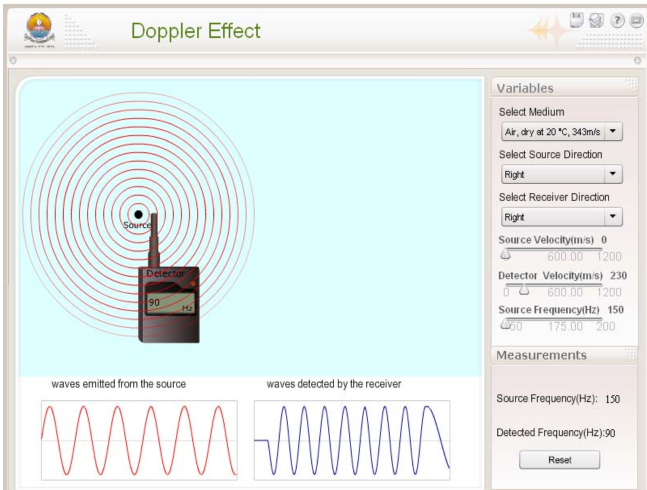


Figure 1: The simulation of Virtual lab of Doppler Effect

ii) Van De Graff Generator (VDG) – The principle of Van De Graff generator is based on generation and transfer of charges between two conductors. With the ability to produce high voltages of between 0.5 million to 20 million volts, the challenges of using this apparatus relates to its hazardous set up. Safety precautions are high with risks of sparks that may cause injury. Additionally the cost and sensitive nature of the equipment components to dust and moisture make it difficult to maintain and nearly impossible for students to operate. Hence teachers resort to typical classroom description by showing the image of the generator, the belt over a pulley and the two electrodes. Gire et. al [14] describe the student understanding of pulleys through physical and virtual manipulative. In the classroom, the governing equations are explained to demonstrate the basic functionality. Motion of the pulley affecting the transfer of charge and the accumulation and transfer of charges etc. is left to the imagination of the student.

Figure 2: Simulation of Van De Graff generator

Virtual lab based learning: Using VL simulations of Van De Graff generator (Figure 2), the visual aspects designed to enhance the conceptual understanding include 1) a cross-sectional view of the generator 2) the transportation of charges from the movement of the belt 3) uniform accumulation of charges on the metallic dome until the threshold ionization intensity is reached 4) the dielectric breakdown with generator discharge of static charges in the form of a spark 5) variation in distance between the hollow and charged conductor and its influence on the charge transfer.

iii) Electron Charge Measurement – Millikan's oil drop experiment (MOD) is one of the finest experiments used to quantify the charge of an electron that any physics student should understand. Compensating the gravitational pull of an oil droplet by an electric field and controlling its fall, the charge of a single electron is computed. It is a rarity to find Millikan's apparatus in any physics laboratory. In cases where this instrument is available, a short focal telescope is integrated to view the suspension and fall of the oil drop. However, viewing the oil drops is cumbersome and cause strain to the observer. Hence conceptualizing this phenomenon is challenging.

Virtual lab based learning: Using VL simulations of Millikan's oil drop experiment, the understanding the forces affecting moving particles in an electric field is presented in a simplistic fashion. The visual cues and features in this experiment include 1) magnified view of the chamber used to suspend particles 2) viewing the fall of droplets as a function of applied voltage 3) measuring the rate of fall between the cross-wires using the timer 4) ionization of air from turning on the x-rays and its impact on the oil droplets and 2) repeating the process to observe differences between glycerine and olive oil. The magnified view of this chamber and the intricacies of the experiment in addition to controlling the external electric field, provoke high order thinking that would be impossible to achieve otherwise amongst students.

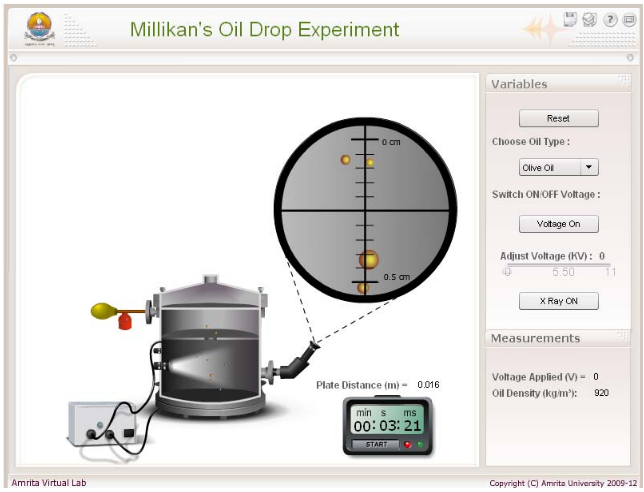
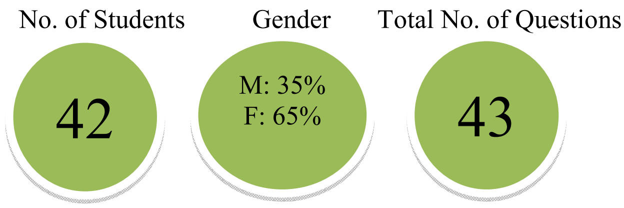


