DEVELOPMENT OF INNOVATIVE EXPERIMENTAL PROBLEMS AND DEMONSTRATIONS IN PHYSICS WITH SUITABLE INSTRUCTIONAL STRATEGY FOR THEM AND INVESTIGATING THEIR EFFECTIVENESS IN LABORATORY TRAINING

A thesis submitted to the
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the Ph. D. degree in Science Education

by

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STATUTORY DECLARATIONS

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STATEMENT BY THE CANDIDATE

As required by the University Ordinances 770 and 771, I wish to state that the work embodied in this thesis titled **"Development of Innovative Experimental Problems and Demonstrations in Physics with Suitable Instructional Strategy for Them and Investigating Their Effectiveness in Laboratory Training."** forms my own contribution to the research work carried out under the guidance of **Prof. H. C. Pradhan** at the **Homi Bhabha Centre for Science Education, Tata Institute of Fundamental Research**, **Mumbai**. This work has not been submitted for any other degree of this or any other University. Whenever references have been made to previous works of others, it has been clearly indicated as such and included in the Bibliography.

Certified by:

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Signature of Guide	Signature of Candidate
Name of Guide: **H. C. Pradhan**	Name of Candidate: **Rajesh B. Khaparde**

CERTIFICATE

This is certified that the work incorporated in the thesis **"Development of Innovative Experimental Problems and Demonstrations in Physics with Suitable Instructional Strategy for Them and Investigating Their Effectiveness in Laboratory Training."** submitted by **Rajesh B. Khaparde** was carried out by the candidate under my supervision. Such material as has been obtained from other sources has been duly acknowledged in the thesis.

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Guide

(H. C. Pradhan)

I dedicate this work to my mother

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1) Khaparde Rajesh B., Meera B. N., Pradhan H. C., **Study of Stationary Longitudinal Oscillations on a Soft Spring**, *Physics Education (India)*, Vol.- 14, No.- 1, April -June 1997, pp. 13 - 19.

2) Khaparde Rajesh B., Meera B. N., Pradhan H. C., **An Inexpensive Technique of Interfacing Photogates with Digital Stop-clocks and Its Applications**, *Physics Education (India)*, Vol - 14, No. - 2, July - September 1997, pp. 131 - 138.

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SYNOPSIS

A) Motivation

Physics is a fundamental science, which deals with the principles and the basic laws that govern the behavior of nature and its constituents. It is an experimental science, which is mainly based on observations and planned quantitative measurements. The teaching and learning of physics is incomplete and inadequate, unless students gain significant experience in experimental or practical and well-planned laboratory work. Today, at almost every college and university the world over, laboratory training has been given a central, important and respectable place in physics teaching. The curricula for the practical work and the laboratory training at post school and university level are normally designed with some well-defined objectives and goals.

It is felt that, the present practices of performing a set of experiments in physics laboratories in Indian colleges and Universities at +2 and undergraduate level hardly help to fulfill the goals set out for physics laboratory training. We believe that there is an urgent need for attempts to improve the quality of physics laboratory training being offered at Indian colleges and universities. This belief has motivated us to take up a pilot research and development project in the field of physics laboratory training.

After a critical analysis of the strengths and weaknesses of the present system of physics laboratory training in India, we conclude that the improvement of the quality of physics laboratory training should essentially be made through efforts in two important aspects:

1) Development of innovative experiments and demonstrations,

2) Development of an instructional strategy for laboratory training.

We undertook a pilot project embodying the above two objectives and carried out the necessary research and development. The research work presented in this thesis describes the development and evaluation of the pilot project.

B) Review of earlier efforts

We carried out an extensive survey of the research conducted by many researchers, educationists and teachers on the two aspects of physics laboratory training cited above. A brief review of the earlier efforts along these lines in the world in general, and in India in particular is given below.

