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
University of Mumbai
for
the Ph. D. degree in Science Education

by

Rajesh B. Khaparde

Homi Bhabha Centre for Science Education
Tata Institute of Fundamental Research
Mumbai, India

2001

STATUTORY DECLARATIONS

Name of the Candidate	**:**	**Rajesh B. Khaparde**
Title of the Thesis	**:**	**“Development of Innovative Experimental Problems and Demonstrations in Physics with Suitable Instructional Strategy for Them and Investigating Their Effectiveness in Laboratory Training.”**
Degree	**:**	**Ph. D.**
Subject	**:**	**Science Education**
Name of the Guide	**:**	**Prof. H. C. Pradhan**
Registration Number and Date	**:**	**170, (19/12/1997)**
Place of Research	**:**	**Homi Bhabha Centre for Science Education Tata Institute of Fundamental Research V. N. Purav Marg, Mankhurd, Mumbai - 400 088 India**

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:

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

ACKNOWLEDGEMENT

The work presented in this thesis was carried out under the guidance of Prof. H. C. Pradhan. I express my gratitude to him for his motivation, encouragement and support during all stages of this work. I take this opportunity to thank Prof. Arvind Kumar, Centre Director, for providing me the required facilities and an opportunity to develop a new physics laboratory at Homi Bhabha Centre for Science Education (HBCSE).

I am thankful to my friends Dhruva, Pravin, Mandar, Meera, Shekhar, Shirish, Vineet, Shaker, Mahesh and Atul for their assistance and help offered to me at various stages of my research work. I am also thankful to all my friends Arun, Bipin, Gobindchandra, Jaywant, Mahesh, Manish, Manisha, Narottam, Nivrutti, Prakash, Pravin, Ravindra, Sanjay, Santosh, Shilpa, Shivaji, Smita, Suman and Umesh for their help, support and encouragement offered to me at one or the other stage of my research work. I am grateful to Mr. A. W. Joshi, for his invaluable support extended to me at all times and in every respect including help in typing of this thesis.

I wish to thank all my colleagues, academic, scientific and administrative staff at HBCSE for their ready help and willing cooperation at all times, with special mention of Dr. Chitra Natarajan, Dr. Savita Ladage and Dr. Sugra Chunawala. I thank Mr. A. D. Ghaisas and Mr. M. D Mastakar for their help at some crucial stages of this thesis. I am also thankful to the HBCSE and TIFR library and workshop staff.

I take this opportunity to express my gratitude to my family members and relatives, in particular to my sisters, Seema, Nilima and Vijaya, who supported me in every possible way at all times and showed a great belief in me and my work, in spite of all odds and hurdles.

I am thankful to all those students, teachers and principals from various colleges, particularly, to Prof. R. M. Dharkar and Prof. D. A. Desai, who helped me at different stages, especially during the design and evaluation stage of the project.

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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)

CHAPTER I

Introduction

This chapter gives the brief background of the research work presented in this thesis and a statement of the research problem. It also describes the significance of the research work and the plan of the thesis.

1.1 Background of the research work

Homi Bhabha Centre for Science Education (HBSCE), a National Centre of Tata Institute of Fundamental Research, Mumbai, is devoted to research, development and teacher / student training work in the field of science and mathematics education from the primary school to the college levels. One of the important components of the research and development carried out at HBCSE is the research in the field of physics education and particularly the research in laboratory training. Since the researcher also was interested in the area of development of experiments in particular and the physics laboratory training in general, we thought it appropriate to take up a research and development project in the field of physics laboratory training with an aim to improve the quality of the laboratory training being given at various colleges and universities in India at +2 (i.e. higher secondary) and undergraduate level.

We began our work with an exhaustive and critical study of the physics laboratory training in India at +2 and undergraduate levels. After this study and a critical analysis of the present system, we felt, what the system urgently needs is innovative experiments, demonstrations and a suitable instructional strategy for them. We then undertook such a research project and carried out the necessary research, development and evaluation work.

1.2 Statement of the research problem

We studied the various past and present practices of conducting laboratory courses world over with respect to content, mode of presentation, methods of instruction and the methods of evaluation. From this study we felt that if we intend to improve the present system of laboratory training in India, then we need to 1) develop highly innovative and carefully designed experiments and demonstrations. 2) develop a novel format or mode of presentation of these experiments and demonstrations and thus develop an innovative instructional strategy for the delivery of these experiments and demonstrations to the students.

We then adopted and extended the ‘Investigative Work in Science Curriculum’ carried out by Gott and Duggan (1995) and developed a novel conceptual framework for the project. We used this framework along with our experience with the International Physics Olympiad (IPhO) programme and developed a new format or mode of presentation of an experiment and demonstration. We combined a ‘problem-solving’ approach and a ‘guided design’ mode for the instructional strategy. Thus it may be said that we use a ‘guided problem solving’ mode in which, an experiment is presented in the form of an experimental problem with guiding instructions and a related demonstration is given as an introductory prelude to it.

Specifically we developed a set of ten innovative experimental problems and demonstrations in physics with suitable instructional strategy for them. We then designed and implemented a method of evaluation for the research project in which we investigated the effectiveness of these experimental problems, demonstrations and the instructional strategy in the physics laboratory training.

The statement of the research problem putting the above in a capsule form is the **“Development of Innovative Experimental Problems and Demonstrations in Physics with Suitable Instructional Strategy for Them and Investigating Their Effectiveness in Laboratory Training”**.

1.3 Significance of the work

We believe that the research work presented in this thesis significantly contributes to the improvement of the quality of physics laboratory training in colleges and universities in India at +2 and undergraduate level mainly because of the following developments carried out in the research work.

1) The development of a set of ten concrete innovative and carefully designed, experimental problems and their demonstrations, which can be used for laboratory training in physics. For this development, we designed and fabricated ourselves the necessary experimental set-ups, instruments and apparatus.
2) The development of a novel instructional strategy for the delivery of these experimental problems and demonstrations to students in the physics laboratory training.

3) The development of an innovative format or mode of presentation of experiments and the identification of various aspects of experimental physics, which should be considered while designing a new experiment.
4) The development of a novel approach for the presentation of the demonstrations in an interactive mode, to a small group of students.
5) The use or introduction of the ‘guided problem solving’ mode for the instructional strategy for the laboratory training in physics.
6) The development of a 15 days course on experiment physics, which can be easily used as a remedial course to supplement the regular physics laboratory training conducted in various colleges for the +2 and undergraduate students.
7) The development of a framework for a possible design of a novel strategy of evaluation of students’ practical work and also the effectiveness of various laboratory courses in science.
8) The detailed identification of various aspects of experimental physics, which should be emphasized during the physics laboratory training. We identified ‘procedural understanding’ as an important component of practical science and we feel that, it should be emphasized and given an important place in the physics laboratory training.

1.4 Plan of the thesis

Chapter I, is an introduction to the research work presented in this thesis. In this chapter, we give the brief background of the research work and the statement of the research problem and discuss the significance of the research work. We then present the plan of the thesis.

In Chapter II, we take a critical review of physics laboratory training. We first describe the brief history of laboratory training. We then discuss the importance and role and goals of laboratory training and the classification of practical work, depending on its nature or aim, into various types such as inquiry, illustration, skill, observation, investigation or exploration type. We then describe the present state of physics laboratory training at +2 and undergraduate levels in India. We analyze the status with respect to its strengths and weaknesses and identify the need of the 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. At the end of the chapter, the genesis of the research project is presented.

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

Chapter IV is devoted to the description of the research project and its evaluation design. Beginning with the objectives, we give a description of the research project. We discuss the different aspects of the development of innovative experimental problems, demonstrations and their instructional strategy. Here we first explain our idea of 'an experimental problem' and then describe various developmental guidelines and stages of development. This is followed by a list of ten experimental problems and their demonstrations. Next comes the discussion of the instructional strategy developed by us for the delivery of the experimental problems and demonstrations to the students. In the next section, which is on the design of the evaluation of the project, first the evaluation methodology is described and then information about the course on experimental physics and the tools of evaluation is given in brief.

Chapter V gives the description of the innovative experimental problems and their demonstrations. Here one specimen experimental problem and its demonstration is discussed in detail. This includes the problem, the experimental arrangement, the handout given to the students, instruction sheets, the model answer and the analysis of the experimental problem. For the demonstration, the objective, the experimental arrangement and the handout given to the instructor who carries out the demonstration are presented. A brief sketch of the other nine experimental problems and their demonstrations follows this. Here, we limit to a brief description, the experimental arrangement and salient features for the experimental problems and to the objective and brief description for the demonstrations.

Chapter VI explains the course on experimental physics and the evaluation of the project. In first section of the chapter, we give the objectives, plan and contents of the course. We also describe the sample group, its selection and how we administered the course and finally we discuss the limitations of the course. The next section is on the evaluation of the project. We begin with presenting the methodology of evaluation. We then describe various tools of evaluation and analyze students' performance. Here the design and administration, the marking scheme and the analysis of students' performance in case of the tests on conceptual understanding, procedural understanding, the experimental test and a questionnaire on attitudinal and other affective aspects is systematically put forth. The chapter ends with an analysis of the qualitative tools and the results of students' feedback.

Chapter VII is dedicated to conclusions and recommendations. Here conclusions of the research work, recommendations for improving the quality of physics laboratory training in India, suggestions for further research work and finally the limitations of the research work are presented.

CHAPTER II

A Critical Review of Physics Laboratory Training

In the present chapter, we take a critical review of physics laboratory training. Beginning with a brief history of laboratory training, we discuss the different aspects of physics laboratory training, namely, importance and role of laboratory training, goals of laboratory training and the classification of practical work. We then describe the present state of physics laboratory training in India, mainly at the +2 and undergraduate levels. We analyze the status with respect to its strengths and weaknesses and finally identify the need for the improvement in the present practices of laboratory training in physics. We also give a brief review of earlier efforts that were made with respect to the identified need. At the end of the chapter, the genesis of the research project is presented.

2.1 Brief history of laboratory training

Galileo may be credited with giving us experimental physics, although he did not have what could be called a laboratory. Gilbert's book on magnetism (around 1600 AD) was the first report of connected, sustained and reconfirmed experiments in the history of physics. During the first half of the 18th century, demonstration experiments entered university courses. Makers of demonstration equipment began to publish catalogues in Britain in mid 18th century and in U.S. early in the 19th century.

It is reported that in 1806, Stromeyer at the University of Gottengen began the first chemistry teaching laboratory for his students. By 1830, Thomas Graham had set up the first student physics laboratory in Britain at the Royal Technical College, London and around the same time Michael Faraday had published a laboratory manual stressing the importance of manipulative skills.

In the middle of the 19th century, many advanced student laboratories were developed for practical instruction. Heinrich G. Magnus developed a new physics laboratory at University of Berlin in 1863. William Thomson (Lord Kelvin) developed an advanced physics laboratory at University of Glasgow in 1866. Students' physics laboratories were set up in University College, London (1866) and King's College, London (1868) and at Oxford, Cambridge, Manchester, California and Chicago. Individual laboratory work, however, was not integrated into and made compulsory for the study of physics for the first few years.

Edward Charles Pickering had designed and initiated a physics laboratory at Massachusetts Institute of Technology in 1869. He had also published a book ‘Elements of Practical Manipulation’, Volume I (in 1873) and Volume II (in 1876). E.H. Hall of Harvard University published a list and write-ups of forty experiments in 1887. By the end of the 19th century many universities had instituted physics laboratories and so had most colleges. The practical work in school level science education was introduced in the middle of the 19th century. The emphasis was very much on demonstrations by teachers with a clear focus on the illustration of particular concepts.

It was probably in the second half of the 19th century, that teaching of science started in India and there were some schools and universities where demonstration experiments were introduced. In the first quarter of the 20th century, many colleges and universities established science departments along with laboratory facilities. Subsequent to the criticism by Hartog committee (1929) and later by the Central Advisory Board for post-war educational development in India (Sargent Plan, 1944), there were some measures taken to improve school and university education in India. In 1948, Government of India appointed a University Education Commission under the chairmanship of Dr. S. Radhakrishnan to report on Indian university education and suggest improvements. In their report among other improvements they suggested that the old laboratories be reconstructed and furnished with buildings, necessary fittings and accessories; they be well equipped and a laboratory workshop manned by technicians be set up at each university.

In 1964, the Government of India set up the Kothari Commission. In its report the commission stressed the importance of basic science education in schools. The commission recommended that in addition to continuous internal assessment there should also be at the end of the course a separate evaluation of practical abilities and skills with considerable weightage given to them. In 1970-71 the University Grants Commission started two programs, College Science Improvement Program (COSIP) and University Leadership Project (ULP), under which funds were made available to improve laboratory facilities at universities and colleges.

2.2 Importance and role of laboratory training

Physics is a fundamental science, which provides a picture of how the world behaves and how the laws of nature operate. Physicists try to understand the physical universe in order to predict its behavior. It can be said that physics is mainly based on experimental observations and quantitative measurements. The teaching and learning of physics is incomplete and inadequate unless it includes to a significant extent students' experience in independent practical and laboratory activities. These activities involve and develop abilities both intellectual and manual with a proper co-ordination between them. Hence the training in experimental physics becomes an integral and indispensable part of physics education. Today virtually at every college and university world over, laboratory training has been given an important and respectable place in physics teaching.

The role of laboratory training is succinctly expressed in the words of the well-known educationist Asubel (1968) "The laboratory gives students appreciation of the spirit and method of science…, provides students with some understanding of the nature of science…, promotes problem solving, analytic and generalization ability".

2.3 Goals of laboratory training

In 1954, V. E. Eaton described the following objectives of laboratory training.

1) Better and longer lasting understanding of physical principles,
2) Exercise in solving problems based upon real physical situations,
3) Experience with and appreciation of various methods used in experimental science,
4) Better understanding of and competence in the use of standard apparatus,
5) Training in precision and accuracy and awareness of the problems involved in laboratory work,
6) Increased confidence in concepts and laws of physics obtained by checking validity and use of these concepts and laws.

Shulman and Tamir (1973) proposed the following general goals for laboratory training in physics education.

1) To arouse and maintain interest, attitude, satisfaction, open-mindedness and curiosity in science,
2) To develop creative thinking and problem solving ability,
3) To promote aspects of scientific thinking and the scientific method (e.g. formulating hypotheses, making assumptions)
4) To develop conceptual understanding and intellectual ability and
5) To develop practical abilities (e.g. designing and executing investigations and observations, recording data and analyzing and interpreting results).

Anderson (1976) summarized the goals of laboratory training in four major areas as described below.

