Research based Pedagogical Protocols for Laboratory Courses

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Abstract— Current curricula in most academic institutes in India train the students in information gathering for most time and honing of theoretical knowledge at best. The emphasis on skill development and its use towards acquiring holistic knowledge has been waning over the last few decades. The well-documented ill of emphasis on marks as opposed to learning is mostly responsible for this state of affairs. The inability to implement new ideas in the laboratories is of deep concern in a field like Physics, which in its essence is an experimental science. A three-pronged approach is being tried out at the Central University of Tamil Nadu (CUTN) in the department of Physics to address the issue, namely (a) a vertical integration of concepts taught in Physics from the 1st to 5th year of the Integrated Masters (IMSc) program (b) gradual transition from instructional laboratories in the first year to research based laboratory in the last teaching laboratory followed by (c) a research based project. In this paper, we will discuss the pedagogical protocol developed and implemented in the Integrated Mater of Science (IMSc) (Physics) program and the results it has yielded in the form of better-prepared students.

Keywords: Pedagogical Protocols, Laboratory Courses

I. INTRODUCTION

Opinions on higher education pedagogy are split into two main domains – one which believes that domain knowledge yields pedagogical knowledge and the other which insists on the development of pedagogical knowledge in order to impart domain knowledge. The first idea is exhibited in our Indian educational system where one written exam testing domain knowledge, namely the NET/SLET/GATE exams, qualifies a candidate as a teacher/faculty. In reality, there is a large gap between domain knowledge (also called content knowledge) and pedagogical skills. The lack of pedagogical skills on part of the educator(s) can make the student turn away from the domain.

Some people acquire pedagogical skills through additional educational qualifications; most others learn it on the run. In order to impart the necessary domain knowledge and skills to the students, the educator must be self-aware (in terms of domain knowledge, communication skills, technological know-how etc.) and also be aware of the needs of the students (their short-falls in learning, the probable sources of misconceptions, the strengths and weakness of every batch of students, if not every student).

In this paper, we discuss our experience in introducing long-term (5 year) research-oriented pedagogical ideas into the IMSc (Physics) laboratory programs at CUTN and present the results with 2 batches as a case study.

Based on the experience gained from years of teaching Physics for UG (major and minor subject), PG students and research scholars, the present authors are convinced of the following, as far as teaching Physics goes.

- The over-emphasis on marks, especially at the school level has led to students relying on rote memory and not on understanding the concepts. Memory based learning falls in the lowest rung of learning based on Bloom’s taxonomy of learning [1] and in that modified by Anderson and Krathwohl (2).
- This has further lead to the students not honing their analytical abilities.
- The overarching problem with this rote-memory kind of approach to teaching is that the students tend to compartmentalize the sub-fields of Core Physics (classical, quantum, mathematics etc..) into distinct baskets and make no attempt at having a holistic knowledge of Physics.
- There is a serious disconnect between “theory” and “lab”. The overemphasis given to written exams has led to the laboratory often being a perfunctory entity in most educational institutes, starting from the schools. This is a dangerous trend for an experimental science like Physics. (Unavailability of even moderately equipped laboratories compounded by the unwillingness of schools to emphasize laboratory teaching and learning process is also the reason for the labs to become a perfunctory entity).
- These factors have further lead to a significant deterioration in the hands-on skills of the students and the subsequent lack of what it means to do scientific experiments. They are not aware of concepts such as repeatability, reproducibility, error, accuracy, sensitivity, resolution and precision.
- Thus the students expect to be hand-held even when they grow to be research scholars.

On one end of the IMSc program at CUTN, given that the student input we get is from various school boards, one of the important tasks while setting up laboratory curricula is the need to equalize their strengths and weaknesses as soon as possible so as to enable us to have a uniform pedagogical pattern. On the other end of this, at the end of 5 years of training, the students should be made ready for a possible career in research. In a period of 5 years we have to, ideally, make the transformation of the students from a rote-memory learning based student to an independent researcher. As is well known, teaching for the sake of understanding by students and not for marks is an enormous task [3]. We present here the methodology adopted over the 5 years in the laboratories.
II. METHODOLOGY

There is a vertical integration of core-domain-knowledge over the 5 years of the IMSc program in Physics at CUTN. This essentially means that we treat the first year student as a Masters student, in principle, being wholly aware of the large gaps of knowledge that need to be filled. The first two years of the program are common to students of all science streams namely IMSc (Chemistry, Mathematics and Life Sciences) and the Physics students also learn other allied subjects. The next three years are dedicated to learning Physics.

A. General Methods Used:

1. All laboratory courses are related to at least one theory paper being taught that semester to enable the students to actually experiment the Physics that they are learning.
2. Evaluation Process: The students are introduced to the idea of grading on the curve (bell-shape curve analysis) [4]. They are told that mere collection/reproduction of data, with correct analysis and presentation, will fetch them an average mark of 80%. Any deviation from this will depend on the innovation/understanding shown by the student, or the lack of it. Hence the students are immediately made aware that mere reproduction of “correct data” will not fetch them marks, nor will just writing beautiful records. They are encouraged to have a single observation cum record where all mistakes are noted and “Procedure” can be given as bulleted points. This takes away the stress of students from vernacular medium of instructions in writing complete sentences and hence eliminates the need to copy and paste.
3. Marks are given for debugging mistakes and deviations from the “correct” answers. Viva and interaction is given high importance.
4. Attendance: attendance is given importance since skill development happens only with regular effort.
5. Instructional method: as a matter of principle, the authors avoid giving hand-outs/lab-manuals of experiments. We employ a Socratic pedagogical methodology [5]. The students are asked probing questions so as to let them develop the “experimental procedure” logically.