In the first quarter of the 20th century, the teaching community began to realize the importance of appropriate curricula for laboratory training in physics. Around the same time many organizations, associations and universities initiated research and development projects with an objective to develop new experiments, demonstrations, strategies of instruction and laboratory courses and curricula. These projects produced some exciting new approaches and content for the laboratory training and were effectively implemented, changing to some extent the practice of physics laboratory training in countries like U.S.A. and U.K. In the second and third quarter of the 20th century, several books were published on various aspects of laboratory training, including some on new experiments and demonstrations. Even at the present time, the colleges and universities abroad, a variety of courses on experimental physics and the laboratory training are being conducted with differing objectives, contents and strategies of laboratory instructions.

The physics laboratory training in Indian colleges and universities at +2 and undergraduate level adopted and still follows the contents, strategies of instruction and the laboratory courses, that were designed and used at some major universities in the U.K. at the end of the 19th century. It was only in the second half of the 20th century that researchers, educationists and teachers in this country began to think about and work on possible changes in the laboratory curricula, contents and the instructional strategy for physics laboratory training in India.

During the period 1963-73, a number of summer programmes were conducted by the National Council of Educational Research and Training (NCERT) and University Grant Commission (UGC) to upgrade the level of in particular, the laboratory training, and in general, the teaching of physics at the +2 and undergraduate levels. In the year 1970-71 a number of College Science Improvement Programs (COSIPs) and University Leadership Projects (ULPs) were initiated by UGC at several colleges and universities with the primary intention of upgrading physics laboratories. The first major effort in the development of new experiments and demonstrations in physics was that of a team headed by Prof. B. Saraf, at the *University* of Rajasthan, Jaipur. Under the ULP, They developed a number of novel experiments and demonstrations along with the necessary equipment, apparatus and experimental set-ups. The group published their work in the form of books, 'Physics through Experiments' Vol. I in 1975, and Vol. II in 1979. After the publication of these two books, several individuals and groups began work on these lines and published books and articles on experiments and demonstrations. Some of the most appreciated books of these were the ones written by Prof. D.P. Khandelwal of

HBTI, Kanpur and by Prof. R.S. Sirohi of I.I.T., Madras. Some other ULPs and COSIPs also produced important results, in the development of new experiments and the relevant material. The most prominent of these were initiated at the Punjab University and Poona University.

After the adoption of the new 10+2+3 scheme of education, a team headed by Prof. V. G. Bhide at NCERT, started working on the development of new experiments and the laboratory curriculum for +2 level. They wrote a 'Physics Laboratory Manual for Class XI' and 'Physics Laboratory Manual for Class XII', both in the year 1989. These books were published by NCERT and were designed as laboratory textbooks for the respective classes.

Thus, there have been efforts to develop new experiments and demonstrations but unfortunately very little thought has gone into changing the instructional strategy used for laboratory training in physics. This may partly explain why in spite of the efforts to improve the quality of laboratory training in physics, the practice of the laboratory training has remained unchanged for years together.

C) Research objectives

Having identified the need for improvement through a critical analysis of physics laboratory training in India, we arrived at a need to develop experiments and demonstrations with a novel format of presentation and an appropriate instructional strategy. We used our experience with the International Physics Olympiad (IPhO) program and the 'investigative work in the science curriculum' carried out by Gott and Duggan (1995), to develop a new format of presentation of the experiments and demonstrations and also to develop the instructional strategy for them. We used a 'guided problem solving' approach to design the instructional strategy, in which each experiment is presented as an experimental problem and a related demonstration is given as an introductory prelude.

The objectives of the research work carried out by the researcher and presented in this thesis are:

1) **To develop a set of innovative experimental problems and related demonstrations in physics, suitable for the laboratory training of higher secondary (i.e. +2 level) and undergraduate students of Indian colleges and universities.**

2) **To develop a suitable instructional strategy for the delivery of these experimental problems and demonstrations to students, which is usable for physics laboratory training in India.**
3) **To investigate and evaluate the effectiveness of these experimental problems and demonstrations and the instructional strategy developed.**

D) Research summary

The work was initiated with a critical review of physics laboratory training. We studied briefly the history, importance and role, and the goals of laboratory training. We also studied the classification of experimental work, based on its nature or aim, such as enquiry, illustration, skills, observation, investigation and exploration. We then analyzed the present status of physics laboratory training in India. We identified the two major aspects as described earlier, with respect to which we believe that there is a need for improvement. We thus formulated a research project in which we undertook the development of experimental problems and related demonstrations along with a suitable instructional strategy for them.