1) To foster knowledge of the human enterprise of science so as to enhance students' intellectual and aesthetic understanding,
2) To foster science inquiry skills that can transfer to other spheres of problem solving,
3) To help the student appreciate and in part emulate the role of the scientist and
4) To help the student grow both an appreciation of the orderliness of scientific knowledge and also understanding the tentative nature of scientific theories and models.

The objectives of the present laboratory training practices that have come to be accepted all over the world are more or less identical with those described by authorities as stated above. We list them below for reference.

1) To develop a better and longer lasting understanding of facts, concepts, principles and laws of science,
2) To develop procedural abilities related to practical science such as designing investigations, planning measurements and observations, and analyzing data,
3) To foster different cognitive abilities, such as hypothesizing, predicting, observing, classifying, interpreting and inferring,
4) To develop skills for the use of wide range of laboratory instruments, apparatus and tools,
5) To develop expertise in methods, processes and techniques used in experimental science,
6) To foster independence and creativity, and build problem solving ability,
7) To maintain and develop curiosity, interest and open-mindedness and scientific attitude,
8) To learn to value and critically appreciate science and the role of laboratory in science.

2.4 Classification of practical work

Laboratory practicals may be classified on the basis of their respective roles and learning outcomes or their methods of instruction. In the classification of practical work presented below, we have mainly followed the work by Gott and Duggan (1995). They have identified five types of practicals: inquiry, illustration, skills, observations, and investigations. This classification is mainly based on the roles and major learning outcomes of the practicals. *Inquiry* practicals are designed to acquire different concepts, laws or principles. *Illustrative* practicals usually are concerned with understanding or consolidation of substantive concepts. *Skill* type of practicals is meant for acquiring and practising different experimental skills. *Observation* practicals are mainly about application and synthesis of conceptual understanding. *Investigations* provide the opportunity for students to synthesize conceptual and procedural understanding[1] and skills to solve an experimental problem.

In the traditional classification of practicals, the criterion for classification is the method of instruction in addition to the role and learning outcomes of the practicals. See for example, Gupta V. K. (1995). In the traditional classification, they identify six types, namely 1) Inductive, 2) Deductive, 3) Verification, 4) Skills, 5) Investigations and 6) Exploratory practicals. *Skills* and *investigations* are common to both the traditional and Gott and Duggan's classification. The *inductive* type is almost the same as the *inquiry* type and the *verification* type is identical with the *illustration* type. The *deductive* type can be linked to the *observation* type, because both involve theory-laden observations. The exploratory type is not included in Gott and Duggan's classification. We feel that this type is important and is distinct from the others. We have therefore added this type to the five types described by Gott and Duggan. Exploratory practicals develop both conceptual and procedural understanding, but are different from investigations, in the sense that they are explorations of different questions and relationships in an unknown situation and do not have constraints of a definite design. Thus in the classification described below, we have six broad types of practicals. Each type of practical has a significant role to play in practical instruction. The boundaries between these types are not watertight; a practical activity can clearly include more than one type. For example, an inquiry practical will not be without skills or data interpretation.

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[1] Procedural understanding is complimentary to conceptual understanding. Conceptual understanding refers to the understanding of the substantive concepts of science, whereas, procedural understanding refers to that understanding, which is often 'implicit' and goes behind the planning and execution of experimental science in order to systematically generate scientific knowledge from it.

a) Inquiry type

This type of practical is structured to allow students to discover on their own a particular concept, law or principle, which is not introduced to them earlier. Practicals of this type have to be carefully planned and set-up to enable all students to arrive at the same end point. Here, the guided discovery approach is employed, in which questions may be posed to the students and the necessary instructions given. Students are required to organize facts, observations and the results to derive meaningful generalizations and principles. The main objective of this type practical is concept acquisition. A planned and guided experiment in which the volume of an irregular body made of a material with unknown density is to be determined, without any prior knowledge of Archimedes' principle, is an example of Inquiry type of practical.

b) Illustration type

The main aim of this type practical work is to illustrate or verify a particular concept, law or principle, which has already been introduced by the teacher. Students are provided opportunities to witness events and 'see' the concepts in action, so that they relate theory more closely to reality. This builds students' confidence and belief in concepts, laws or principles. This practical may take form of either a demonstration by the teacher or an experiment where students are given detailed instructions to follow. The objective of these practicals is concept consolidation. An experiment performed (either by a teacher or a student) with prior knowledge of Ohm's law, on the study of the variation of the current passing through a resistor with the applied voltage for different fixed value resistors is a typical example of illustration or verification type practical.

c) Skill type

In this type of practical students are given opportunities to acquire and practise relevant psychomotor and other skills. These practicals may involve setting up of apparatus, use of instruments, and making measurements or they might require students to learn and practice skills such as recording observations and data and plotting of graphs. The main aim of skill type of practicals is acquiring basic skills necessary for carrying out practical work. An activity, in which the density of the material of various rectangular or square blocks is to be determined by measuring their masses and dimensions, is an example of a skill type of practical.

d) Observation type

This type of practical has often has been described as 'theory-laden' activities. Students are asked to observe an event or a phenomenon and they are encouraged to apply previously learned principles to predict, describe or explain the event under observation. The main aim of the observation type of practicals is to develop an ability to apply conceptual understanding in a new situation or to reinforce major concepts, laws or principles. An example of observation type of practical is an activity in which a tiny spherical metal ball is allowed to fall through a highly viscous liquid and students are encouraged to observe the motion of the ball with respect to its velocity and explain the motion on the basis of previously learned principles of mechanics.

e) Investigation type

This type of practical usually offers several alternative ways of reaching a solution to a problem so that the design is much less controlled than illustrative or inquiry practicals. In investigative practicals students are supposed to use previously learned knowledge to solve a scientific problem or to study a phenomenon or an event. These practicals provide students an opportunity to achieve a thorough grasp of procedural understanding, while at the same time they allow students to use and refine their conceptual understanding. The main aim of investigation type of practicals is to allow students to use or apply concepts, cognitive processes and skills in an integrated manner to solve a problem. An experiment in which students are asked to investigate into the relation between the conductivity of the material of a given metallic block and its temperature, without substantial guidance or procedural instructions, is an example of investigation type practical.

f) Exploratory type

In this type of practicals students are given the necessary and possible apparatus and are encouraged to probe and build up new information through open-ended problems. In exploratory practicals the end point is not fixed and hence the design is not at all controlled. In this type of practical no guidance is given. Instead, students are given a free hand to choose particular apparatus, procedures and methods to manipulate concrete materials and to explore questions and relationships of interest. The information gathered through exploratory activities is utilized by the students to process new information and to find scientific relationships. Exploratory activities help students to foster creativity in, interest in and motivation towards the subject. The main aim of the exploratory practicals is to develop an understanding of the processes of science. An activity in which students are given, along with the other apparatus, a set of pendulum bob like objects of (i) the same mass and shape but of different volumes, (ii) the same volume and shape but of different masses, and (iii) the same mass and volume but of different shapes, and are expected to explore the dependence of time period of oscillation of a simple pendulum on the volume, mass, shape of the object and the length of the pendulum in each case, is an example of an exploratory practical.

2.5 Physics laboratory training in India

Today in most of the Indian schools, it is found that, in case of science teaching up to 10th Std., the laboratory activities are given a secondary role in relation to theory teaching. Fortunately, this is not the case with the teaching of physics at the +2 and undergraduate levels.

2.5.1 Physics laboratory training at the +2, i.e., higher secondary level

In a typical two year +2, i.e. higher secondary level science curriculum, out of about eight periods (40 minutes each) available for teaching of physics per week, three periods (2 hours) are spent in laboratory training along with four periods of theory lectures and one period of theory/laboratory tutorial. At this level, students spend a considerable time in laboratory activities and during the two years course they perform about 30 to 40 experiments. Experiments are performed in pairs or sometimes in a group of three or four. The students appear for a practical examination at the end of each year and about 15 to 30 percent of the total subject marks are allotted to laboratory tests.

2.5.2 Physics laboratory training at the undergraduate (B.Sc.) level

In a typical undergraduate three-year (B.Sc.) course, with physics as a major subject, usually students spend about 35 to 50 percent of the total time allotted for physics teaching, in the laboratory. During this three year course they perform about 50 to 80 experiments, typically one experiment in a two or three hour session. In most of the colleges students perform experiments in pairs or sometimes in groups of three. They appear for one or two practical examinations at the end of each year and about 20 to 40 percent of the total subject marks are assigned to the laboratory examinations.

2.5.3 Analysis of the present status

It has been observed that in most of the colleges, students perform experiments mechanically. They are generally given detailed instructions either by a teacher in the classroom or in the form of written sheets. These instructions include, guidelines for performing the experiments according to a set pattern and sometimes the instructions may even include expected results and inferences. In this ‘cookbook’ mode, students are deprived of opportunities to learn by themselves and frequently leave the laboratory having performed the exercise well, but with low and superficial retention of knowledge and skills. The laboratory is simply a center of verification of information and hence students may not find any charm and interest in them. The students hardly develop a feel for the role and importance of experimental training.

I) Strengths

As seen from the above discussion, considerable amount of time is devoted to physics laboratory training in India at the +2 and undergraduate levels. As a result of this training it is found that, students.

1) perform many experiments with wide coverage of topics,
2) develop some, although superficial conceptual knowledge,
3) develop “know how” of a wide range of laboratory instruments and tools,
4) develop ability and skills needed to use some standard instruments,
5) develop to some extent abilities like plotting of graphs, mathematical calculations and reporting of laboratory work.

II) Weaknesses

In most of the colleges, it is found that most of the experiments are of ‘verification’ and ‘determination’ type. A very limited number of experiments are performed which have investigative (or project like) components. It has been observed that the number of experiments, their topics and instructions, keep on changing from the first year of the course to the next, but the mode of conducting practicals more or less remains the same once introduced at Std. XI till the post graduation level.

It can be said that the present practice of laboratory training in India at the +2 and undergraduate levels is inadequate with respect to the following.

1) Linking theory and experiments,
2) Development of important cognitive skills like formulating hypotheses, making assumptions, planning and design of experiments, interpretation and application of experimental findings,
3) Development of higher order abilities, like becoming careful and keen observers, ability to make accurate measurements, proper handling of measured data for objective reasoning and drawing conclusions and making generalizations,
4) Ability to solve new experimental problems and perform investigative practicals,
5) Development of an insight into the processes of science,
6) Fostering scientific thinking and reasoning ability,
7) Opportunities to discover new information and thereby develop curiosity in science,
8) Development of interest in and motivation towards physics,
9) Development of self-activity and independent working habits.

2.5.4 Need for improvement

It is evident that the present practices of performing a set of experiments in college physics laboratories in India hardly go towards fulfilling the goals setout for the laboratory training. The situation calls for improvement. We believe that the attempts for improvement should essentially have following two important aspects:

a) Development of innovative experiments and demonstrations in physics,
b) Development of an instructional strategy for laboratory training in physics.

We describe below in more detail the different aspects of these suggested measures to improve the quality of the physics laboratory training in India.

a) Development of innovative experiments and demonstrations

In case of +2 level and undergraduate courses in India, students perform many experiments during the physics laboratory training. These experiments are mainly based on topics from mechanics, optics, heat and electronics. It has been observed that although there are some very good experiments in the present curricula, very few experiments are based on basic concepts in physics and their applications. There are many experiments, which are based on the study of basic electronic devices or circuits, which require very little skills to perform the experiment. Most of these experiments are of the 'connect and read' type, in which students are supposed to make some connections and take readings by varying either current or voltage, perform routine mathematical calculations and plot graphs to obtain expected results.

It has been observed that most of the experiments employ obsolete versions of measuring instruments. Recent technological advancements have resulted in development of new measuring techniques and instruments. These instruments are far more reliable and accurate compared to older versions and are widely used in advanced research and industries. It is necessary to introduce and expose students to these new techniques and instruments during their laboratory training so as to equip them better to face the challenge of research and industries.

This calls for introducing some carefully designed innovative experiments based on basic concepts in physics and their applications and which involve use of new measuring techniques and instruments. These experiments have to be so designed as to develop experimental ingenuity and capacity to solve new experimental problems. Thus we feel that it is necessary to introduce some innovative experiments, in the present list of experiments at the +2 level and undergraduate level physics laboratory curriculum.

One also observes that there is little emphasis on demonstration experiments in physics teaching in India. The demonstration experiments serve a specific role of illustration of a concept, a law, a principle, a technique, the use of an instrument or an experimental set up. Such experiments performed by the teacher or students help students to recall and refine their conceptual understanding and the understanding of tools, methods and processes involved in science. They also help students to develop interest, curiosity, reasoning ability and scientific thinking. We feel that it is necessary to introduce some innovative demonstrations in physics teaching.

b) Development of an instructional strategy

It is also been felt that the very mode in which students perform experiments in colleges needs a major change. In the present format most of the students perform experiments mechanically, with only superficial understanding of the procedural or conceptual aspects involved in experimentation. It is also seen that in the present method of instruction, there is very little scope for students' self-planned and independent experimental work during physics laboratory training. Also it rarely offers training with an aim of developing procedural understanding and problem solving ability. A laboratory atmosphere where students are impelled to think and take decisions about procedural details and aspects like data handling, interpretation and drawing inferences from observations, with a minimum necessary guidance from the teacher is called for. Thus there is a need for developing a suitable instructional strategy (method of instruction) for laboratory training in Indian higher secondary schools / colleges / universities.

It is important here to note that, the identification of the need was mainly based on the analysis of the present system of physics laboratory training in Indian colleges and universities carried out by us. During this analysis, we did have many fruitful discussions with some of our colleagues at HBCSE, physics teachers and students of various colleges and universities in India. Even though we do not have any written report of the discussions with teachers and students or a thorough analysis of the present system, the identification of the need was indeed based on many attempts to go into the root cause and identify the lacunas of the system. Thus, it may be said that even though the need was basically identified by the researcher, it is based on the opinions about the need and the change required in the system as expressed by teachers and students.

2.6 Review of earlier efforts

After the identification of the need, we looked for and studied the earlier major contributions of researchers and teachers, with respect to these two aspects of physics laboratory training at the post school and undergraduate levels. We did an extensive survey in which we collected many relevant papers published in *American Journal of Physics* and some other physics education journals published abroad as well as in India. We give below a brief overview of the earlier efforts that were made for the improvement of the quality of physics laboratory training at the post school and undergraduate level.

In the beginning of the 20th century, many educational organizations, science educators and teachers including the members of the *American Association of Physics Teachers (AAPT)* realized the importance of experimental work in the physics teaching. In the first half of 20th century, AAPT started or supported many projects in which the developmental work was taken up at various places in the US. The development was mainly centered on the development of new experiments, demonstrations, strategies of instruction, laboratory courses and curricula. These projects resulted in considerable developmental work and a number of books and articles on experiments, demonstrations, laboratory curricula, courses and strategies of instructions were published. An excellent collection of 'demonstration experiments in physics' was prepared under the auspices of AAPT and published by McGraw-Hill Book Co. in 1938. This book was edited by Prof. R.M. Sutton of Haverford College.