B. The First Year Laboratories:

In the first year labs, the emphasis is on introduction to what “experiments” mean. The initial experiments are designed so as to introduce the ideas of sensitivity, resolution/least count, accuracy and precision. Students are taught to report results to the correct number of significant figures. The concept of error bars is introduced. The laboratory equipments are such that they evoke curiosity in the students (e.g., a roller coaster for studying the conservation of energy). At the same time, this equipment also has a computer interface component, thus introducing the students to the idea of “computer controlled experiments” which are a large part of research level experiments. In short, the first year labs are intended to evoke the curiosity of the students in domains that they are already comfortable with (waves and oscillations and mechanics), while hand-holding them and introducing them to the essentials of experimental physics.

C. The Second Year Laboratories:

From the second year, the students are encouraged to be creative and come up with new ideas/experiments pertinent to the given paper. They are encouraged to find literature and resources to enable them to explore the concepts being taught. Stress is given to repeatability and reproducibility of results. The emphasis is on developing the art of experiments and analytical analysis of data. The first and second year labs act as introductory physics lab for further development of experimental skills of students.

D. The Third Year Laboratories:

By the third year, the students are fully into learning Physics. At this stage, the lab courses strongly encourage the students to expand the scope of each experiment. For example, in an experiment titled “Study of Balmer Series of Hydrogen Spectra”, the students are encouraged to discuss line and band spectra, observe them in the lab and also try and observe the Fraunhauer lines of the solar spectra. If the final results deviate from the standard results, the students have to try and explain the cause of deviation instead of getting the correct readings. Conceptual learning is emphasized. Along with all these, the students were taught to write their laboratory records using Latex and plot graphs using graphing software such as Origin.

The laboratory courses for the first three years meet with the five criteria namely (i) art of experimentation (ii) experimental and analytical skills (iii) conceptual learning (iv) understanding the basis of knowledge in Physics and (v) developing collaborative learning skills, suggested by American Association of Physics Teachers for basic laboratory programs [6].

E. Fourth Year Lab:

The students are coupled with fresh research scholars, since learning from demonstrations is enhanced by peer-discussion and peer-demonstration [7]. The students were divided in to groups of 3-4 students per group and a feasible research level topic is suggested to each group. The students are not only encouraged and taught to survey literature to appreciate the importance of the problem on hand but also compel them to come up with a feasible methodology to approach the problem. The students are further encouraged to come up with suggestions on the instruments required to give a meaningful result for the given problem. Finally they are asked to submit a scientific report that consolidates their results, discussions and conclusions. For example, one of the problems chosen for study was that of weak inter-molecular interactions. The students were briefly taught on the use of spectroscopic techniques to study such interactions. The students, on reading about this topic and knowing what instruments were available in the lab, proceeded to obtain FTIR spectra of binary mixture of two liquids over the entire
concentration range. They also recorded the broadband dielectric spectra of the same. While consolidating the results, they found that they were unable to visualize the interactions. One of them, who was previously working on computational aspects of molecular interactions with one of the authors, took up the task of running initio calculations of the binary system under study, thus giving not just visualization but also a theoretical platform to interpret the results. We encourage the students to present these original results at national level conferences and present the data to seniors in the field in order to prepare them for full involvement in research.

F. Fifth Year Project:
The fifth year consists of a one-semester pre-project and one semester of research based project. At the end of the training provided by the 8 semesters of laboratory courses, the students who chose to take up experimental projects were able to take up original research as project work.

III. TANGIBLE RESULTS SEEN
1) Many of the students who were never exposed to even school level projects sought out to do summer research projects in many premier institutes of the country (through personal contacts and also through agencies such as IAS etc.). These summer projects are a practical way to give the students real world application in their domain area [8]
2) A few conference papers were presented by the students based on their work in the lab and based on their active interactions with research groups outside the working hours.
3) The students were constantly contributing to the lab program through new experiments/demonstrations etc.
4) When the students come to the fifth year, they are in a position to take up research level project work, without fear or doubt. Some of our students, who came from a rural background, did their projects at IIT Madras, HCU and were much appreciated for their attitude and dedication towards research.

IV. CONCLUSIONS
Some of the significant steps of Research Based Instructional Strategies (RBIS) are enlisted in [9]. At the end of five years, we see that our laboratory instructional strategies have met more-or-less all the criteria required for RBIS. We thus conclude that teaching laboratory courses over a period of four years, based on ideas from research is useful to train an average student to be prepared for research based project work in the fifth year of their IMSc program. And trust will help them in taking up their career in research.

REFERENCES