What are the objectives and goals of physics laboratory courses? A survey of college teachers

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Abstract. The objectives and goals of experimental work carried out by students during laboratory courses at school and university level have been evolving over the past century. A number of objectives and goals of physics laboratory training have been identified and listed by several researchers and teachers from all over the world. It was observed that several teachers and instructors have hardly given a serious thought on the objectives and goals of Physics laboratory courses offered during a three year university degree programme and the methods, abilities and aspects these laboratory courses are supposed to teach and develop in students. This motivated the author to conduct a survey and collect feedback from teachers to understand their views on objectives and goals of physics laboratory courses. Thus, a pilot survey that involved free response sessions was conducted without giving any expert input to the college and university teachers. In this paper, the author presents the responses received from teachers.

1. Introduction
It is now well accepted that the teaching and learning of physics at the university level is incomplete and inadequate, unless students gain direct and individual experience in experimental physics through laboratory courses. Therefore, at almost every college and university the world over, physics laboratory courses have been given an indispensable role in physics education in spite of consuming a lot of time and funding. The objectives and goals of physics laboratory courses have been evolving over the past century. A number of objectives and goals of physics laboratory training have been listed by researchers and teachers from all over the world.

In 1954, Braddick [1] described the following objectives of the laboratory training: a) better and longer lasting understanding of physical principles; b) an exercise in solving problems based upon real physical situations; c) experience and appreciation of the various methods used in experimental physics; d) better understanding of and competence in the use of standard apparatus; e) training in precision, accuracy and awareness of the problems involved in laboratory work; and f) increased confidence in concepts and laws of physics obtained by checking validity and use of these concepts and laws.

In 1973, Shulman and Tamir [2] proposed the following general goals for laboratory training in physics education: a) to arouse and maintain interest, attitude, satisfaction, open-mindedness and curiosity in science; b) to develop creative thinking and problem-solving ability; c) to promote aspects of scientific thinking and the scientific method; d) to develop conceptual understanding and intellectual
ability; and e) to develop practical abilities (e.g., designing and executing investigations and observations, recording data and analyzing and interpreting results).

In 1976, Anderson [3] summarized the goals of laboratory training in four major areas: a) to foster knowledge of the human enterprise of science so as to enhance students’ intellectual and aesthetic understanding; b) to foster science inquiry skills that can be transferred to other spheres of problem solving; c) to help the student appreciate and in part emulate the role of the scientist; d) to help the student develop an appreciation of the orderliness of scientific knowledge and an understanding of the tentative nature of scientific theories and models.

The American Association of Physics Teachers (AAPT) published ‘Goals of the Introductory Physics Laboratory’ [4], which emphasized the following aspects: a) The Art of Experimentation: the introductory laboratory should engage each student in significant experiences with experimental processes, including some experience designing investigations; b) Experimental and Analytical Skills: the laboratory should help the student develop a broad array of basic skills and tools of experimental physics and data analysis; c) Conceptual Learning: the laboratory should help students master basic physics concepts; d) Understanding the Basis of Knowledge in Physics: the laboratory should help students understand the role of direct observation in physics and to distinguish between inferences based on theory and on the outcomes of experiments; and, e) Developing Collaborative Learning Skills: the laboratory should help students develop collaborative learning skills that are vital to success in many lifelong endeavors.

More recently, a list of the learning objectives of laboratory courses at university level was prepared [5] with inputs from 15 faculty members from the department of Physics, University of Colorado at Boulder, which categorizes various objectives in following four broad themes: modelling, design, communication and technical laboratory skills. A more detailed list was prepared [6] at Stanford university. Further researchers have also described [7, 8, 9] objectives and goals of laboratory work in chemistry and engineering disciplines.

2. General objectives and goals of laboratory courses
It is often accepted that the laboratory courses are supposed to develop in students a variety of content, cognitive, psychomotor, procedural, attitudinal and affective abilities related to understanding and ‘doing’ physics. The objectives of physics laboratory education at the university level described more recently [10] include the following: a) development of a better and long-lasting understanding of facts, concepts, principles and laws of physics; b) development of procedural understanding / abilities related to modelling, designing experiments, planning measurements / observations and analyzing data; c) development of experimental skills for the use, alignment and handling of a wide range of laboratory instruments and tools; d) fostering various cognitive abilities like hypothesizing, predicting, observing, classifying, interpreting and inferring; e) development of the ability to solve experimental problems on the basis of methods, processes and techniques commonly used in experimental physics; f) training in the handling of experimental data, making the students aware of the uncertainties involved in various measurements and development of abilities with respect to the treatment of data, error analysis and reporting of experimental activities; g) development of higher order abilities, such as careful and keen powers of observation, the ability to make accurate measurements, handle measured data for objective reasoning correctly, draw conclusions and make generalizations; h) development of interest, motivation, open-mindedness, creativity, curiosity, scientific thinking/attitude, self-activity and independent working habits; i) Learning to work in team and collaborate among peers; and j) learn to communicate the observations and results.

3. Motivation and the survey
During the author’s interaction of more than 20 years on various aspects of laboratory training, it was observed that several teachers and instructors have hardly given a serious thought to the objectives and goals of physics laboratory courses offered during a three year university degree programme in India and what these laboratory courses are supposed to ‘teach’ and develop in the students. This motivated
the author to conduct a survey and collect responses from teachers. It was noted that there have been a few interesting surveys on teachers’ views on aims and objectives of experimental or practical work at the secondary school level [11, 12].

The aim of the survey and this paper was to i) find out the objectives and goals in-service teachers associate with laboratory courses; ii) to check if the teachers are aware of the often projected objectives and goals of the laboratory courses; 3) present a sample list of objectives and goals as identified by teachers; and iv) put forth a need to revisit and discuss the content, instructional strategies and assessment of laboratory courses.