After the first half of the 20th century many universities and colleges in U.S.A., U.K. and some other countries, started revising and reformulating their laboratory courses in science. During the first few decades of the second half of the century, many new projects were taken up and new courses, experiments, demonstrations, curricula, and strategies were developed all over the world.

Around the same time, the Nuffield scheme came in to picture in U.K., under which, they developed their 'A' and 'O' level courses. In these courses, an emphasis was given on the laboratory work and the inquiry based learning approach was adopted. For this curriculum, a comprehensive set of books on various laboratory and classroom experiments and demonstrations was developed and published. In most of the universities abroad, at present, courses on experimental physics are conducted with varying objectives, strategies and content.

Most of the universities, in India, were constituted on the model of London University. Even the courses and the contents of the courses were directly adopted from this and few other universities in U.K. As far as the physics laboratory training in Indian colleges and universities is concerned, we have adopted the strategy, content and the courses, as were being used or followed in universities and colleges in U.K. Even the experiments, demonstrations, their write-ups, apparatus and experimental set-ups were taken from the physics laboratory courses conducted in U.K.

In India, it was only after the first half of the 20th century, people started thinking about and working on the various possible changes in the curricula, content, and teaching strategies for various science courses. During the period 1963-1973, a number of summer institutes were conducted at various places in India by National Council of Educational Research and Training (NCERT) and University Grants Commission (UGC) to upgrade the level of teachers and the teaching of physics. In the year 1970-71 a number of College Science Improvement programs (COSIP's) and University Leadership Projects (ULP's) were initiated with primary attention on the upgradation of college level laboratories.

The first major effort towards the development of new experiments and demonstrations in physics suitable for undergraduate level was that of a team headed by Prof. B. Saraf, at University of Rajasthan, Jaipur. They developed under the ULP some excellent new equipment, apparata and set-ups, experiments and demonstrations. The group published their books on ‘Physics Through Experiments’ Vol. I in 1975, and Vol. II in 1979.

Some other ULP’s and COSIP’s produced some important results and contributions. The most prominent of them were those taken up at the Punjab University and the University of Pune. These universities also published books and reports based on the projects taken up for the improvement of laboratory training. In the year 1985, Prof. D.P. Khandelwal of HBTI, Kanpur, published a ‘Laboratory Manual of Physics for Undergraduate Classes’. In the same year, Prof. R.S. Sirohi of I.I.T., Madras, published a book on ‘A Course of Experiments with He-Ne Laser’. After 1970’s many individuals and groups started working on the development and published books on some new and old experiments put together for the undergraduate classes of Indian universities.

Unfortunately very few of the new experiments developed in this period, found their place in the actual laboratory training conducted at various colleges and universities.

After the adoption of 10+2+3 scheme of Education, A team headed by Prof. V.G. Bhide started working mainly at NCERT on developing new experiments and demonstrations and subsequently on books for class XI and XII laboratory course. They published ‘Physics Laboratory Manual for Class XI’ and ‘Physics Laboratory Manual for Class XII’ both in 1989. These books were published by NCERT and were designed as laboratory textbooks for these classes.

Thus in India, many programs were taken up for the development of new experiments and demonstrations in physics. But unfortunately very few projects were taken up to handle the other aspects of improvement of laboratory training in physics. There were very few attempts towards changing or modifying the existing ‘prescriptive’ or ‘programmed’ format or approach which is adopted in India for physics laboratory training. Also there were no major efforts towards improving the reliability and the quality of the strategy of evaluation used for evaluating the students’ laboratory work.

It is important here to note that, a major attempt was made in 1983 by Prof. D. P. Khandelwal, to change the format of existing laboratory experiments for better educational value. Few other researchers from, Madurai Kamraj University, Banaras

Hindu University, Poona University, and NCERT, presented some similar work. But none of them developed a suitable, acceptable and detailed strategy of delivery of the experiments and demonstrations.

2.7 Genesis of the research project

In the year 1995, Homi Bhabha Centre for Science Education (HBCSE), undertook a major project in which new laboratory development programme in physics, chemistry and biology (suitable for higher secondary and undergraduate level) was initiated. The researcher was involved in the development of the physics laboratory at HBCSE.

In case of physics laboratory development, simultaneously as the actual developmental work was undertaken, we began an extensive study of different aspects of physics laboratory training. This led us to look into the history, importance and role, goals of laboratory training and different types of practical work. This formed the basis on which we analyzed the present state of physics laboratory training in India. Our detailed analysis with respect to the strengths and weaknesses of the present practices allowed us to identify two major aspects (described in the earlier section) of any effort at improvement of the physics laboratory training in Indian colleges and universities at the +2 and undergraduate levels. We felt in the first place a pilot project embodying these two aspects and carrying out the necessary research and development should be undertaken. The research project reported in this thesis is precisely such a pilot project. It was undertaken, with the following two clear objectives:

1) The development of innovative experiments and demonstrations for the laboratory training in physics at the +2 and undergraduate levels.
2) The development of a suitable instructional strategy for the delivery of these experiments and demonstrations to the students.

We studied the different past and present practices of conducting laboratory training world over, with respect to content, methods of instruction and also the methods of evaluation. This study provided us many inputs with respect to the content and strategies of the laboratory training in physics. We found it necessary to design a new format of presentation of an experiment to the students and a matching instructional strategy. The main inputs, which we have utilized, are described below.

1) The main input with respect to ‘what the format of the experiment should be’ and also about the content, was derived from recent experimental examinations of the International Physics Olympiads (IPhO). We noticed that in the last few IPhO examinations, almost all the experiments were presented in an identical format, even though no olympiad document explicitly describes a specific format of presentation for experiments. We found this format of presentation to be novel in many respects and most suitable for our research work. Besides the format, the content of the experiments, what the students were asked to do was indeed innovative. We therefore, decided to use this IPhO model as a guide for designing the format and content of the experiments to be developed in this research project. A critical analysis of the IPhO question papers helped us identify the areas in which innovation may be introduced.

2) The second major input was derived from the work by Gott and Duggan (1995) on ‘investigative work in the science curriculum’. The work presented by them (even though it is limited to school level science teaching) describes an innovative perspective of practical science. We found that the perspective to be useful in many ways, for example, in identifying the importance and content of procedural understanding and in understanding the relevant taxonomies and defining different learning objectives of laboratory training. Actually our idea of an ‘experimental problem’ was generated only after a critical analysis of the model of science, based on the problem solving approach, described by Gott and Duggan. The perspective subsequently guided us in designing the content and format of experiments to be presented as experimental problems and the strategy of their delivery i.e. the necessary instructional strategy. We thus adopted the perspective as developed by them for practical science and applied it in our research work (with appropriate modifications) to conceptualize the project. The resulting conceptual framework of the research project is described in the next chapter of the thesis. The conceptual framework guided us in many ways. It gave us basic ideas about content and design of experimental problems. It helped us in defining and developing a new format of presentation of experiments, in identifying different aspects and abilities to be emphasized during the laboratory training and in working out a systematic approach for delivery of the experimental problems and thus developing a suitable instructional strategy.

With the above-mentioned two inputs we have formulated the research project in which we undertook the development of experimental problems and related demonstrations for the laboratory training in physics along with a suitable instructional strategy for them, which we describe in chapter IV and V of this thesis. We have used the problem-solving approach to develop and present the experiments in the form of experimental problems and combined it with a guided design method for an instructional strategy in which a related demonstration is given as a prelude to the experimental problem.

CHAPTER III

The Conceptual Framework

In the present chapter, we describe briefly, the conceptual framework of the research project. We describe the perspective, which we follow from the work by Gott and Duggan (1995). The perspective developed by them is a new and enlightening way of looking at practical science, which we believe, provides an appropriate framework for our project. Their key contribution is the introduction of the concept of procedural understanding. For them, procedural understanding plays an important role in science just as conceptual understanding. In order to highlight this, they adopt a simplified model of science in which both conceptual and procedural understanding have an equally important role to play. Based on this model they develop appropriate taxonomies in both conceptual and procedural aspects of the cognitive domain following Bloom’s taxonomy of educational objectives.

3.1 A new perspective of practical science

It has been normally observed that conceptual understanding and practical skills are the only aspects recognized in formulating the objectives of practical science in India. What has been by and large overlooked is the component of procedural understanding. Procedural understanding forms a link between conceptual understanding and practical skills; in other words it controls the application of skills to build conceptual understanding.

The perspective of practical science as developed by Gott and Duggan gives emphasis on and importance to procedural understanding. They have also developed a detailed taxonomy for procedural understanding along with a corresponding taxonomy for conceptual understanding. We feel that the taxonomy for the procedural understanding as developed by them is the most suitable and acceptable taxonomy of objectives for our project, since it also defines clearly the ‘contents’ of the procedural aspect of the science. In this section, we first describe the simplified model of science and then give the taxonomies developed by Gott and Duggan.

3.1.1 A model of science

The model of science, described below, was first developed by Gott and Mashiter (1991) and then adopted by Gott and Duggan (1995). This model is a basic and deliberately simplified model for the whole of science and not solely for practical science. In this model, some factors such as motivation, context or the students' expectations of what should be done in science teaching, each of which can have a significant effect on performance are omitted for simplification. For the implications of the model to be clear, we first briefly describe the terms used within it.

a) Conceptual understanding and facts

We here describe the definitions given by Williams and Haladyna (1982). They define facts as 'associations between names, other symbols, objects and locations', and concepts as 'classes of objects or events that are grouped together by virtue of sharing common defining attributes'. For example, in case of a situation wherein an object is dropped freely under gravitational force, statements such as a) the object falls towards the ground, b) the object reaches ground some time after its release, c) the object falls with changing velocity, d) the time the object takes to reach the ground depends on the height from which it is released, are the examples of facts. Further velocity, acceleration, force, time of flight are examples of concepts. The conceptual understanding refers to the 'understanding of the ideas in science, which are based on facts, laws and principles and what are sometimes referred to as 'substantive' or 'declarative' concepts. For example, if the object falls only under the influence of the gravitational force, which is a constant force near the surface of the earth (neglecting the air friction), then the understanding that the acceleration of the object will be constant, i.e. the rate of change of its velocity will be the same, is an example of conceptual understanding.

b) Procedural understanding and skills

Skills here refer to activities such as the use of measuring instruments and construction of tables and graphs. Use of a thermometer for measuring the temperature of water, use of a scale for measuring the length of a wire or the use of a stop clock to measure periodic time of a pendulum, etc. are examples of skills. Procedural understanding is the understanding of a set of ideas, which may be termed as 'concepts of evidence', related to the 'knowing how' of science and needed to put science into practice. It is distinct from, yet complimentary to conceptual understanding. It is the thinking behind the doing, or the decisions that have to be made for doing practical work. That is, if a student is asked to study the motion of a freely falling body, with respect to its changing velocity, then all such knowledge as planning of the experiment and decisions to be taken as to what is to be measured, what the appropriate range of readings will be, with what accuracy and at what intervals the measurement will be carried out and how one may derive meaningful outcome from the measured data constitutes procedural understanding.

c) Cognitive processes

Conceptual and procedural understanding cannot be independent of one another: some understanding of substantive concepts is necessary to carry out most procedural aspects of science, and similarly procedural understanding is necessary to put substantive concepts into practice. The cognitive processes refer to this interaction, involving the selection and application of facts and skills, between conceptual understanding and procedural understanding. These cognitive processes are the means of obtaining or processing the information needed to tackle a problem. They include hypothesizing, predicting, observing, classifying, interpreting and inferring.

d) Solving problems

A very catholic definition of a 'problem' is adopted here; a problem includes any activity that requires a student to apply his or her understanding in a new situation. This will include explanation of phenomena, applied science problems, theoretical problems as well as practical investigations. The difference between these is with respect to the relative emphasis on conceptual and procedural understanding. For example, suppose a student is asked to determine the acceleration of an object of mass m moving down on a frictionless inclined plane (with an angle of inclination q) without sliding. This problem may be solved theoretically or may as well take the form of an experimental investigation (if all the necessary apparatus including a frictionless plane is provided).

The model

The model of science described by Gott and Duggan is presented below. It is based on an assumption that solving problems is the main objective of science. As said earlier, in this model, both conceptual as well as procedural understanding have been given an important place. For solving any scientific problem, we need to know both the conceptual and procedural components' understanding related to the problem, which then are combined and processed to derive the solution of the problem. Here, the cognitive processes needed to solve the problem are seen as an interaction between 'conceptual' and 'procedural' understanding. The conceptual understanding will always be based on facts and the procedural understanding always needs skills to generate the necessary data.

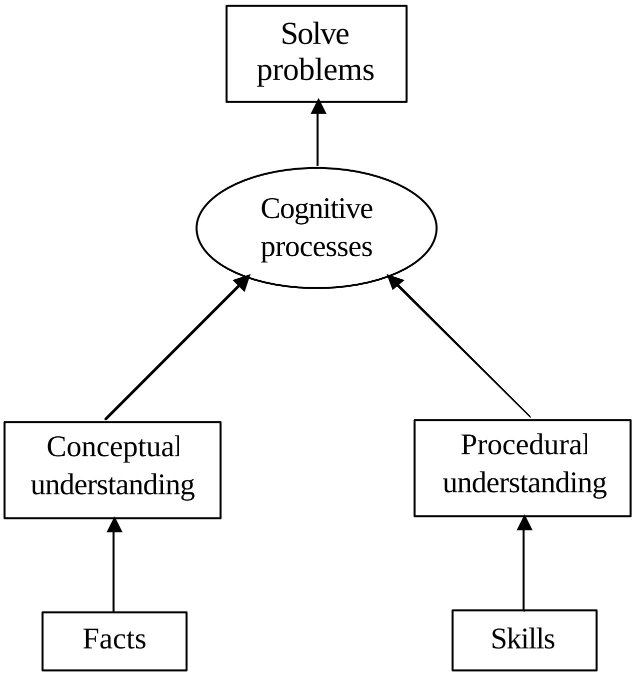

Fig. 3.1 A model of science

It should be noted that the model does not imply that these two types of understanding are mutually exclusive. Although procedural and conceptual understandings are intertwined in this way, the distinction between them is useful in unraveling the complexities of science education. The emphasis of a particular task may be more on one side of the model than the other. Hence when the conceptual understanding required to solve a problem is very hard and the procedural understanding easy then the balance is to the left and vice versa.