We then developed a conceptual framework of the project. As said earlier, the framework is based on the work by Gott and Duggan. The framework offers a new perspective of practical science. In this, a model of science, based on the problem solving approach is used and the content of the terms 'conceptual understanding' and 'procedural understanding' is defined. Procedural understanding is identified as an important aspect of practical science. Whereas the conceptual understanding is the understanding of the underlying substantive concepts or of the 'physics' involved in the experiments, the procedural understanding corresponds to that understanding which enables experimentalists to use experimental skills for verifying theory or discovering new knowledge; it is the understanding of concepts of evidence, like designing and planning of experimental procedure, choice of instruments, deciding the range of observations and the accuracy required, handling of data obtained and so on, which mediates between the conceptual understanding and the skills. We have followed the appropriate taxonomies for these understandings that have been developed based on the Bloom's original taxonomy of educational objectives.

After conceptualizing the research project, we designed and developed a set of (ten) innovative experimental problems and demonstrations. We devised and fabricated the apparatus and the set-ups of the experimental problems and the demonstrations. We

designed the format of presentation of each experimental problem with an accompanying demonstration. We then designed a detailed instructional strategy for the delivery of these experimental problems and demonstrations to the students, which may be used for the physics laboratory training. Also, the written material required as per the format was prepared for each of these experimental problems and demonstrations.

After completing the development, we undertook the evaluation work wherein we investigated the effectiveness of the innovative experimental problems, their accompanying demonstrations and the instructional strategy for them in the physics laboratory training. For the evaluation, we designed a 15-day course on experimental physics, based entirely on the developmental work of the project. We also developed comprehensive tools of evaluation. We then conducted this course in two batches for a total of forty students and administered the tools of evaluation using a single group pre-post test design

The detailed analysis of the generated data, showed that the innovative experimental problems, demonstrations and their instructional strategy as developed in this project, when delivered to the undergraduate students in the form of a course on experimental physics, effectively enhances related conceptual understanding, procedural understanding, experimental skills and problem solving abilities and brings about a positive change in attitude towards experimental physics and towards physics as a subject.

E) Organization of the thesis

Chapter I is an introduction to the research work presented in this thesis. In this chapter, we describe the statement of the research problem along with the background information and significance of the research work. We then describe the plan of the thesis.

In Chapter II we take a critical review of physics laboratory training. We first present a brief history of laboratory training. We discuss the importance and role and goals of laboratory training. We also describe, in detail, various types of practical work. We then review the present state of physics laboratory training at the +2 and undergraduate levels in India. We analyze the status with respect to its strengths and weaknesses and identify the need for improvement in the present physics laboratory training. We then take a brief review of the earlier efforts that were made with respect to the identified need. The chapter ends with the genesis of the research project.

Chapter III is devoted to the conceptual framework of the research project, which is based on a new perspective of practical science, which we follow from Gott and Duggan. Here a model of science is described, which is centered on the problem solving approach, and which defines the role of and emphasizes the importance of 'procedural understanding' in practical science. Based on this model, an appropriate taxonomy in both conceptual and procedural aspects of the cognitive domain (following the Bloom's taxonomy of educational objectives) of science is presented. The meaning and contents of 'concepts of evidence', which form an important basis of the procedural understanding, is defined and explained. At the end of this chapter, we describe the implications of the conceptual framework for the research project.

In Chapter IV we describe the research project and its evaluation design. Beginning with the objectives of the project, we discuss the different aspects of the development of innovative experimental problems, demonstrations and their instructional strategy. We first explain our idea of 'an experimental problem' and then discuss the guidelines for and stages of the development of the experimental problems and their demonstrations. We then describe the salient features as well as the details of the instructional strategy for delivery of the experimental problems and demonstrations to students. This is followed by the evaluation design of the project. This section begins with an explanation of the methodology of evaluation followed by information about the course on experimental physics and the tools of evaluation.

