Chapter 8

Analysis, Conclusions & Future Plans

8.1 Implementation of our experiments

Some of the experiments described in this thesis have been implemented in physics teaching laboratories in Guru Nanak Dev University (Amritsar), Indian Institute of Science Education & Research (Mohali) and the Indian Institute of Technology (Chennai). In particular, the random sampling of an AC source experiment has been most widely used and appreciated. The parallel plate capacitor setup has also been a successful inclusion in physics laboratories at these institutions. The Coriolis force setup has been used as a demonstration equipment in various institutions and conferences on physics education. Similarly the two-dimensional pendulum demonstrating normal modes has also been widely used as a demonstration equipment. In particular, a workshop of college teachers was organized at Khalsa College, Amritsar, where some of these experiments were demonstrated and teacher feedback collected. The experiments were also demonstrated to physics teachers in a physics teaching conference at St Bede's College Shimla and at a workshop in Purnaprajana Institute Bangalore. A lecture-demonstration was given in IUAC New Delhi. Detailed feedback (in the form of sample questionnaires) was collected from participants at these lecture-demonstrations and workshops. Queries addressed to teachers included finding out what specific difficulties with the setup the students faced, what were the physics concepts that
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the students understood and what were the kinds of questions the experiment motivated them to ask, whether there were already existing experiments in these labs that dealt with the same or similar pedagogical themes, and if yes how our experimental setups compared with existing setups in terms of conceptual understanding on the part of the students. The summary of the feedback collected during these demonstrations and from the teachers who have implemented these experiments in their teaching laboratories is delineated below.

8.1.1 Feedback on two-dimensional pendulum

The expected learning goals in this experiment include: basic concepts of a two-dimensional oscillator, cylindrical symmetry, degenerate normal modes, symmetry breaking, angular momentum and conservation, and the connection with Foucault's pendulum. Existing experimental setups which touch upon these themes in most physics laboratories in India are few and far between and typically consist of a coupled oscillator setup or a double pendulum. Most of the above mentioned concepts were conveyed well by the teachers and students were able to easily grasp them. The main difficulty faced by students was with the measurement process and the clear feedback received was that a better measurement scheme should be incorporated, preferably with an automation feature. Also, the time taken to complete the experiment was around two hours, which some students and instructors found somewhat time-consuming.

8.1.2 Feedback on Coriolis force setup

The expected learning goals in this experiment include: basic understanding of a two-dimensional oscillator, plane of oscillation, rotating frames, trapping potential, feedback circuits and perpetual motion, Foucault pendulum, Coriolis force and geometric phase. This demonstration setup was widely appreciated and was well-liked by teachers and students alike. Most of the key concepts mentioned above were demonstrated and communicated well through this setup. There were two main points in terms of feedback for improvement of the setup. One, it was felt that quantitative measurements with the current setup are not possible, which teachers felt is a desirable feature if the setup has to become part of a regular laboratory schedule. Two, the trapping coil and the feedback mechanism to keep the perpetual motion going was found difficult for some teachers to explain
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to students and they felt that more elaborate instructions should be evolved to properly communicate these aspects.

8.1.3 Feedback on parallel plate capacitor

The learning goals in this experimental setup include: dependence of capacitance on area, dependence on distance, the effect of ac and measuring very small ac currents. This experimental setup was a success in terms of explaining the above concepts. The main point which the teachers appreciated was that although the parallel plate capacitor is taught to students right from school onward there is no explicit experimental laboratory on this important component even at the undergraduate level. The students liked the fact that they could change various parameters in the setup such as area and distance and were able to directly measure the change in the capacitance. The main difficulty with this experimental setup was the appreciation of ac response as a device to measure capacitance. Most teachers and students felt they would be more comfortable working with a dc based setup. In any case the strength of our setup lies in its being based on ac measurements where even in small capacitors one can explore the basic physics of the capacitor through the use of high frequencies. We plan on incorporating a few of these suggestions and a few clarifications about the measuring technique may be needed so that the student is able to appreciate the fact that a very small ac current is being measured by an interesting electronic method.