An example will serve to illustrate how this model can be applied. Suppose that the problem is to find out how the average or final speed of an object moving down an inclined track is related to its weight. The student first needs to understand the concept of speed and know that it involves distance and time (conceptual understanding). He or she will need to have the skills to be able to measure the distance, time and weight. Then he or she must decide how to construct a fair test and what distance and time to measure (procedural understanding). All this information has to be processed in designing the investigation, examining the obtained data and drawing appropriate inferences.

3.1.2 Developing the taxonomies

An attempt has been made to identify, in greater detail, the types and levels of conceptual and particularly, procedural understanding which students need in science

(Gott and Duggan, 1995). In order to do this, Bloom's taxonomy of 'educational objectives for the cognitive domain' (Bloom et al (1956)) was used and modified. This taxonomy is applicable to both conceptual and procedural understanding used in the model of science. Its application to the familiar concepts of science is described briefly, so that it can then be demonstrated that a parallel structure for a procedural understanding can be defined.

3.1.2.1 Bloom's taxonomy and conceptual understanding

Bloom's original taxonomy contains six different levels of cognitive ability, which are hierarchical, in the sense that higher levels subsume lower levels. Kempa (1986) reformulated this taxonomy giving only a four level classification. Gott and Duggan (1995) simplified the classification and applied it to conceptual as well as procedural understanding. They use the classification merely as a description with no implications that it has a hierarchical structure. The original classification was developed by Bloom for assessment purposes to enable teachers to relate educational objectives in terms of subject content to the thinking process involved. Gott and Duggan use it as a way to describe what science might contain, without getting in to the complexities of whether or not it is possible to use the hierarchical structure to predict levels of difficulty.

I) A conceptual taxonomy

Gott and Duggan's four level taxonomy applied to conceptual understanding is shown below.

Conceptual Taxonomy
1) Knowledge and recall of facts
2) Understanding of concepts
3) Application of concepts (in unfamiliar situation)
4) Synthesis of concepts (in problem solving)

According to them, in case of the conceptual understanding, there would be a place for the simple recall for some parsimonious selection of facts. There must also be room for an understanding of the ideas, how the facts interrelate in the context in which they were taught, as well as the application of those ideas in novel situations and finally in the context of solving problems, students must synthesize knowledge and conceptual understanding.

One of the weaknesses of this taxonomy is that concepts can become more like facts with increasing age and experience. For instance, distance can be a concept in one situation to a 5-6 year old student, but may be recalled and used much like a fact in another situation by an older student. This, however, does not mean that the taxonomy cannot be used as a descriptive tool in making some overall sense of the complexities inherent in the cognitive abilities required in science.

3.1.2.2 Bloom’s taxonomy and procedural understanding

Bloom’s taxonomy is extended to procedural understanding by Gott and Duggan, who base it on skills and ‘concepts of evidence’, which are complimentary to the facts and substantive concepts occurring in the conceptual taxonomy. It is important to clarify the meaning of the term ‘concept of evidence’ before we describe the structure of the procedural taxonomy.

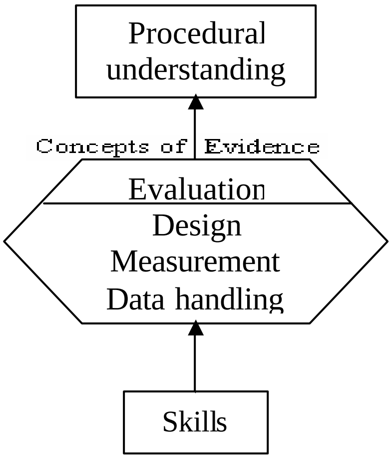

Fig. 3.2 Procedural understanding and concepts of evidence

I) Concepts of evidence

The phrase ‘concepts of evidence’ refers to the concepts, which are associated with procedural understanding. The phrase draws attention to the importance of procedural understanding and the concepts underlying the doing of science in relation to the evidence as a whole.

These concepts of evidence have been structured around the four main stages of investigative work; namely, the design of the task, measurement, data handling and finally but crucially, the evaluation of the complete task in terms of the reliability and validity of the ensuing evidence. By stages, one does not mean, stages in time, since these stages are often revisited. For instance, at the data handling stage a decision may be made to take more measurements. The evaluation of the task requires an understanding of all three stages; design, measurement, and data handling, and this understanding of evaluation is needed as much as at the beginning as at the end of the task. The kind of understanding associated with each of these main stages is defined in table 3.1.

Table 3.1 Concepts of evidence and their definitions

Concepts of evidence		**Definition**
Associated with design	Variable identification	Understanding the idea of a variable and identifying the relevant variable to change (the independent variable) and to measure, or assess if qualitative (the dependent variable)
	Fair test	Understanding the structure of the fair test in terms of controlling the necessary variables and its importance in relation to the validity of any resulting evidence.
	Sample size	Understanding the significance of an appropriate sample size to allow.
	Variable types	Understanding the distinction between categorical, discrete, continuous and derived variables and how they link to different graph types.
Associated with measurement	Relative scale	Understanding the need to choose sensible values for quantities so that resulting measurement will be meaningful.
	Range and Interval	Understanding the need to select a sensible range of values of the variables within the task so that the

		resulting line graph consists of values, which are spread sufficiently widely and reasonably spaced out so that the 'whole' pattern can be seen. A suitable number of readings are therefore also subsumed in this concept.
	Choice of instrument	Understanding the relationship between the choice of instrument and the required scale, range of readings required, and their interval (spread) and accuracy.
	Repeatability	Understanding that the inherent variability in any physical measurement requires a consideration of the need for repeats, if necessary, to give reliable data.
	Accuracy	Understanding the appropriate degree of accuracy that is required to provide reliable data, which will allow meaningful interpretation.
Associated with data handling	Tables	Understanding that tables are more than ways of presenting data after they have been collected. They can be used as ways of organizing the design and subsequent data collection and analysis in advance of the whole experiment.
	Graph type	Understanding that there is a close link between graphical representations and the type of variable they are to represent. For example, a categorical independent variable (such as type of surface) cannot be displayed sensibly in a line graph. The behavior of a continuous variable, on the other hand, is best shown in a line graph.

	Patterns Multivariate data	Understanding that patterns represent the behavior of variables and that they can be seen in tables and graphs. Understanding the nature of multivariate data and how particular variables within those data can be held constant to discover the effect of one variable on another.
Associated with the evaluation of the complete task	Reliability Validity	Understanding the implications of the measurement strategy for the reliability of the resulting data; can the data be believed? Understanding the implications of the design for the validity of the resulting data; an overall view of the task to check that it can answer the question.

The term variable has been used in table 3.1 to refer to any observation, which can be described by different values for example, temperature, length, or time. Variables can be classified in terms of their roles and functions in the structure of the activity as *independent*, *dependent* or *control* variables. The values for the *independent* variable are chosen and manipulated by the investigator. The value of the *dependent* variable is then measured for each change in the value of *independent* variable. *Control* variables are those, which must be kept constant while the *independent* variable is changed to make the test ‘fair’.

It is important to note that concepts of measurement are to do with the decisions that have to be taken about measurement rather than to do with the skill of measurement itself. Concepts associated with data handling include the understanding of the use of a table as a way of organizing data rather than the construction of a table itself. A further aspect of data handling is the isolation of the required variable from the multivariate data. The final evaluation stage subsumes all other concepts of evidence because reliability and validity can only be considered in the context of the strategy of the whole task. In the above discussion an attempt has been made to restrict the definition of concepts of evidence to ideas that relate data to reality, which is a crucial distinction between mathematics and science.

The taxonomies and the model of science, which are described here, are based on the assumption that evidence is an important notion in science education. The degree of importance of evidence may very from situation to situation. For example, given the universal law of gravitation, measuring acceleration due to gravity on the surface if the earth and relating it to the universal gravitational constant, the mass of the earth and the radius of the earth corresponds to a situation where the evidence is of secondary importance. On the other hand, if the phenomenon of elasticity is considered, then Hooke's law can be used to explain stretching reasonably well, although the relationship varies with different materials and the law is only applicable within certain limits. In this example, sound evidence is crucial because data are required to make the law usable, a spring constant needs to be calculated for specific instances. In certain situations, like considering the water flow in a river, one cannot even start without empirical evidence. This does not however mean that the substantive concepts do not guide the model. They do; for example, in the river flow problem, the concept of friction will play an important role in determining the flow rate at various locations.

II) A procedural taxonomy

The taxonomy is based on skills and concepts of evidence as described below.

Procedural Taxonomy
1) Knowledge and recall of skills
2) Understanding of concepts of evidence
3) Application of concepts of evidence (in unfamiliar situation)
4) Synthesis of skills and concepts of evidence (in problem solving)

An example may help to show how the taxonomy might be applied. As with the conceptual version discussed earlier, procedural aspect contains the knowledge and recall of skills such as the use of thermometer. It should also encompass the understanding of concepts of evidence, as in the understanding of the role of the fair test within a familiar context, or the range and number of readings required in measurements of temperature. The concepts must also be applied to novel situations. The ability to apply the notion of the fair test should be available in a whole range of circumstances. Finally we have the ability to synthesize skills and concepts of evidence into the solution to the problem where, for instance, the links between a fair test and the validity of any resulting data, or between the accuracy of a set of readings and the reliability of the data are taken into account in generating ‘believable’ data.

It can be said, therefore that the descriptive model which has been so influential in structuring and assessing the conceptual component of science curriculum can also be applied in a similar way to the procedural component. The importance of this is not in some arbitrary mirroring of an existing structure or imposing a needless level of complexity on an already complex enough situation. Rather, it is to do with recognizing that there is a ‘content’ to the procedural side of science which can be well described and which must be recognized.

3.2 Implications for the research project

In chapter II, we described the present state of physics laboratory training in India at +2 (i.e. higher secondary) and undergraduate level. There we identified two major aspects of any attempt of improving physics laboratory training in India. The work presented in this thesis is an exploration in that direction. This research project is aimed at development of experiments and demonstrations and a suitable instructional strategy for them, which could be used for physics laboratory training at +2 and undergraduate level.

As described in section 2.7 of chapter II, the main inputs, which we have utilized in this research project, are from i) the experimental examinations of the International Physics Olympiads (IPhO) and ii) the work by Gott and Duggan on the investigative work in the science curriculum. The former gave us innovative ideas for the subject content of the experiments and helped us to design a new format of presenting an experiment and the latter helped us in identifying and defining the different learning outcomes, particularly the procedural understanding and concepts of evidence, which should be emphasized during the laboratory training.

As said earlier, Gott and Duggan base their work on a model of science with focus on practical science. This model views science as a problem solving activity. The cognitive inputs for solving the problems relevant to science come from the interaction of two types of understanding; one is the conceptual understanding, which is well known and well accepted. The other is the procedural understanding not so well known. All this has been discussed earlier.

Conceptual understanding is the understanding of substantive concepts, which are derived from facts. Gott and Duggan build up the notion of procedural understanding in a parallel manner to the notion of conceptual understanding. They draw attention to the fact that science is validated only by evidence, that all laws and generalizations in science are derived from evidence, i.e. observed behavior of nature. Collection of evidence requires experimental skills; but skills are not enough, they need to be guided and informed by decisions like, what to look for, planning of necessary stages of experimentation and measurements, understanding of accuracy of measurement, range of data and knowledge of data processing.

The collected evidence also has to be weighed or evaluated. Gott and Duggan introduce the concepts of evidence, which are involved both in the collection and in the evaluation of evidence. (These have been listed earlier in the chapter). Procedural understanding is the understanding of the concepts of evidence. The conceptual and procedural taxonomies given by these authors clearly show the parallelism between the two types of understanding. Their main contribution is in bringing out the importance of procedural understanding in science; they say that it is an understanding in its own right and is essential for the development of science.

This perspective has two implications for the present research project. One is with respect to the problem-solving approach. We adopt this approach for presenting the experiments to students as ‘experimental problems’ to be solved by them. (Hereafter we use the term experimental problem instead of an experiment). Gott and Duggan view science as a problem-solving activity; their focus is practical science. We follow this perspective of practical science as a problem solving activity and apply it with necessary modifications to physics laboratory training. Further, one of the objectives of teaching science is to impart the culture of science, the scientific method to the students. The problem-solving approach incorporates this objective in a natural way.

In case of the International Physics Olympiad competitions, the experimental tests are presented in a format which may be termed an ‘experimental problem’ format, even though no olympiad documents state this explicitly. This supports the format we adopt in this project for the presentation of experiments. Since the experimental problems, we have developed are presented for the purpose of training and not for competitive evaluation, we do not present them as single, monolithic problems but break each experimental problem into a series of steps, each step being a smaller problem. Thus each experimental problem is a collection of relatively simple experimental situations or problems, in which students need to perform operations involving combination of conceptual understanding, procedural understanding, scientific processes and skills to arrive at the desired state.

The second implication of the perspective is with respect to incorporating in a purposeful conscious way the development of procedural understanding as an objective of the instructional strategy for the experimental problems developed. No body before Gott and Duggan had brought this out more succinctly. We explicitly build the development of the understanding of various concepts of evidence, listed by these authors into our experimental stages or procedural instructions to be presented to students.

The next chapter further elaborates what we mean by ‘an experimental problem’. The chapter also describes the guidelines and stages of the development of the experimental problems and demonstrations, and their instructional strategy along with the detailed format of presentation.

CHAPTER IV

The Research Project and Evaluation Design

In the present chapter, we describe the detailed design of our research work. We first define the objectives and design of the research project and then describe the different aspects of the development of innovative experimental problems, demonstrations and the instructional strategy. Here we explain our idea of 'an experimental problem' and discuss different developmental stages of the experimental problems and related demonstrations and give a list of the experimental problems and demonstrations. In case of the instructional strategy, beginning with a brief introduction, we describe in detail the strategy developed by us for experimental problems and demonstrations.

We then, briefly discuss the design of the evaluation of the research project. In this, first the methodology and then the design of a course on experimental physics is presented along with the contents of the course and tools of evaluation.

4.1 Objectives of the project

The research project is designed around the two earlier described aspects of laboratory training in physics, namely, development of innovative experiments and demonstrations and development of an appropriate instructional strategy. The objectives of this project, presented earlier, at the end of the chapter II, may now be cast in specific operational terms and stated as follows:

1) **To develop a set of ten innovative experimental problems and related demonstrations in physics, suitable for the laboratory training of the +2 (i.e. higher secondary) 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 the students, which may be used for laboratory training in physics.**

We discuss below these objectives in greater detail.