Chapter V gives the description of the innovative experimental problems and their demonstrations. One specimen experimental problem and its demonstration is discussed in detail including the statement of its problem, experimental arrangement, students' handout, instruction sheets, the model answer and the analysis of the experimental problem. For the accompanying demonstration, the objective, the experimental arrangement and the instructors' handout are presented. This is followed by a brief sketch of the other nine experimental problems and their demonstrations. These are limited to a brief description of the experimental problems and the corresponding demonstrations (the experimental arrangement, salient features and objectives).

Chapter VI explains the course on experimental physics and the evaluation of the project. In the first section of this chapter, we give the objectives, plan and content of the course. We also discuss the sample group and its selection. Following a description of how the course was administered, we discuss the limitations of the course. The next

section is on the evaluation of the project and begins with a discussion on the methodology of evaluation. We then describe various tools of the evaluation, their administration, the marking scheme and the analysis of students' performance. The tools consist of tests on conceptual understanding and procedural understanding, an experimental test and a questionnaire on attitudinal and other affective aspects. At the end of the chapter, we give an analysis of the qualitative tools and the results of students' feedback.

Chapter VII is on conclusions and recommendations. Besides listing conclusions of the present research work, the chapter offers recommendations for improving the quality of physics laboratory training in India and suggests further research work. The limitations of the research work are also presented.

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Statements required by the University

I) Statement regarding discovery of new facts

This thesis describes a pilot research and developmental project and its evaluation. In this project a set of ten experimental problems and demonstrations covering core areas of physics has been developed. A suitable instructional strategy for the delivery of these experimental problems and demonstrations to the higher secondary and undergraduate students also has been developed. This developmental work was carried out at **Homi Bhabha Centre for Science Education (HBCSE), TIFR, Mumbai**. The evaluation of the project was done to investigate the effectiveness of the experimental problems, demonstrations and the instructional strategy in physics laboratory training. The evaluation was carried out through a specially designed course on experimental physics conducted at HBCSE, which incorporated the developments of this research project.

The following aspects of the thesis are new to the best of our knowledge.

1) The design of experimental arrangements used for all the ten experimental problems and demonstrations;

2) The objectives for experimental problems and the corresponding demonstrations;

3) The format of presentation of experimental problems and demonstrations along with the instructional strategy for them;

4) The design of a course on experimental physics, including the detailed plan, contents and mode of administration;

5) The tools of evaluation developed for investigating the effectiveness of innovative experimental problems, demonstrations and the instructional strategy; We have identified three well defined dependant variables, namely, conceptual understanding, procedural understanding, and experimental skills and problem

solving ability. We designed appropriate tests on these three aspects and used them as tools for generating the relevant data for evaluation.

6) The results obtained from the evaluation of the effectiveness of the innovative experimental problems, demonstrations and the instructional strategy; In the evaluation work, the detailed analysis of the generated data, showed that the innovative experimental problems, demonstrations and their instructional strategy as developed in this project, when delivered to the undergraduate students in the form of a course on experimental physics, effectively enhances related conceptual understanding, procedural understanding, experimental skills and problem solving abilities. It also brings about a positive change in attitude towards experimental physics and towards physics as a subject.

II) Statements including the sources of information, etc.

The work described in this thesis was conducted under the guidance of Prof. H. C. Pradhan. The project on development of new higher secondary level science laboratories initiated at HBCSE in the year 1995, offered me an opportunity to carry out the research and development work presented in this thesis. Various teachers and students' courses conducted by HBCSE were useful, as they exposed me to research in science education and also helped me to analyze the present state of physics laboratory training in India and thereby identify the need for improvement in the quality of physics laboratory training.

The entire work presented in this thesis including, design and development of innovative experimental problems, demonstrations, the instructional strategy, a course on experimental physics and the tools of data collection and evaluation was done independently by me. I was helped by Dr. B. N. Meera and Mr. Dhruva Bhattacharjee of HBCSE in the development of few a experimental problems.

a) References are stated at appropriate places in the thesis, whenever works of other people have been used. The rest of the thesis may be claimed to be original.

b) I, hereby declare that the work described in this thesis has not been submitted previously to this or to any other University for any degree and no degree, diploma or distinction has been awarded to me for this work by this or any other University.

(Rajesh B. Khaparde)