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A PATH FOR HORIZING YOUR INNOVATIVE WORK

ADVANCING PHYSICS LEARNING THROUGH UNDERSTANDING ERRORS

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Abstract: Physics grows through the scientific method of seeking agreement between theory and experiment. Study of the various errors that creep in the experimental investigations and theoretical modelling thus forms an integral part of research in physics. Though this method is followed in an open ended manner by researchers pursuing their doctoral degrees, undergraduate students often miss this spirit of learning due to the limitations of educational structures. This work is an attempt to introduce this spirit among the first year students pursuing undergraduate engineering. For this purpose we reoriented experiments prescribed in the syllabus of the first year Engineering Physics course of the R. T. M. Nagpur University using this approach. The investigation brought out that the use of scientific method and estimation and understanding of errors is effective in motivating students to understand the reasons for the departure of the theory from the experiment. This, in turn, is useful in developing valuable insights into learning both theory and applications.

Keywords: Scientific Method, Knowledge Center, Higher Education, Engineering Physics, Error Analysis

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INTRODUCTION

Physics embodies knowledge that connects concept with application, theory with practice and discovery with development. However, these close links are often obscured in our rigid structures of education and a need for a knowledge based approach has been expressed by several thinkers and workers in the past.[1-3] Recently we have taken a proactive initiative to address these concerns by starting a physics knowledge center in our institute. The initiative aimed at facilitating natural learning of physics in an open and flexible manner based on the ignorance and curiosity of learners, i.e., what they don't know and want to know. The present work is motivated by our encouraging experience of this initiative and our recent work on these lines.[4-10]

In this initiative a student is looked upon as a young researcher rather than one who is studying only for marks and degree. Here it is important to differentiate between this researcher and a researcher pursuing doctoral degree. For a doctoral degree the research is aimed at new knowledge (for everyone) whereas this research aims at new knowledge for

only that researcher, i.e., at the better understanding of the available knowledge. Thus this researcher is not expected to build new models or discover new experiments but being deft in experiments means acquiring new skills and better grasping of theories means coming closer to what the physicists who developed these theories thought once upon a time.

Learning by Scientific Method

In our structured education system theory and experiment are often distanced from each other through the use of separate books, time slots, and rooms conveying an impression that the two are independent of each other. In our initiative, we integrated experiments into theory to stress that both are *equally important* and *interdependent* components of physics and adopted the scientific method of learning by seeking agreement between the experiment (observation) and the theory (explanation).

Attempts were made to convince students that experiments are strong techniques of learning physics if performed with total involvement and curious mind. The meaning of equation was clarified in this context as a mathematical statement that the left side equals the right side under some assumptions. It was emphasized that this equation is not a universal statement but can by checked by performing an experiment, substituting the measured values in the equation and looking for the agreement between the left side and the right side of the equation. In seeking this agreement the role of errors become very crucial.

Error Analysis

Errors are always involved in the measurement of any physical quantity and these errors play a role in the results obtained in any experiment. In any experiment we directly measure some physical quantities and then determine others using known mathematical formulae. Thus the final result is also in error. If we measure the quantities x_1, x_2, and x_3 experimentally using instruments having least counts Δx_1, Δx_2, and Δx_3 respectively and determine a parameter $y = f(x_1, x_2, x_3)$, then the net error in y is given by

$$\Delta y = |\partial f/\partial x_1|\,\Delta x_1 + |\partial f/\partial x_2|\,\Delta x_2 + |\partial f/\partial x_3|\,\Delta x_3 \text{ --- (1)}$$

Equation 1 gives the absolute error in y. The fractional or relative error in y is given by $(\Delta y/y)$ and $(\Delta y/y) \times 100$ gives the percentage error in y.

For example, in an experiment of determination of unknown wavelength using plane diffraction grating, the wavelength is determined by the formula, $(a+b) \sin\theta_n = n\lambda$ ----- (2), where a+b is the grating element, given by $a+b = (2.54/N)$ cm ----- (3), where N is the number of lines ruled per inch on the grating, θ_n is the angle of diffraction of order n and λ is the wavelength of sodium light.

The error $\Delta\lambda$ in the estimation of λ, obtained using Eq. (1), is $\Delta\lambda = [(a+b) / n] \cos\theta_n \, \Delta\theta$ ----- (4) where, $\Delta\theta$ is the error in the reading of spectrometer.

For example, for the measured data, $a+b = 16933.3$ Å, $\theta_1 = 20.29^\circ$, least count of the spectrometer $= (1/60)^\circ$, we have, $\Delta\theta = ½(1/60)^\circ$ and for the first order we get,

$\lambda = (a+b) \sin\theta_1 = 16933.3$ Å $\sin(20.29^\circ) = 5872$ Å and $\Delta\lambda = 16933.3\text{Å} \times \cos(20.29^\circ) \times ½ \times (1/60)^\circ \times (\pi/180) = 2.31$ Å.

Thus the relative error in $\lambda = \Delta\lambda/\lambda = 2.31\text{Å}/5872\text{Å} = 3.94 \times 10^{-4}$ and the percentage error is 0.04 % .