1) In the light of the framework described in the earlier chapter (i.e. Chapter III), it may be noted that the laboratory training in laboratories in Indian colleges and universities

is not enough for development of the procedural understanding (the understanding of concepts of evidence) and problem solving ability in students. As described earlier, we believe that the experiments, presented in the form of experimental problems, will effectively serve the purpose of developing these important, and yet usually ignored, aspects of experimental physics. As said earlier, for each experimental problem a related demonstration may be given as a prelude, which should be based either on the key concept of the experimental problem or on the use of a relevant measuring instrument or a technique or on a key aspect of the experimental arrangement.

The major objective of this project is to develop a set of ten innovative experimental units, each experimental unit consisting of a five to six hours long experimental problem and a thirty minutes long related demonstration. The experimental problems and the demonstrations should be suitably designed so that they may be directly used for the higher secondary and undergraduate physics laboratory curriculum of Indian colleges and universities.

2) In case of the physics laboratory training in Indian colleges and universities at the senior secondary and the undergraduate level, there is not much scope for students' self-designed and independent experimental work. The students are guided with a 'cookbook' mode of instruction, in which they rarely develop various types of understanding, experimental skills and abilities related to laboratory training. Thus as described earlier, there is a need for the development of a new instructional strategy in which students will be trained and guided to perform experiments with their own design and method and they may be provided a 'free' atmosphere to work in the physics laboratory.

As said earlier, we believe that method of instruction based on the problem-solving approach will yield better results compared to the traditional cookbook method of instruction for the laboratory training in physics. In this approach, students may be guided and trained to understand and solve experimental problems and thereby develop different related types of understanding, skills and abilities. Thus the second major objective of the research project is to develop a suitable instructional strategy for the delivery of these experimental problems and demonstrations to the students, which may be used for laboratory training in physics at the higher secondary and undergraduate level.

Since these experimental problems and demonstrations and their instructional strategy are primarily aimed at training students in different aspects of experimental physics, we need to consider the initial level of preparation of the students for whom the training would be conducted (i.e. higher secondary and undergraduate students in India.) Such consideration would prevent a monolithic, single step, totally open approach to the experimental problem, but in stead would call for a graded stepwise approach. In fact, even the olympiads, though they are international competitive examinations and not training courses in experimental physics desist from taking a monolithic approach. We therefore, divide each experimental problem into stepwise tasks. The tasks may be of different kinds, some may be procedural, some may involve construction and measurements, and some may be pure reasoning tasks. The tasks are woven in succession so that the whole problem unfolds through them and students following them are guided toward the solution, making definite progress through each step. The tasks and therefore the whole problem are wide and open enough and far from being specifically detailed as in programmed learning. In a sense, they are similar to the tasks in the guided discovery method, yet in every task or in the problem as a whole there is not necessarily a discovery to be made (for the students). Further the guided discovery method has been used basically for conceptual understanding. Our experimental problems are multidimensional in objectives with procedural understanding and experimental skills being as important as conceptual understanding. Also, for conceptual understanding purpose, they are not unitary, i.e. not directed toward a single concept or principle, but directed toward interpretation of many concepts and principles. It may be appropriate to describe our approach as ‘guided problem solving’.

4.2 Description of the project

As explained in the earlier section in this project we developed a set of ten experimental problems from different areas of physics. Accompanying each of these experimental problems there was a demonstration. In the following sections, we discuss the development of these experimental problems and demonstrations. A set of guidelines and other related considerations for the development of both the experimental problems and demonstrations was first formulated. This is presented along with stages of the development and their description. A list of the experimental problems and demonstrations developed is then given. Next, the instructional strategy developed in this project for the innovative experimental problems and demonstrations is described. The next section is devoted to the evaluation aspect of the project. The ten experimental problems and the accompanying demonstrations formed units of a course on experimental physics, which is essentially the basis of evaluation of the whole project. The course was administered to a group of undergraduate physics students. These students were given pre and post tests to note behavioral change, in them, if any, due to the course The detailed design of the course and the evaluation of the project through it are discussed at the end of the chapter.

4.2.1 Development of experimental problems and demonstrations

In this research project, we have designed and developed a set of ten experimental units; each experimental unit consisting of a five to six hours long experimental problem and a thirty minutes long related demonstration which is to be given as a prelude to the experimental problem. These experimental problems are designed to be delivered in a problem mode suitable for the laboratory training in physics at the higher secondary and undergraduate level of Indian colleges and universities. Before discussing different designing and developmental aspects of the experimental problems and demonstrations, in the first place, we need to explain what we mean by the term ‘experimental problem’.

4.2.1.1 What is an experimental problem ?

The terms ‘*problem*’ and ‘*problem solving*’ has no unique definitions, which convey their meaning as stated and understood by different researchers. A *problem* is often seen as a stimulus situation for which there is no ready response and the solution calls for either a novel action or a new integration of available actions.

Now days the term *problem solving* has been applied to many subject areas. In mathematics and also even in science, for instance, it has frequently been applied to cognitive written problems. Recently the problem-solving approach has been evolved as an effective method of teaching and learning science, which includes practical science too. For example investigative practical work can be seen as a type of problem solving activity, since an investigation, which is a systematic practical inquiry into some effect, relation or phenomenon, involves problem-solving tasks.

The experimental problem as the name indicates is a situation, which involves knowledge of problem solving. It is, however, different from a pen and paper type cognitive problems as it is experimental in nature and requires different materials and operations to be used unlike the latter. **An *experimental problem* may thus be seen as an experimental situation in which one cannot see a direct solution and needs to perform operations involving combination of conceptual understanding, procedural understanding, scientific processes and skills to arrive at the desired solution.** In the practical work involving experimental problems, emphasis is given on autonomy in making decisions, planning the experimental stages and integration of knowledge, understanding and skills to derive the desired outcome.

In these experimental problems, the task or the expected final stage may be clearly stated and explained but the detailed instructions, which a student may follow to reach to the desired state are not given. Instead, some starting hints and instructions are given, which may guide the students towards the solution of the problem. In solving an experimental problem the student may have to work on variable based tasks, logical reasoning tasks, measurement focused tasks or the constructional / technological tasks.

In case of this research project, we have designed and developed the experimental problems with an aim to use them for the training in different aspects of experimental physics and not with the purpose of evaluation of the students with respect to different abilities related to experimental physics. An added objective of the project is developing students' problem solving ability and independent working habits.

Our approach has been explained already at the end of section 4.1 on objectives of the project. It is what we call guided problem solving. Students are supplied with all the necessary and relevant material for them to proceed with the 'experimental problem'. The problem is broken into smaller sections and interspersed with questions, answers to which help the students both conceptually and procedurally. (The questions may also serve to an extent for evaluation of a student's performance giving the instructors a valuable feedback.) The sections and the questions properly follow in succession, so as to gradually build up the solution to the problem. The students are guided through them and yet there is enough autonomy to them in making decisions involving various concepts of evidence (for example, variable identification, sample size, relative scale, range and interval etc.) and other procedural aspects of experimental work.

The various considerations and limitations mentioned above have led us to a unique and innovative format of presentation of experiments, in which the innovative experiments developed by us are presented in the form of ‘experimental problems’. In our typical experimental problem, students are given a handout, which consists of 1) the clearly stated objective of the problem 2) the apparatus provided 3) conceptual introduction to the problem 4) brief description of the apparatus and the experimental arrangement 5) the theoretical basis of the problem 6) procedural instructions 7) data required and 8) the related references.

The students are given an instructional sheet explaining the use of different instruments and apparatus. They are not directly guided by an instructor with respect to any experimental or procedural aspect, but the instructor may help them to understand the theoretical basis of the problem. They are provided with all the required and related extra apparatus and are given a free hand to work in the laboratory. The handouts also contain questions on different aspects of the experimental problem, including conceptual and procedural understanding, which students are supposed to answer and report in the answer sheet of the problem. To explain the format of presentation in greater detail we describe a specimen experimental problem and its demonstration in the next chapter and give the related handouts, instruction sheets, details of experimental arrangement, the model answer of the problem and finally, our analysis of the problem with respect to its different learning outcomes.

4.2.1.2 Development of experimental problems

As said earlier, in this research project, we have designed and developed a set of ten experimental problems. Before the developmental work was undertaken, we identified and listed a set of broad guidelines and constraints for the design and the development of the experimental problems. These guidelines are basically clear statements summarizing all the various considerations emerging from Chapters II, III and the earlier sections of this chapter. We have tried our best to follow these guidelines; we do not, however, claim that this has been possible for every experimental problem. Moreover, all the guidelines may not apply to all the experimental problems. Some of them may and may not apply to some experimental problems. These guidelines and considerations are listed below:

1) The experimental problems should be suitable for higher secondary i.e. the +2 level and undergraduate curriculum of Indian colleges and universities and hence they should be designed keeping in mind the initial level of preparation of the +2 level and undergraduate students.

2) The experimental problems are to be carefully designed so that they are to be used for training for the development of different aspects of practical science and not the evaluation of different aspects and abilities.
3) The experimental situation and hence the experiment should be developed and presented in a problem solving mode.
4) The experimental problem should emphasize the development of all three important aspects of physics laboratory training i.e. conceptual understanding, procedural understanding and concepts of evidence and practical skills.
5) Although an experimental problem may involve different types of practical work, its emphasis should be on one particular type. Further, There should always be an investigative component in the experimental problem, even if the type of practical work emphasized in it is not investigation.
6) Each experimental problem should be concept based, based on either a substantive concept or a concept of evidence.
7) The experimental problems may involve the combination and application of concepts from different branches of physics.
8) Each experimental problem should be innovative with respect to either the experimental situation, the conceptual content, experimental design or the techniques used.
9) An experimental problem should aim at a) development of higher-level cognitive abilities like designing, predicting, observing, classifying, application, synthesis, interpreting, inferring and problem solving. b) introduction and development of expertise in simple and advanced experimental methods, scientific processes, techniques and skills used in experimental physics. c) direct or indirect development of affective abilities like interest, curiosity, creativity and open-mindedness. d) cultivation of scientific attitude and independent working habits.
10) The designed development of an experimental problem should proceed with identification of its learning outcomes with respect to concepts, cognitive abilities, skills and techniques to be learnt by the students and these learning outcomes should be emphasized through it.
11) Each experimental problem should be a collection of smaller sections, with each section devoted to a specific task or goal to accomplish. Each section may have different focus and learning outcome.

12) Each experimental problem should be designed so that it fits into the format of presentation of the problems as described earlier.
13) The apparatus and the instruments used in the experimental set up should be as far as possible simple and easy to operate. It should not be confusing and scaring to the students.
14) The experimental arrangement and the measuring instruments used should be so selected, designed or built that they are sturdy and work satisfactorily for a long time giving reliable results with good repeatability and accuracy.
15) The experimental arrangement for the experimental problem should be simple in construction, easily duplicable or reproducible and also repairable.

To these 15 development guidelines we added one constraining guideline:

16) Each experimental problem should be so devised that a typical Indian undergraduate student should take about and not much longer than six hours to solve the problem and come out with the desired outcomes.

One more specific constraint due to our laboratory facilities and our preference was that although guideline (7) says that the experimental problems developed should involve substantive concepts from various areas of physics and should be representative of +2 level and undergraduate physics, our development was confined to mechanics, optics, electricity and magnetism only. Though these topics are the main conceptual and therefore core areas of +2 level and undergraduate physics, two important areas, namely, heat and modern physics did get left out from the development.

After the delineation of above-mentioned guidelines for the development of experimental problems, we actually undertook the design and development work. The experimental problems were designed and developed not in a definite order and certainly not in the order in which they are presented in this thesis. Often the development of two or three experimental problems took place simultaneously.

The design and development went through the following main stages.

1) **Identification of the experimental situation**
2) **Developing or understanding the theoretical basis of the experimental situation**
3) **Designing the experimental problem**

4) **Identification of the required tools, devices, instruments and the experimental arrangement**
5) **Design and fabrication of the apparatus and the experimental setup**
6) **Assembling the complete experimental setup**
7) **Checking for the correctness of the experimental problem and obtaining the solution of the problem with required data and results**
8) **Developing and preparing the supporting written material**

The order of the stages described above was not the exact temporal order in which they were carried out. Many a time, we had to go back to an earlier stage and reconsider and redesign the situation, the problem or the apparatus for obtaining satisfactory results and desired learning outcomes. We also had to modify the experimental problems and the experimental arrangement after a trial given to some of our colleagues and after discussions with them about various aspects and learning outcomes of the problems.

We describe below in detail the above-mentioned stages involved in the design and development of the experimental problems.

1) Identification of the experimental situation

The identification of an appropriate experimental situation started with our survey of articles published in journals of physics and physics education. We have extensively used the articles published in *American Journal of Physics*. Also, we have used the question papers set at the International and National Physics Olympiads for the past few years published by various agencies. We also took the help of some recent and some not-so-recent but standard books on mechanics, optics, electricity and magnetism. We also consulted many books on experimental physics, laboratory experiments, data analysis and modern measuring techniques and instruments. In case of each experimental problem we have listed a few of these references at the end of its students' handout. In some cases the experimental situation originated while we were trying to understand a modern technique or the use and principle of working of a device or an instrument. In some cases, the application of simple theory to novel and real life situations led us to design the experimental situations. In case of some experimental problems, the experimental situation is a result of combination of a theoretical idea and its thorough analysis with an attempt to verify it experimentally.

2) Developing or understanding the theoretical basis of the experimental situation

After identifying the experimental situation, the next important stage of development of an experimental problem is to understand or develop the theoretical basis of the experimental situation. In this case we took help from some old and standard books on mechanics, optics, electricity and magnetism. In many cases we worked out the theoretical explanation of the phenomenon or the effect to formulate a theoretical basis of the problem. For understanding the theoretical basis, many a time we combined and applied our knowledge and understanding of different concepts, principles and laws from different branches of physics.

In understanding the theoretical basis, we first theoretically analyze the experimental situation and then derive and construct the necessary expressions to explain the experimental situation with respect to different parameters involved. Many a time, this extensive study of relationships and interdependence of different parameters helped us design the problem and also the questions to be asked in the students' handouts.

3) Designing the experimental problem

After identifying the experimental situation and understanding the related theory, we analyzed the situation with respect to different learning objectives and other aspects, which should be emphasized. This usually started our design of the problem. As described earlier, each experimental problem is presented as a collection of smaller sections; each section may have different learning outcomes and different foci and may also involve different types of practical work. With such considerations, we designed different sections or parts of the problems. In first one or two parts, students are given preliminary tasks aiming at the introduction to the apparatus and the problem in general. The different parts of the experimental problems are designed carefully with a clear understanding of what concepts, methods, skills or other abilities students are expected to learn or develop through each part. We also took care of what instructions on procedural aspects be provided to the students and what kind of questions be asked so that development of procedural understanding and the understanding of concepts of evidence is adequately emphasized.