A survey that involved free response sessions was conducted without discussing or giving any input to the college and university teachers. Each participating teacher was asked to individually prepare a comprehensive list of the objectives and goals of physics laboratory courses offered at his/her college and university during a typical three-year university degree programme. The written responses were collected from 58 teachers across the country.

4. Responses from teachers
The responses received from teachers were quite descriptive with a lot of overlap and intertwined. This indicated that there was no clarity in teacher’s ideas and thoughts on this issue. It was observed that several teachers gave an almost similar set of objectives and goals but described in different words. It was noted that a large number of teachers (54 out of 58) identified “aspects related to understanding of physics” as the most important objective. Furthermore, 51 out of 58 teachers identified aspects which they categorised as “experimental skills” as the second most important objective of the laboratory courses. Teachers identified several other objectives and goals, in relatively smaller occurrences, related to instrumentation and tools, methods and processes used in experimental physics, cognitive abilities, collaboration, communication, affective and attitudinal aspects. A collated list of objectives and goals of physics laboratory courses as identified by participating university teachers are presented below, which by no means indicate an ideal or recommended list of objectives and goals of physics laboratory courses at the university level:

1) To understand the concepts of physics taught in the class; 2) To foster theoretical knowledge; 3) To validate different theoretical models; 4) To understand applications of theory; 5) To widen students’ knowledge; 6) To ‘do’ what is taught in the class; 7) Translating theory to experiments; 8) To improve proper understanding of practical applications of theory taught in classrooms; 9) To link theoretical results studied in the class with experimental observations; 10) To perform an experiment verifying the laws and concepts that the student has studied in theory; 11) To develop a feeling that most of the laws/concepts studied in the theory can be verifed by experiments; 12) To introduce a physical phenomenon and carry out systematic study; 13) To help students play with various parameters and ‘see’ their effects; 14) To solve problem quantitatively; 15) To help visualize various systems and concepts through laboratory work; 16) To foster visual analysis that helps to understand and think; 17) To inculcate a vision to think beyond the given concepts; 18) To identify the variables associated with a particular problem; 19) To appreciate the importance of measurements; 20) To develop ability to choose a measuring instrument for desired accuracy; 21) To learn how to work with/use instruments in a laboratory; 22) To perform an experiment, take readings, plot graphs and derive conclusions; 23) To train students to take correct/precise measurements of various quantities; 24) To develop appreciation for accuracies and errors that are part of any measurement; 25) To develop ability to plot graphs and analyse them; 26) To appreciate the error involved in the determination of a variable/parameter; 27) To develop ability to do data analysis and estimate errors; 28) To develop a logical way of interpreting and analyzing the data; 29) To appreciate precautions or constraints associated with particular system / instrument; 30) To improve psycho-motor and cognitive skills of students; 31) To develop skill to set up an experiment; 32) To develop troubleshooting skills; 33) To learn to calibrate equipment; 34) To get some exposure to new techniques of experimentation; 35) To learn to use software / simulation tools; 36) To interpret the observations/result obtained; 37) To learn to draw inference from the observations;
References to undergraduate level in India. The author is indebted to the NIUS for providing the required funding and to understand the existing issues and improve this survey was part of the author’s efforts under the National Initiative on Undergraduate Science (NIUS) to develop further ideas related to a particular experiment; 42) To correlate various things in nature with their experiments; 43) To know why they need to perform the experiment; 44) To make students think more in terms of physics involved in natural phenomena at the macro and microscopic levels; 45) To develop coherence between what one can learn and what can be done with that learning; 46) To learn how to systematically achieve the aim set and get it in observational limits; 47) Learn to design an experimental setup for a given problem; 48) To understand that experimentation is an essential part of the scientific learning; 49) To explore and enjoy the various aspects of the experiments; 50) To build scientific attitude and scientific thinking; 51) To develop scientific spirit of enquiry; 52) To foster students’ creativity and to ask questions; 53) Laboratory training makes physics attractive and enjoyable; 54) To train students to learn by ‘doing’; 55) To experience the exhilaration when the observed result matches with that in theory; 56) To learn to work in a team; 57) To learn to share ideas in the laboratory with each other and teachers; 58) To evaluate the knowledge of the student; and 59) To learn to manage things with limited resources.

5. Conclusions

It was noted that several teachers emphasized aspects related to understanding of physics and experimental skills while many gave an ambitious and eye-opening list of abilities and skills that they would like their students to develop through laboratory courses. It is evident from the list that many teachers fail to understand the details of various skills and abilities which may be categorized as cognitive, modeling and processing, psychomotor, affective, attitudinal, information and knowledge. This exhaustive list actually poses a more important question; “to what extent the listed objectives and goals could be actually achieved with the present set of laboratory courses in India”. And if not, what is wrong with the present set of courses and what can be done about it.

Clearly, comparing the conclusions of this survey and the current state of training in experimental physics and laboratory courses offered in Indian colleges and Universities, it is evident that there is a great disparity between teacher’s expectations and what actually is achieved. Thus, there is an urgent need to give a serious thought to this issue, raise valid questions and implement plausible corrective measures. It is important to state and define objectives and goals of each laboratory course and select the ‘contents’ (experiments, investigations, projects and demonstrations) and ‘strategies’ which include instructional and assessment strategies for laboratory courses so as to emphasize the objectives and goals.

Acknowledgements

The author is grateful to all 58 teachers who participated in this survey and provided their responses. This survey was part of the author’s efforts under the National Initiative on Undergraduate Science (NIUS) to understand the existing issues and improve the quality of laboratory courses offered at the undergraduate level in India. The author is indebted to the NIUS for providing the required funding and to the NIUS staff for all their help.

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