Figure 3: Simulation of Millikan's oil drop experiment

III. RESEARCH METHODOLOGY

In our study, 42 students participated. All students were undergraduate engineering students in the first year of their study and had physical labs and virtual labs as part of their curriculum. None of the students had any exposure to these experiments prior to this study.



There were two steps to our research study.

1. In this step, students were explained the theory behind the experiments without any visuals or visit to real labs. Then the students took the assessment based on classroom teaching only. Figure 4 shows the results from this assessment.
2. In the next step, students that performed poorly in the assessment were exposed to the VDG, DOP and MOD experiments in Virtual Lab environment. The same set of students re-took the same assessment again.

Summative assessments were designed in such a way that it included both visual & conceptual type questions. Visual type questions included those that could be answered after seeing the animated representations of the phenomena. By understanding the governing equations alone may not assist their complete comprehension. Hence questions were framed based on invisibility of the phenomena. Sample questions listed below were some of the most difficult ones from our survey. Every experiment had a summative assessment that had on an average 14 questions (50% of them were visual and the remaining 50% of them were conceptual in nature)

They are:

1. What is the electric field inside the charged hollow sphere? (Figure 5)

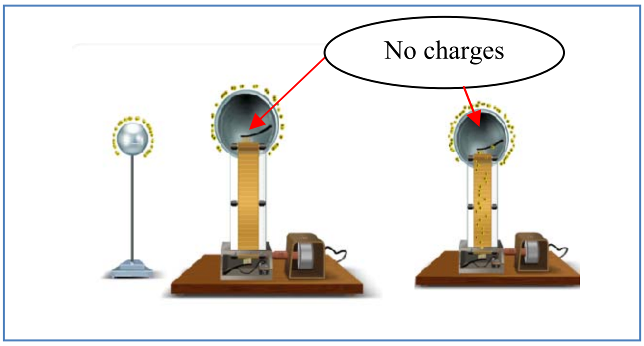


Figure 5: VDG: Visual question

2. What happens to the oil drops when the x-ray source is switched on? (Figure 6)

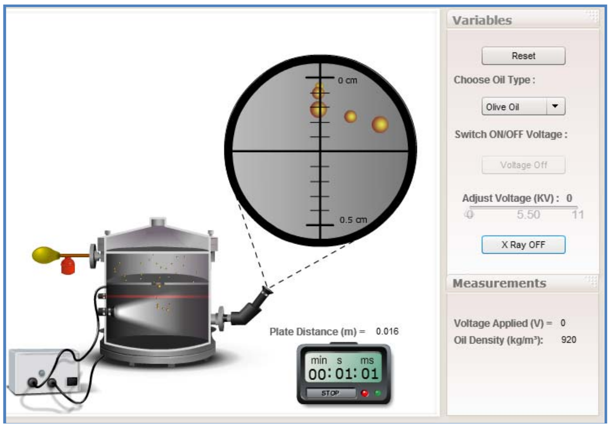


Figure 6: MOD: X-Ray source is ON

3. Which of the following best represents the sound wave if the source is moving towards the observer? (Figure 7)

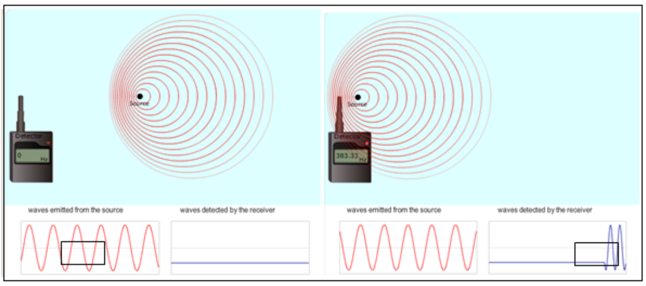


Figure 7: DOP: Change in frequency.