In designing an experimental problem, considerations such as what kind of instruments and apparatus is needed, how much space is required, what risk factors are involved, what practical problems one may have to face affecting the feasibility of the problem, availability of the measuring and recording instruments etc. These factors some time made us change or modify one or more sections of the problem and thus redesign the experimental problem. Before the final design of the problem was made, we analyzed the problem with respect to different learning objectives, aspects and practical abilities which students are supposed to develop through the given experimental problem.

4) Identification of the required tools, devices, instruments and the experimental arrangement

After designing the experimental problem, next important step is to identify the required tools, devices, measuring instruments and the experimental arrangement in general. This is an important stage of the development of an experimental problem, since at this stage one considers what measurements are involved, which experimental skills are to be stressed, how sophisticated the setup should be, what should be the level of accuracy and reliability of the measurements, how the overall setup will look, what instruments are required etc. After identification of the required tools, devices, instruments, and the experimental arrangement we worked out their detailed specifications. We tried our best to follow the guidelines, which were stated earlier, although within practical limitations. As far as possible, we used a wide range of tools and instruments and even when we had to use routine instruments, we tried to do so in an innovative manner.

5) Design and fabrication of the apparatus and the experimental setup

Once the required tools, devices and instruments were identified, the next step was to design and fabricate them. In every experimental problem we primarily tried to use the standard instruments, which are easily available in college physics laboratories. Sometimes we had to modify them to some extent in order to suit our purpose. In every case, however, invariably one or more of the instruments had to be designed and fabricated by us. In most cases, the basic experimental arrangement is new and designed by us. We followed the guidelines discussed earlier in designing the experimental arrangement. We tried to make the apparatus and the experimental setup as sturdy as possible. We took every care with respect to the reliability, longer operating life, accuracy, precision, repeatability etc of the apparatus and the setups. Thus the design of all our setups was completely carried out by the researcher. The TIFR workshop facility was used for some necessary fabrication. We have also developed a rudimentary and basic facility for fabricating simple experimental setups at the physics developmental laboratory of Homi Bhabha Centre for Science Education (HBCSE). In fact, a majority of the setups and apparatus were fabricated by us at the physics laboratory. We also designed and fabricated some devices and measuring instruments at this laboratory. These include, the time measuring units (digital timers), photo-detectors, the diffractometer arrangement, a mechanical vibrator assembly, a goniometer arrangement for mounting the syringe etc. Also, the necessary modification and fabrication of some standard instruments or devices was carried out at the physics laboratory. On the whole, this experience has given us considerable confidence and expertise in the area of development and fabrication of experimental set-ups, apparata and instruments.

6) Assembling the complete experimental setup

After designing and fabrication of apparata and the experimental arrangement, the next obvious stage is to assemble them to form an actual complete working experimental setup. Here the most important aspect was to check and study the compatibility and matching of different apparata with respect to their relative accuracy, size, adjustments, combined use and control, impedances in general, reliability, relative levels of inputs and outputs etc. In some cases, we observed that, the instrument was not giving satisfactory results when combined with other instruments. In such cases we had to change some specifications or the arrangement of the instruments and incorporate the necessary change in the experimental arrangement. In some cases sophistication was added to increase the accuracy or reliability of the results; sometimes we even had to redesign the experimental arrangement. Thus, assembling the different apparatus was not as simple as it is generally seen, since in our case most of the instruments and apparatus were and had to be designed by us, and also the assembling involved checking of the working and suitability of each and every part of the set-up required for the experimental problem.

7) Checking for the correctness of the experimental problem and obtaining the solution of the problem with required data and results

After assembling satisfactorily the different apparata and the experimental setup and checking it for working, the next stage is to check the correctness of the experimental problems. For this we actually followed the procedural instructions designed for an experimental problem and performed the necessary measurements and thereby collected the required data step by step, analyzed it using graphs and mathematical manipulations and derived results. In case of few experimental problems, we had to go back and modify the experimental problem and thereafter the setup, after understanding a practical problem with respect to the adjustments and control, or the reliability of the measurements etc. In most of the cases, the results and the data obtained were satisfactory and hence needed no modifications. Thus, checking for the correctness of the experimental problems and obtaining the solution of the problem with data and results was carried out by us. In many cases, this was repeated by us or our colleagues and students to reconfirm the results of the experimental problem. Thus, we have at least two or three sets of data and results for each experimental problem, which were obtained in normal conditions by different people with different experimental abilities. In case of few experimental problems, the discussion that we had with colleagues, teachers and students gave us new ideas, helped us to modify the problem and even add new aspects to the problems.

Thus, going through all the above-discussed stages of development, we designed and developed a set of ten experimental problems.

8) Developing and preparing the supporting written material

This may be said to be the final stage of the development. As described earlier, students are supposed to be given a 'handout' and instruction sheet for every problem. We have also prepared the model answer for each problem, which was useful to the instructors during the time when the students were solving the problems and may be given to the students after solving the problem. The students' handout consists of a statement of the objective of the problem, a list of apparatus provided, a brief introduction to the problem, the description of the apparatus and experimental arrangement, basic theory of the experimental problem, procedural instructions, necessary data and a list of references.

Procedural instructions are carefully designed covering various aspects for the different parts of the problem. Also, a number of questions are inserted as students work. These are mainly based on procedural and conceptual understanding and other related aspects. The students are expected not to proceed to the next part of the problem, unless they answer these questions on a given section. The instruction sheet essentially consists of information on use and specifications of different apparata, their adjustments and controls and the necessary data and values of constants and other parameters. Special care was exercised so that no direct instruction on appropriate concepts of evidence was provided to the students. This was with a definite objective of making them aware and inculcating in them the required aspect of procedural understanding. A model answer essentially consisted of the report of the required laboratory work and the solution to the problem, with typical measurements and results, presented carefully and with all the precautions, which the students are supposed to take. The model answer also included the answers to different questions asked in the handout. Thus the preparation of the written material was a crucial and important stage of the development of the experimental problems.

As said earlier, a set of ten experimental problems suitable for the physics laboratory training at the +2 and undergraduate level has been developed under the project. These problems are based on different substantive concepts from mechanics, optics, electricity and magnetism. They have been planned so that a typical physics +2 level or undergraduate student should not take more than six hours to solve the problem and derive the results.

The next chapter describes in detail one specimen of an experimental problem and in brief the other nine experimental problems. Also the students' handout of all these nine experimental problems are given in the **Appendix A** of this thesis.

4.2.1.3 Development of demonstrations

As said earlier, each of the ten experimental problems developed by us is coupled with a specific demonstration, which is a complimentary prelude to the corresponding experimental problem. These demonstrations are based either on the key concept of the corresponding experimental problem or on the most crucial factor of the experimental technique, instrumentation used or the experimental arrangement. The demonstrations are aimed at and designed for helping and guiding students to handle the experimental problems more efficiently.

In case of the development of demonstrations also we began with identification of guidelines, which we tried our best to follow during the development. We however, do not and cannot claim that each demonstration has been designed strictly in accordance with these guidelines. This has happened due to some limiting considerations and practical hurdles, while the developmental work was undertaken. The list of the guidelines for the development of the demonstrations runs as follows:

1) Each demonstration should be designed so that a time span of thirty minutes should be sufficient for an instructor to demonstrate and discuss the designed activities and questions.
2) Each demonstration should be based either on the key concept of the corresponding experimental problem or on the use of the tools / measuring instruments / experimental techniques / complete experimental arrangement.
3) The demonstration may involve the application and illustration of the key concept using a related situation, which may mot be necessarily be from the given experimental problem.
4) Each demonstration may involve one or more types of practical work, but will basically be of illustration and observation type.
5) The demonstration should be a collection of simple activities, questions and related discussions and should be presented in an interactive mode.
6) Each demonstration should be neat and attractive and have such visual impact that students are drawn towards it.
7) Each demonstration should be so simple to operate and present and should have such conditions of smooth flow of ideas, activities and discussions, that replacement of a particular instructor or demonstrator should not affect its effectiveness.
8) Each demonstration should stimulate thinking in students and help them develop different cognitive abilities like keen observation, application, synthesis, interpretation and inferring and affective abilities like creativity, curiosity, interest, open-mindedness and scientific attitude.
9) The design and development of each demonstration should be preceded with the identification of its learning outcomes with respect to substantive concepts, cognitive abilities, skills and techniques to be learnt by the students and these learning outcomes should be emphasized through it.
10) The experimental arrangement should be easily duplicable or reproducible and even repairable.
11) The experimental arrangement and the measuring instruments used should be so selected or designed and built that they are sturdy and work satisfactorily for a long time giving reliable results with good repeatability and accuracy.

Identification of these guidelines was followed by the actual development of the demonstrations. Development of a particular demonstration was done only after the complete development of the corresponding experimental problem. The design and development of a demonstration involves the following main stages.

1) **Identifying the objective of the demonstration**
2) **Designing the demonstration**
3) **Identification of the required tools, devices, instruments and the experimental arrangement**
4) **Design and fabrication of the apparatus and the experimental set-up**
5) **Assembling and checking the complete set-up**
6) **Checking the correctness of the demonstration and recording the relevant data**
7) **Developing and preparing the instructors' handout for each demonstration**

As in the case of development of the experimental problems here, too, the stages described are not according to a strict temporal order. Many a time we had to go back to earlier stages and redesign the demonstration or modify the desired learning outcomes.

We now describe in detail, the above-mentioned stages involved in the design and development of the set of ten demonstrations accompanying the experimental problems.

1) Identifying the objective of the demonstrations

The demonstrations are to be designed to be complementary preludes to the corresponding experimental problems. They are expected to help and guide students to the main aspects of the experimental problem and thus to handle the experimental problem more efficiently. They illustrate either the key concept of the experimental problem, the experimental technique used or the measuring instruments or the experimental arrangement, which students are supposed to use in the corresponding experimental problem. Thus identification of what the demonstration is supposed to introduce, explain and illustrate is the most important aspect of the development. We started the development work by identifying the different objectives of the demonstration. We found that in a few cases the conceptual understanding involved in the experimental problem was complex; at times the concepts were simple, but they were applied to a novel situation. In some cases, we found, the experimental techniques, methods or the instruments which students were supposed to use in the experimental problems, were 'new' to them and were not very simple to understand. Thus in case of each experimental problem we were able to identify the major aspects and objectives of the corresponding demonstration, which the demonstration was supposed to satisfactorily achieve and deliver to the students.

2) Designing the demonstration

Once the objectives of the demonstration were clearly identified, we started working on the designing of the demonstration. This essentially involves identification of different possible designs of the demonstration and understanding or developing their theoretical basis. For this purpose we have used articles published in different journals of physics and physics education especially, journals like *American Journal of Physics*, or *Physics Education*. We also took help from some books on mechanics optics, electricity, magnetism and some other related field. Using all these sources of information and ideas, we broadly identified different possible designs of the demonstration. The next important stage was to understand or develop the necessary theoretical basis of the above identified different designs of the demonstration. For this, we took help of some standard books on different branches of physics. For most of the demonstration we used the same references as used for the corresponding experimental problem.

After understanding the theoretical basis of different designs of the demonstration, we analyzed them with respect to the desired objectives, necessary requirements and the guidelines described earlier and only then the demonstration was supposed to be finally designed. Each demonstration involves collection of simple activities, questions and related discussion and is presented in interactive mode. We tried our best to follow the guidelines identified earlier for the development of demonstrations, but we do not claim that each demonstration strictly follows each of the guidelines.

3) Identification of the required tools, devices, instruments and the experimental arrangement

After designing the demonstration the next important step is to identify the required tools, devices, instruments and the general experimental arrangement. In identifying the required experimental set-up, we chose the apparatus, which was simple to understand, easy to operate, easily duplicable and / or repairable and also attractive to look at. Also the experimental set-up should work satisfactorily for a longtime and give reliable results with good repeatability and accuracy. We also took care of other related aspects such as, what measurements are involved, what kind of sophistication is necessary etc. All such considerations were applied to identify the required tools, devices, instruments and the experimental arrangement in case of each of the ten demonstrations.

4) Design and fabrication of the apparatus and the experimental set-up

Once the required tools, devices, instruments and the demonstration set-up were identified, the next step was to design and fabricate them. In case of most of the demonstrations the experimental set-up necessary for the demonstration was designed and fabricated by us. We first identified the detailed specifications of the different instruments and apparatus. We followed the guidelines as described earlier for designing the experimental set-ups for the demonstrations. The experimental set-ups were as sturdy as possible so that even on rough use, it should not be easily damaged. We took utmost care with respect to reliability, longer operating life, accuracy, precision, repeatability etc. For the fabrication of some the set-ups, we have used the T.I.F.R. workshop facility, but the designing was completely done by the researcher. In case of most other set-ups we fabricated the apparatus at the physics laboratory of H.B.C.S.E. In case of few demonstrations, where the tools, instruments, experimental or measuring technique or the experimental arrangement, was supposed to be introduced to the students through the demonstration, we have used either the same apparatus as used in the corresponding experimental problem or modified it a minor way to suit our purpose.

5) Assembling and checking the complete set-up

After fabricating the different apparatus required for a demonstration, the next obvious stage is to assemble the complete arrangement of the demonstration. In this, it was most important to check and study the compatibility and matching of different apparatus with respect to adjustments, combined use, required control, impedances in general, reliability, accuracy size etc. We assembled each instrument and apparatus to get the required set-up for the demonstration and checked the working of each combination with other instruments and devices. In some cases we had to change the design or alignment to get satisfactory results, after tackling an unseen practical problem or an unexpected effect of the combined use of different apparatus.

6) Checking the correctness of the demonstration and recording the relevant data

After assembling satisfactorily the different apparatus and checking the working of different instruments, the next stage is to check the correctness of the designed demonstration. For this, we checked the demonstration as designed by us to be given to the students, through activities, questions and discussion. We took help of our colleagues and students for this purpose. We carried out the necessary adjustments and alignments, performed the measurements and collected required data. In case of most of the demonstration the results and the data obtained were satisfactory. Thus we checked the correctness of the demonstration and also thereby recorded the relevant data.

7) Developing and preparing the instructors' handout for each demonstration

Developing and preparing the instructors' handout for all the ten demonstrations was the final but the most important and difficult stage involved in the development of the demonstrations. As described earlier our emphasis was on replicability and not on specific skills of demonstration on the part of the instructor. We took care that change of instructor would minimally change the effectiveness of the demonstration.