MATERIALS AND METHODS

In this work the experiments prescribed by the R. T. M. Nagpur University for the first year engineering physics course were reoriented to suit the objectives of this study. Students were involved in comparing theoretical expectations with experimental results in each experiment. Further, students were involved in researching into the reasons for disagreement between theory and experiment.

For example, the Newton's rings experiment motivated research into departure of experiment from theory such as blurring of fringe pattern at large distances from the centre and not getting a perfectly dark spot at the centre. The reasons for the departure were sought in understanding the crucial role of factors like coherence of light source, departure of lens surface from strictly spherical shape and presence of minute dust particles between the lens and the glass plate.

Students were also involved in deriving the formulae for estimating errors in various experiments using Eq. 1 and using them for estimating and understanding errors. For example, in the diffraction grating experiment discussed above it was understood how major errors can creep in if the rulings on grating are non uniform. For example, if the number of lines etched on the grating departs from 15,000 by $\pm$ 500 then the error which creeps into the calculation of λ is $\Delta\lambda = (2.54 \sin\theta_n/n)\,(1/N^2)\,\Delta N = (\Delta N/N)\,\lambda = (500/15000)\,\lambda = \lambda/30 = 196.3\ A^{\circ} = 3.3\ \%$. This error completely swamps out the error due to instrumental limitations of spectrometer estimated above.

Learning in this way facilitates deepening and broadening of knowledge by opening knowledge windows to the world of theory and applications. Such learning was promoted through activities of knowledge center such as curiosity corner (arousing and satisfying learner's curiosity) and knowledge cafe (making routes from classroom learning to industry applications visible to learners).[5]

RESULTS AND DISCUSSION

Table 1 shows the agreement between theory and experiment observed in the various experiments. With the quality of instrumentation available in UG institutes only qualitative agreements can be reached. However, it is appreciated that it is not the actual agreement but the training of seeking agreement between theory and experiment that is important. Table 2 shows few examples of promoting learning in a knowledge centric way. This table shows how this approach brings to fore the potential of experiments as knowledge windows to the deeper world of theories in physics and the wider world of applications in engineering.

CONCLUSION

This study concludes that the use of scientific method and estimation and understanding of errors is effective in motivating students to deepen and broaden their interest in both the theoretical concepts in physics and their application to engineering. As one starts explaining what one observes and starts observing what one expects the process of learning becomes most natural!

Our work has brought to fore how the journey of an undergraduate student from a young researcher to a mature researcher can be a journey from broader and coarser levels of agreement to deeper and finer levels of agreement between the theory and the experiment. The work has also enabled us to appreciate that challenges in learning means better and better understanding of the available knowledge just as challenges in research mean newer and newer knowledge.

Table 1 Agreement Between Theory and Experiment

In the interference experiments using Biprism and Wedge shaped film straight-line fringes are observed and the separation of fringes is found to same within experimental limits in agreement with the expression for the fringe width that is independent of fringe number.
In the Newton's rings experiment, circular ring pattern is seen and it is observed that rings get closer as one moves away from the centre in agreement with the expression for ring diameter that is proportional to square roots of natural numbers.
In the Diffraction Grating experiment maximum intensity is observed at angles predicted by the Grating equation. Spacing between lines is more in second order than in first order in agreement with the expressions for dispersion and resolving power.
In the experiment of Resistivity by Four-probe method the experimental graph of logρ versus 10^3/T (ρ is resistivity and T is temperature) is in agreement with the prediction of band theory that the resistivity of a semiconductor should decrease with increase in temperature.
In the diode experiment the observations that (i) a certain minimum voltage is required for the diode to start conducting, (ii) current in forward bias is large and increases rapidly with voltage (iii) current in reverse bias is small and almost independent of voltage are in agreement with the predictions of band theory that a potential barrier exists across the p-n junction which decreases under forward bias and increases under reverse bias.
In the Hall effect experiment Hall voltage is found to increase with both the current and the magnetic field in agreement with the expressions for Hall voltage and Lorentz force.
In the transistor experiment the observed input and output characteristics of a transistor are in agreement with the forward and reverse characteristics of the Emitter Base diode and the Collector base diode.

Table 2 Examples of promoting learning in a knowledge centric way

Curiosity Corner
Interference experiments motivated probing the role of coherence of the light source in the fringe pattern, which further led to the study of correlation of the number and quality of fringes with the spatial and temporal coherence of the light source. This further offered an insight into the science of interferometry.
Transistor experiment revealed why transistor is considered a scientific marvel that brought about a revolution in technology. As diode was already in use before the discovery of transistor one may think of transistor as an extension of diode. However, the peculiar construction of base region and a particular way of biasing makes a transistor behave in a manner very different from what could be achieved by merely connecting two diodes back to back. These revelations enabled students to appreciate that how good a transistor behaves is decided by how thin and lightly doped its base region is.
Knowledge Cafe
The interference experiments brought out the application potential of the phenomenon of interference in measurement of very small dimensions using interferometric techniques.
The hall effect experiment comes as a novel application of our knowledge of motion of charged particles in electric and magnetic fields to the determination of solid state properties such as polarity, mobility and density of charge carriers in a solid under study.
The experiment of resistivity by four probe method brought to fore how the knowledge of behavior of semiconductor as a function of temperature forms the basis of devices such as thermal diode or photodiode.

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