8.1.4 Feedback on random sampling of an AC source

The learning goals in this experiment include: the possibility of random outcomes of measurements, the notion of probability distribution as a measured quantity, changing the variable inside a probability distribution, characterizing the probability distribution of waveforms and functions, and waveform reconstruction. The experiment was well appreciated by teachers and students. However it was also found somewhat difficult to grasp. Based on this feedback, we later divided the experiment into two parts. In the lower level labs, only the characteristic probability distribution of waveforms was analyzed. The more subtle concepts of waveform reconstruction etc was done in more advanced labs. With this modification, the experiment was a success in terms of its ability to help the students achieve their basic learning goals. Since a large number of observations are required in
this experiment, some students found it too laborious while others found it very interesting and even went beyond the prescribed number of measurements. It is worth noting that we either got a very clear positive or clear negative response to this experiment. In a few places, while replicating the apparatus because of the unavailability of good transformers with a perfect linear response, this led to harmonic generation which spoilt the probability distribution. We helped the instructor set things correctly in such cases by supplying them the apparatus. We have made and supplied copies of this particular apparatus to a large number of teachers.

Although the other experiments have been introduced to teachers and students, a formal feedback on these setups has not yet been collected. This task will be undertaken subsequently.

8.2 Context of this work

The context of this work is the broad dictum that Indian physics teaching laboratories lack well-designed and innovative experimental setups. Most labs still depend on age-old traditional and standard experiments. Two themes have been explored in-depth in this thesis in this context. The first theme has experiments which are built around the two-dimensional oscillator, its symmetry breaking characteristics and its connection with rotating frames, Coriolis force and the Foucault pendulum. The second theme explored in this thesis is the study of the capacitor and related concepts with ac sources. Each of these two themes can in fact become a thematic lab in itself, and we will work further to develop these aspects.

8.2.1 Major issue

The major issue we have faced in implementing these labs and incorporating our experimental design in the Indian university context, is the rigid syllabus structure in Indian universities, wherein the experiments are pre-prescribed and the instructor does not have the freedom to design and introduce new experiments. We at our level are not able to immediately address this issue. We plan on working on a two-fold strategy: one that a few of our experiments are included in university syllabi and other being to motivate physics teachers to ask universities
to change the rigid structure to a more flexible one, where the university specifies only broad themes and instructors are encouraged to develop their own labs to explore these themes. We have also interacted with the scientific instrumentation industry and we are keen that some of our setups are manufactured commercially. In this context we have interacted strongly with the scientific instrumentation industry located in Ambala. However, getting industries interested in making our instruments primarily depends on getting these setups included in the university syllabi.

8.3 Conclusions

Several novel experiments that were specifically conceptualized, designed and fabricated for introduction in a physics undergraduate teaching laboratory have been described in detail in this thesis. The experimental setups have been conceptualized around they broad themes of mechanics, electromagnetism and fluid dynamics. We were able to identify several conceptual problems that students are unable to resolve in their theory physics courses and we then built these novel setups in order to clear some common student misconceptions. Specifically the six setups described in this thesis deal with the idea of normal modes and symmetry breaking in a two-dimensional pendulums, Coriolis force and rotating frames of reference and the subtle connection with Foucault’s pendulum, current flow in capacitor circuits and capacitor as a sink of charge, verifying the basic laws governing parallel plate capacitors, probabilistic observations, random sampling of an ac source and reconstruction of source waveform, and a study of molecular diffusion in a liquid.

8.4 Future plans

In the future, we plan on refining the design of each of these setups so that they can be easily built and used as full-fledged laboratory experiments by physics teachers working even in geographically remote areas with little access to resources. We also plan on organizing demos and workshops for college physics teachers to explain the conceptualization of each experimental setup, familiarize them with the underlying basic physics concepts and help them gain hands-on
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experience in using the setups. A website with pictorial description of all the experiments in this thesis as well as short pedagogical films has been created and is available at http://www.iisermohali.ac.in/html/faculty/arvind/physicsedu.html.

We also have plans of continuing to contribute to research in the field of physics education and development of novel experiments for physics teaching laboratories. Several of the experiments described in this thesis are already being used in different physics laboratories in India and have gathered feedback on them from teachers and students. We plan on taking these experiments to many more teaching laboratories and coming up with a detailed questionnaire format for students and teachers on these experiments. We will then collate this feedback, evolve a methodology for data analysis and use it to refine these setups. We also plan to collect feedback from students and teachers on other misconceptions or concepts that they find difficult to understand or convey and we then plan on designing many more experiments around these ideas. Physics education research is a rapidly advancing field and we look forward to being a part of the exciting ventures in this area in the future.