In an instructors' handout, we give, along with the necessary introduction, the introductory theoretical basis of the demonstration, the apparatus and data required and description of the demonstration. The instructors are supposed to initially give a brief introduction of the demonstration to the students along with certain details of apparatus and the related data. He / she then is supposed to strictly follow the instructions and perform activities, ask questions, try to get them answered from the students or explain the answers as given in the description of the demonstration. The related references should be made available to the instructors, which he / she may use for understanding the demonstration. The instructors' handouts for all the ten demonstrations were thus carefully prepared.

We expect that for any of the ten demonstrations, an instructor should not take on the average more than thirty minutes to demonstrate it and have fairly fruitful and successful discussion with students. We describe all the demonstrations in next chapter. One specimen demonstration has been presented in detail and the other nine demonstrations have been discussed briefly. The instructors' handouts for all these nine demonstrations have been given in the **Appendix B** of this thesis.

4.2.1.4 List of experimental problems and demonstrations

Experimental Problem No. 1

I) To study the phenomenon of electromagnetic damping of a rotating aluminium disc caused by induced eddy currents set-up within the metal disc due to its rotation (under the influence of falling weights) in a magnetic field (localised to a small portion of the disc).

II) To study the variation of the terminal velocity (of the falling weights) with the mass attached.

III) To determine the ratio of magnetic pole strength of two pairs of identical magnets and estimate the frictional torque acting on the disc at the supports.

Demonstration No. 1

Demonstration on the phenomenon of electromagnetic damping in which the damping of the motion of falling magnetic cylinders through hollow cylindrical pipes made of aluminium, brass and PVC is demonstrated.

Experimental Problem No. 2

A) To determine the spring constant and the mass correction factor for a soft massive spring by static method (i.e. Equilibrium extension method.)

B) For a soft massive spring, to determine,

  i) The spring constant and the mass correction factor by dynamic method (i.e. time period of oscillations method).

  ii) Frequency of oscillations of the spring for the zero attached mass.

C) To study the longitudinal stationary waves on a soft massive spring and determination of the fundamental frequency of oscillations of the spring (with both the ends fixed).

Demonstration No. 2

Demonstration of the stationary waves in transverse mode and study of the dependence of the number of harmonics (loops) on the tension and the length of the string.

Experimental Problem No. 3

A) Study of a tunable sharp filter circuit constructed using three operational amplifiers (Op-Amp).

B) To Fourier analyze a square waveform using a sharp Op-Amp filter tuned at a fixed frequency.

C) To Fourier analyze a triangular waveform using a sharp Op-Amp filter tuned at a fixed frequency.

Demonstration No. 3

Demonstration on the use and working of operational amplifier (Op-Amp) as a unity gain inverter and as an integrator.

Experimental Problem No. 4

To study two different configurations of a simple magnetic circuit.

A) A two loop magnetic circuit in which *two coils* are wound on the *central leg* of an ordinary laminated iron core.

B) A two loop magnetic circuit, in which *three coils* are wound on *three legs* of an ordinary laminated iron core.

Demonstration No. 4

Demonstration on a simple configuration of a magnetic circuit to explain how the changing magnetic flux linked with a coil gives rise to an induced emf and thus introduce and illustrate concepts like magnetic flux, electromotive force, magnetic circuit and reflected impedance.

Experimental Problem No. 5

A) To study the variation of the time period of oscillations of a physical pendulum with the position of the axis of rotation (with respect to the center of mass of the pendulum).

B) To determine the local value of the acceleration due to gravity *g*.

C) To determine the magnetic moment of a small magnet mounted on a pendulum oscillating in a magnetic field by measuring effect of the field on the time period of oscillations of the pendulum.

Demonstration No. 5

Demonstration on a physical pendulum to explain 1) the dependence of its time period of oscillation on the distance between the point of suspension and the center of mass of the pendulum. 2) the effect of external magnetic field on the time period of oscillation of magnetic physical pendulum.

Experimental Problem No. 6

I) To study the motion of a spherical ball rolling on a plastic channel inclined at an angle by analyzing its position versus time behavior and to determine its acceleration.

II) To determine the acceleration due to gravity *g* by studying the motion of a freely falling spherical ball.

Demonstration No. 6

Demonstration on the use and the principle of operation of a digital timer for the measurement of time interval between the two events along with the explanation of the mechanism of sensing the passing of a ball through the photo-detector and the concepts like accuracy, precision and calibration.

Experimental Problem No. 7

A) To study the electrostatic field and the equipotential curves between the two conducting parallel plates when a known potential difference is applied between them.

B) To study the equipotential curves for another simple configuration consisting of a metallic L-shaped electrode and a point electrode.

C) To study the equipotential curves for an electrode geometry consisting of two concentric circles and study the uniqueness theorem.

D) To study the method of images using the most basic plate and point geometry.

Demonstration No.7

Demonstration on the introduction and explanation of the experimental arrangement and the method or technique of plotting the equipotential curves using an electrolytic tank.

Experimental Problem No. 8

I) To determine the unknown transmission axes of the polarizer and the analyzer using a polarizer of known transmission axis.

II) To study the relationship between the intensity of light incident on the photo-detector and its output current (using the law of Malus).

III) To study the reflection of polarized light (with the plane of polarization parallel and perpendicular to the plane of incidence) from the surface of a transparent prism.

  a) To study the variation of the reflectivity of the surface of the prism, with the angle of incidence for the plane polarized light with its plane of polarization parallel to the plane of incidence.

  b) To determine the refractive index of the material of the prism by using the Brewster's law.

  c) To study the variation of the reflectively of the surface of the prism, with the angle of incidence for the plane polarized light with its plane of polarization perpendicular to the plane of incidence.

Demonstration No. 8

Demonstration on 1) the use of different instruments and optical components and related precautions and 2) the polarization of light emitted by a laser source after a reflection from the surface of transparent prism.

Experimental Problem No. 9

I) To study the refraction, internal reflection and dispersion of light due to a water drop, which gives rise to different order rainbows.

II) To determine the refractive index of a given liquid by studying different order rainbows formed due to a drop of the given liquid.

Demonstration No. 9

Demonstration on the method of obtaining the different order rainbows due to a water drop.

Experimental Problem No. 10

I) To determine the wavelength l of the light emitted by a laser source by studying the diffraction of light due to plane diffraction gratings.

II) To determine the size of the circular aperture by studying the diffraction due to a precision circular aperture.

III) To study the two-dimensional diffraction due to two one dimensional plain diffraction gratings inclined at an angle and determination of grating spacings d_1 and d_2 of the gratings and the angle of inclination between the two.

Demonstration No. 10

Demonstration on the diffraction of light emitted by a laser source using a single slit and a plane diffraction grating.

4.2.2 Development of suitable instructional strategy

As identified and discussed in earlier chapters, along with the development of experimental problems and demonstrations in physics, there is a need to develop a suitable instructional strategy for them. The strategy should be aimed at development of 1) Procedural understanding and understanding of concepts of evidence as well as conceptual understanding and practical skills; 2) Experimental problem-solving abilities and independent working habits; 3) Higher-level cognitive abilities like designing, predicting, observing, classifying, application, synthesis, interpreting and inferring; 4) Various attitudinal aspects and affective abilities like, creativity, curiosity, interest and open-mindedness.

In this research project we have also designed and developed an instructional strategy for the delivery to the students of the experiments developed. In this strategy aimed as above, we present the experiments in the form of experimental problems. We have used the ‘guided problem-solving’ approach and developed an innovative format of presentation of experiments. We give a related demonstration as a complementary prelude to the corresponding experimental problem. We now describe the different aspects of the instructional strategy.

4.2.2.1 Features of the instructional strategy

1) After clearly identifying, the different aspects that should be emphasized during the laboratory training in physics and the abilities and understanding that students are expected to develop through the laboratory training, we roughly planned the instructional strategy. We also developed a model of how students are needed to work in the laboratory so that the expected development in students can be efficiently brought out. We felt that there is a need of ‘free’ laboratory atmosphere in which students will be encouraged to carry out self-designed and independent experimental work. Here the ‘free’ laboratory atmosphere does not refer to an open ended laboratory or an exploratory type of experimental work where in students are <u>not</u> told about the expected final outcome of the experimental activity and are expected to

build new knowledge and understanding on their own by observing and analysis the experimental activities and using the reacquired knowledge.

Our idea of ‘free’ laboratory atmosphere is that the students are told about the final outcome of each part of experimental work, but they are given autonomy with respect to, choice of variables, choice of range of values of variables, range of observations, use of instruments and experimental techniques (in some cases), method of data handling and analysis etc. Thus in this case the students are guided to think and take decisions related to the solution of the each small experimental stage or part of the problem. For example, in an experimental problem if students are asked to study the relation of incident intensity to the output current of a photodetector, then they may be given a starting instruction on the possible use of inverse square law for establishing linearity, they may be asked to identify the necessary apparatus with their detailed specification, they may be given some hints for the experimental arrangement, and asked to identify the dependent, independent and control variables, construct a fair test, identify the sample size, understand the types of the variables involved and thus in short design the detailed procedure. Then they may be asked to choose sensible values of variables or parameters, proper range and interval between different values of these parameters. They may then be asked to record the desired data and analyze the data using tables and graphs to derive meaningful and expected results.

In this strategy, the important aspect is the training of students in experimental physics and not the evaluation of their performance and capability. In this strategy, the students are guided through procedural instructions to think of and design their own method, to carryout the measurement, to analyze the data and thus to solve the given experimental problem.

2) In this strategy, we use the problem-solving approach and present the experiment as an experimental problem. As discussed earlier each experimental problem is a collection of small problems or sections. In each small problem, the students are given simple tasks. They thus solve the experimental problem in graded stages. Each of the small problems may have a different focus; each may involve different type of practical work and may have different learning outcomes.

3) No direct guidance with respect to procedural understanding and concepts of evidence is provided by the instructor to help students in solving the experimental

problem. Instead, a related demonstration is given as a complementary prelude to each experimental problem. This demonstration is carefully designed to introduce and illustrate, either, the key concepts involved in the problem, the experimental method or technique or the apparatus or the experimental arrangement. The demonstration is given as a collection of activities, questions and their discussion. The demonstration is presented in an interactive manner and the interaction between the students and the instructor is triggered through questions. Thus along with the ten experimental problems we have developed a set of ten related demonstrations which are to be given as a prelude before the students are given the corresponding experimental problem. These demonstrations help students develop different higher-level cognitive abilities like, predicting, observing, application, synthesis, interpreting and inferring. They also help students to develop different affective abilities like creativity, curiosity, interest, open-mindedness and scientific attitude. Thus in this strategy, once the demonstration is over, during the work on the experimental problem, no direct procedural guidance is given to the students by the instructor.

4) The strategy is flexible with respect to the size of the group of students. We believe that working in groups has its own advantages and disadvantages. In case of the experimental science we believe that cooperative learning helps students to effectively develop different aspects of and abilities related to laboratory training. In this strategy, we suggest that the students should work in pairs in the laboratory to solve a given experimental problem. We believe that if the experimental problems are given to two students who are expected to work together on the same experimental setup, but produce separate reports, then the effectiveness of the training will be maximum. We may give the same experimental problem to even three students who are asked to work on the same experimental set-up but produce the reports separately. The measurements and the data may be the same, but every other else students are expected to carryout and report separately.

5) In this strategy, students are initially given an introductory demonstration by the instructor in separate groups of two for first thirty minutes and then are expected to start solving the experimental problem. Students are given the maximum of six hours for solving each experimental problem. Each experimental problem is carefully

designed so that a typical undergraduate student should not take more than six hours for satisfactorily solving the experimental problem. Thus in this strategy first the demonstration is given for thirty minutes and then six hours are given for students to solve the experimental problem.

6) In this strategy, students are individually given a carefully designed handout for each experimental problem, the corresponding instruction sheet and the answer sheet. The students' handout gives the necessary information on 1) Objective of the problem 2) Apparatus provided 3) Necessary warnings or precautions 4) The conceptual introduction to the problem 5) Description of the apparatus and the experimental arrangement 6) Theoretical basis of the problem 7) Procedural instructions 8) Required data and 9) References. These students' handout also contains some carefully designed questions, mostly on the different aspects of procedural understanding and the understanding of concepts of evidences. Sometimes the questions are also designed to make students think on various substantive concepts involved and use them in a new situation to explain or predict an observation or an effect. Thus the students handout for each experimental problem is carefully designed so that students should be properly guided to develop in them procedural understanding, concepts of evidences, practical skills, and the conceptual understanding. We have also taken the necessary precautions and measures in designing the handouts so that students should also develop different higher level cognitive abilities like designing predicting observing, classifying, application, synthesis, interpreting and inferring.

Along with the handout for the problems students are also given an instruction sheet prepared for that problem. This instruction sheet gives information on the use of different instruments and apparatus, provides the necessary data and tables and also gives the necessary safety instructions and precautions. In our strategy, if students demand or need, the instructor may provide help about the use of a new instrument. The instructor may even help students to understand the principle of working, method of operation, limitations and specifications of different instruments. The users' manual of various instruments published by respective manufacturers may be provided to the students.

7) In this strategy, the necessary reference material and books are made available to the students in the laboratory to be used during the practical work. Students may use these sources of information to understand the theoretical basis of the experimental problems, use, method of operation and principle of working of instruments and sometimes even to develop procedural understanding by studying a similar experimental situation or a demonstration. Students may be allowed to use these reference material and books to answer the questions asked in the handout.

8) In this strategy, students are expected to record and report on every procedural step they adopt during the experimental work, the readings and observations, the method and the detailed data analysis, final results and inferences, in the answer sheet provided to them. Students are not observed by anyone, while they work on experimental problems and hence may not be evaluated on the basis of direct observations by the instructor. Instead, his / her performance is only verified or evaluated by the report of his / her work produced in the answer sheet. Thus, this instructional strategy reduces the instructors intervention into students work and encourages the students self designed independent experimental work.

4.2.2.2 Instructional strategy for experimental problems

As described earlier, in the strategy of instruction as develop by us, we present the experiment as an experimental problem and use the ‘guided problem solving’ approach for the method of delivery. In this strategy students are not offered any direct help from the instructor with respect to procedural aspects instead the instructor plays a role of a silent observer. As an introduction to the experimental problem a related demonstration is given as a complementary prelude. Students are given sufficient amount of time i.e. six hours to solve the given experimental problem. They are given a handout for the problem, the instruction sheet and the answer sheet. Two students are given the same experimental problem and are expected to work on the same set-up. They may use the same set of data but the data analysis (including the plotting of graphs) and every other thing they are expected to do individually and report it separately on their answer sheet. Instructors may help students to understand the use of instruments or even the theoretical basis of the problem. Students may be provided with the necessary books, references, manuals and data sheets.