Conceptual questions that were used for assessment included questions that required applying the knowledge gained by doing VL to some real life applications. Sample questions included:

4. A bunch of paper bits from a paper punch and put them on top of the dome. When the machine turns on, what will happen to the paper bits?
5. What is the terminal velocity of air bubble in Millikan's oil drop experiment?
6. If the moving source of sound passes a stationary observer with a speed much less than the velocity of sound, what would its apparent decrease in frequency be?

IV. RESULT ANALYSIS

As can be seen from Figure 4, significant number of students did poorly when assessed on the three experiments based on traditional classroom teaching only. This could be due to lack of retention and difficulty in grasping of invisible concepts without the aid of visuals and actually performing the experiments.

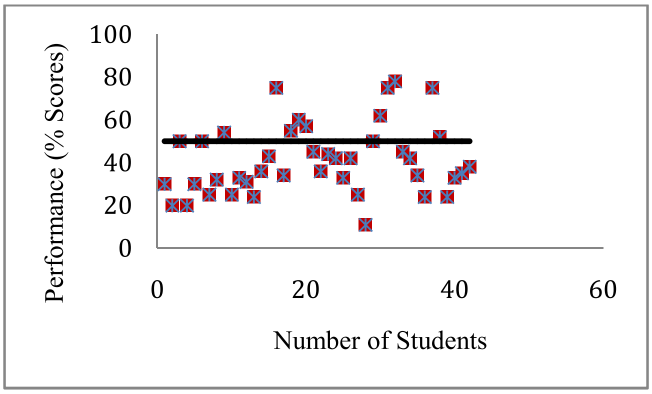


Figure 4: Student performance from traditional classroom teaching

According to the pair wise t-test results (Table 1), students learning outcomes were consistently higher when they used Virtual Lab environment followed by classroom teaching. This was true for both visual and Conceptual type questions.

Table 1 Summary of Hypothesis results

Experiment Name	Question Type	t value	P value
VDG: Van de Graaff Generator	Visual	-6.41	0.000
	Conceptual	-7.39	0.000
MOD: Millikan's Oil Drop	Visual	-9.86	0.000
	Conceptual	-8.43	0.000
DOP: Doppler Effect	Visual	-12.98	0.000
	Conceptual	-12.33	0.000

From the raw data, it was observed that the mean scores were also substantially higher when compared with mean scores based on classroom teaching only which did not involve any Virtual Lab environment. (Table 2)

Table 2 Comparison of Mean Scores

Experiment Name	Question type	Mean Scores	
		Class room teaching only	**Using Virtual Labs**
VDG: Van de Graaff Generator	Visual	5.73	8.52
	Conceptual	6.16	8.35
MOD: Millikan's Oil Drop	Visual	6.57	8.82
	Conceptual	3.71	7.55
DOP: Doppler Effect	Visual	3.60	8.30
	Conceptual	4.08	8.30

Subsequently we analyzed the performance of individual questions 1 through 6 that were initially found difficult for most of the students and that they could not answer. (visual questions 1, 2, 3 and conceptual questions 4, 5, 6); Figure 8 shows the performance improvement on the same questions after the students were exposed to the Virtual Lab (VL) environment.

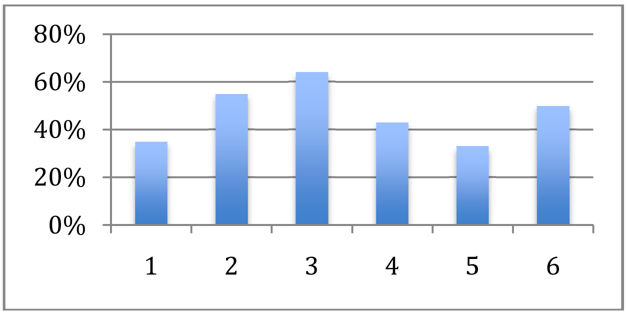


Figure 8: Improvement in scores for visual (1, 2, 3) and conceptual questions (4. 5, 6) using VL

V. CONCLUSION AND FUTUREWORK

Concepts in physics related to harmonic motion & acoustics, electricity and magnetism, where visualization is absolutely critical to concept understanding were analyzed amongst engineering students. Assessments post classroom training revealed below average grasp of fundamental concepts. This was primarily due to the difficulty in discerning phenomena that are invisible and uncontrollable. Through exposure to Virtual Lab learning environment, and using an assessment based on visual perception and conceptual understanding, concrete evidence on the depth of understanding gained from VL was obtained. Most importantly, the students who had low understanding of physics phenomena like Van De Graff Generator, Millikan's Oil Drop, and Doppler Effect showed substantial increase in learning outcomes when the classroom teaching was supplemented with Virtual Labs.

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