Thus after the demonstration, students are expected to read the handout for the problem and clearly understand the objectives of the problem. They are then expected to know and understand the use of different apparatus and the related warnings or precautions. The students are given a brief conceptual introduction to the problem through the handout. They are also given the necessary description of apparatus and the experimental arrangement. The necessary theoretical basis is explained to the students through these handouts. We give the necessary figures, schematics and the derivations of the formulas and relationships. This theoretical basis is given in detail since we want students to understand the required details of theoretical basis of the experimental problem. As said earlier the instructor may help students to understand the theoretical basis of the problem. The students are then given the introductory procedural instructions. These procedural instructions are carefully given through the handout with an intension to 'guide' students but only with respect to a general method of handling the problem. These instructions are carefully designed so that they should trigger and develop thinking about correct procedures, the procedural understanding and the understanding of concepts of evidence related to design, measurement and data handling.

Students are expected to broadly follow these instructions, design an appropriate method on their own, carryout the necessary measurements, record the data, carryout the necessary analysis of the recorded data and derive the required results and inferences. Students are given 'open' instructions, which indirectly guide them on the above mentioned aspects of design, measurement and data handling. These 'open' instructions are not like 'cookbook' type of procedural instructions in which students are "spoon feeded" directly with actual procedural stages without any scope for students independent thinking and hence designing. What we mean by 'open' instructions is that, these instructions guide the students to start with and make them think on various aspects of experimentation. These instructions guide students' thinking but offer a room for their independent thinking, designing and planning of actual procedures. These instructions are like, "you may have to use law of Malus, identify the independent, dependent and control variables, vary the parameter *X* in convenient and appropriate steps and study its effect on parameter *Y*, plot an appropriate graph to determine *Z*, record the necessary data to study the inter-dependence of *X* and *Y*, determine the value of *X* from graph."

Thus in such instructions students are guided but they are required to think and work independently and actually design the given experimental stage. For example in the instruction "determine the value of *X* from graph", students are guided and informed that they are expected to plot the graph and determine the value of parameter *X*, but they are not given any information on different finer stages like, which are independent, dependent and control variables, what should be the scale of the graph, how to determine the value of parameter *X*, and so on. Thus through this simple instruction students are made to think about all such finer stages and appropriately design the detailed procedural stages of the problem.

In some cases, we give some direct procedural instruction, but whenever we give such a direct instruction, we ask students a related question. These questions are carefully designed to develop thinking about, the understanding of and the importance of the given instruction. We use the method of asking questions even to develop different abilities related to data analysis, measurements and adjustments. We ask questions on different aspects like use of a graphical method of data structuring, interpretation and analysis, choice of scale, choice of axis, estimation of errors, understanding of the sources of errors, need and importance of various finer adjustments and control of apparatus, application of conceptual understanding to a new situation etc. These questions serve the purpose of developing the understanding of concepts of evidence and hence procedural understanding, methods and techniques used in experimental science.

Thus students are not given any direct instruction by the instructor but they are guided through the handout. They are expected to record the observations, perform the necessary data analysis, draw required conclusions and derive the results, answer the questions and whenever necessary give procedural details in the answer sheet. The students' answer sheet is treated as the only record of their laboratory work and their solution of the problem. This aspect of the strategy makes it more useful to be applied for a larger group of students since it requires less involvement on part of the instructor.

Thus in this strategy students are provided a 'free' atmosphere with respect to finer procedural stages but still guided with respect to the approach or a possible method of solving the problem. Each experimental problem is given as a collection of simple smaller experimental stages, which are interdependent or hierarchical in time. Students are expected to work independently with a minimum of direct guidance from the instructor but, with guidance provided in graded stages through the handout.

4.2.2.3 Instructional strategy for demonstrations

As described earlier in the instructional strategy as developed by us in this research project, a demonstration, which is related to the experimental problem is to be given as introductory prelude by the instructor for the first thirty minutes of laboratory work. This demonstration is to be separately given for a pair of students for each experimental problem and on all laboratory sessions. They are delivered in an interactive manner. These demonstrations are designed to help and guide students to solve the given experimental problem more efficiently and are designed around either the key substantive concepts involved in the experimental problem, the instruments, the experimental method, the technique or the experimental arrangement.

Thus, each demonstration is presented in an interactive manner and is a collection of simple activities, questions and related discussion. For each demonstration, we have developed an instructors' handout. This instructors' handout gives information on the conceptual introduction to the demonstration, the required apparatus, the required data, description of the demonstration and the related references. The instructor is expected to read the instructors' handout and understand the demonstration in general, use of different instruments and the measurements involved. In the instructors' handout we give detailed step-wise description of the demonstration. Each demonstration is divided into subsections involving various activities, questions, and their explanations.

Every demonstration is designed and planned to involve minimum skills of demonstration on the part of the instructor so that the change of instructor should not majorly change the effectiveness of the demonstration. Thus we have carefully designed the instructors' handout for each demonstration. Most of the demonstrations involve observation and illustration type of practical work.

Thus, the instructor is first expected to explain the experimental arrangement to the students. He is not expected to discuss the theoretical basis or the conceptual understanding involved in the demonstration. (The conceptual introduction given in the instructors' handout is only for the sake of instructor's understanding of the demonstration). Once the experimental arrangement is introduced and the related data is given to the students, then the instructor is supposed to strictly follow the stages of demonstration as described under the title 'description' in the handout. In each demonstration, the instructor is expected to perform activities, which may involve adjustments, control or just an introduction. Through such activities an effect, a phenomenon or an instrument may be introduced to the students. For example, in case of Demonstration No.1, dropping the magnetic cylinder through a hollow aluminum pipe is an activity, through which an effect or a phenomenon is introduced to students. Students are expected to carefully observe the effect and try to understand what is happening in the activity. Then the instructor is expected to perform the necessary measurements or just repeat the activity to make it more clearly observable. The instructor is then expected to ask a question as given in the handout. He should give sufficient time for students to think and answer the question. If students answer the question satisfactorily then it is to be further discussed as per the explanation given in the handout, but if students find it difficult to answer the question then the instructor is expected to guide their thinking, give them hints, and as for as possible get the question answered from students and thus discuss the explanation. Thus after the first activity, the instructor may go to the next stage i.e. another activity or a question. Perform the necessary activity and let students observe it and put a question to the students and get it answered from them. Thus each stage of the demonstration stimulates thinking in students and develops different cognitive abilities like observing, application, synthesis, interpreting and inferring. Each demonstration is designed so that it should have a smooth flow of ideas, activities, questions and their discussion.

As said earlier, each demonstration is presented as a collection of activities, questions and the related discussion. The relative emphasis on activities, questions and discussions varies from one demonstration to the other. For example, in the demonstration which is designed with an objective of introducing the experimental technique, method or the experimental arrangement, there will be more activities than the questions, and the instructor may need to perform the activities. Here, he may just pass the required information to the students through the discussion, which will make that demonstration less interactive. Such possibilities should be minimized. Each demonstration as far as possible should be made interactive and the interaction between the instructor and the students be achieved through questions and related discussions.

Thus in the instructional strategy developed by us for the delivery of the demonstrations to the students, the instructor presents the demonstration in an interactive mode. Also the necessary information on the experimental arrangement and the apparatus is given to the students. The necessary references or the relevant information from the books may be made available to the students after the demonstration is given to strengthen their understanding of the demonstration.

4.3 The evaluation design

As said earlier under the present project, we have developed a set of ten innovative experimental problems and their accompanying demonstration. The objective of the project was not only to develop such experimental problems and demonstrations, but also to develop a suitable instructional strategy for them. The instructional strategy was to present the experiments as experimental problems in a format developed using the experience of International Physics Olympiads and the approach presented by Gott and Duggan (discussed in chapter III, The Conceptual Framework).

Chapter V is devoted to the discussion of these experimental problems and demonstrations. This chapter also gives one experimental problem and its accompanying demonstration in the detailed format, whereas the other nine experimental problems and demonstrations are given in the **Appendix A** and **B**.

The ten experimental problems put into a format as discussed above form a package. We converted the package into a course of fifteen days duration so that it could be tried on a sample of target audience, namely, undergraduate physic students in India. The primary object of the course was to evaluate our research project.

The outline of the course is given in the next section. The course was given to two batches of students each of strength 20, related from undergraduate colleges in Mumbai. During the course the students were given laboratory training for which the institutional strategy developed by us and reported earlier was used. Each student completed the ten experimental problems as per the format and details given in chapter V. The change in their behaviour, cognitive as well as affective was measured through pre and post tests given at the beginning and at the end of the course. This allowed us to conclude about the effectiveness of the package and thereby the effectiveness of our project.

The behavioural change observed had the following three components:

1) Conceptual understanding, i.e. understanding of the substantive concepts underlying the experimental problems. This was measured quantitatively by the students' performance in separately prepared tests on conceptual understanding.
2) Procedural understanding, i.e. understanding of the concepts of evidence that mediate between the conceptual understanding and the specific experimental skills necessary to solve the experimental problem. This was measured quantitatively by the students' performance in separately prepared tests on procedural understanding.
3) Experimental skills, these were quantitatively measured through separate experimental tests. It should be noted that these tests give a composite measure of students cognitive (conceptual and procedural) understanding and the

experimental skills and abilities required to effectively solve the given experimental problem.

Since the instructional strategy was to present the experiments in a experimental problem format, the composite measure also measures to a certain degree the problem solving ability of a student. However since all these components of the composite measure are so integrated with each other that separating there individual effect is hardly possible in an experimental test.

Incidentally, the traditional method of evaluating students' performance in a experimental physics uses only the third component. The first two components are not evaluated separately. The importance of these components was discussed in chapter III, The Conceptual Framework. We believe for a comprehensive evaluation it is necessary to tests both these components separately and in addition to the experimental tests.

Also, it is to be noted that we considerably reduced the element of subjectivity in the evaluation of experimental tests. Here the students were not assessed by examiners during their experimental tests. In fact, supervisors (instructors) present in the laboratory did not interact with the students during their tests, unless a student needed to consult them for technical reasons. Instead, students were asked and instructed to report practically every action, every observation they took through a carefully design test. The comprehensive reporting allowed grading the students' performance after they had the completed the test and reported in their answer sheets. Such reporting rendered it unnecessary to observe and assess the students during the experimental tests. It is the grading through observations that lets subjectivity creep into assessment, which we avoided. This is essentially the method used in the grading of students performance in experimental tests in the International Physics Olympiad examination. It is now adapted for the Indian National Physics Olympiad also.

We used a single group design for drawing inferences from the evaluation. A design with a control group was not considered, since our primary aim was to check whether and to what extent our course was effective in enhancing target group's cognitive and affective abilities and skills. The sample of the target group chosen consisted of students who were at the end of their first year or second year studies of the B. Sc. programme and had physics as one of their (two or three) subjects. These students had three or four years of physics laboratory training already and we believe our course could be seen as a remedial package in experimental physics for them. From this point of view the pre test could be seen as a characterizing instrument for the target group and the post test an achievement instrument after the remedial treatment. Statistically significant difference between the pre and post course tests would show if the course was effective. In this approach it is not possible to separate the effect of experimental problems themselves (i.e. their innovative versus traditional character) and the instructional strategies employed. To separate the effect of these two variables we need three more comparison groups, one with traditional experiments and traditional strategies, the second with traditional experiments and innovative strategies and the third with innovative experiments and traditional strategies. As said above we were interested only in checking the effectiveness of our course and not in its comparison with the traditional method. Moreover, operationally for all the comparisons referred to above we would have required a large sample size and different sets of experiment, which was not possible.

In short our design was as indicated below:

Pre tests ® **Treatment (A course on experimental physics)** ® **Post tests**

Our independent variable was the treatment through the course. The sample was two batches of twenty students studying physics at the undergraduate level from various colleges in Mumbai. These had three or four years of laboratory physics courses already. The dependent variable were three, namely, the difference in the scores of these students in *i*) Conceptual understanding tests, *ii*) Procedural understanding tests and *iii*) Experimental tests

The corresponding null hypotheses tested were:

I) The laboratory training course did not change the students' score in the test on conceptual understanding;

II) The laboratory training course did not change the students' score in the test on procedural understanding;

III) The laboratory training course did not change the students' score in the experimental tests.

In ‘non-operational’ words these hypotheses meant that the course did not make any difference in the level of students’ *i*) Conceptual understanding, *ii*) Procedural understanding and *iii*) The experimental skills and problem solving abilities along with other abilities required for effective performance in the experimental problems.

The tests used were not standardized tests, but they evolved and their validity was checked through 1) Introspection, 2) Discussion with physics teachers teaching both theory and laboratory courses at the given level and 3) Discussion with physics educationists who had previous experience of devising such tests. We also conducted pilot studies on smaller groups of student at the given level. This helped in checking the validity further and also the reliability of the tests. Further these test and some of the experimental problems with somewhat modified versions were tried at the Olympiad Training Camps. The target group there was different; the students in the camps were from standard XI and XII from various Indian schools and colleges. Still the experience lent additional support to the conclusions about the validity of the tests. We are thus fairly confident about both the validity and reliability of the tests both at the level of items and at the level of test as a whole.

The evaluation of the course with respect to three components listed above was complemented qualitatively by two instruments, 1) A questionnaire that included items on the students attitudinal and affective aspects of experimental physics and physics as a subject. This questionnaire also allowed us to note certain gender differences in attitude and some aspects of students’ previous experience. 2) A feedback questionnaire of open ended questions given to the students in a feedback session at the end of the course. The first questionnaire was given to the students without any change both at the beginning and at the end. The pre and post tests given for the three quantitatively measured components were, however, as noted earlier, different although equivalent in contents and their difficulty.

Qualitative observations and judgments of the instructors (who carried out the demonstration and supervised students’ performance in the course and during the tests) were sought at the end of the course. These complimented the feedback obtained from the students in drawing inferences. These inferences were drawn not only with respect to the main objective, namely, to check if the course and the research project was effective, but also with respect to the feasibility of the whole endeavor, i.e. whether the package of experimental problems and demonstrations developed by us formed indeed a remedial course in experimental physics that was deliverable, practically viable and acceptable to student and teaching community.

CHAPTER V

Description of Experimental Problems and Demonstrations

In the present research project we have developed ten units of innovative experimental problems and demonstrations. In each unit, we have an experimental problem along with a demonstration. The demonstration is given in an interactive manner as a prelude to the problem. The demonstration precedes the problem and serves as a prerequisite for the problem either from the point of view of conceptual understanding, procedural understanding or use of instruments / apparatus and other practical skills.

As per the instructional strategy described earlier, with each experimental problem, students are given a demonstration presented in an interactive mode for about thirty minutes. They are then given a handout, giving the necessary information on the experimental problem. They are expected to read the handout, understand the problem and on their own design the method of solving the problem. They are not offered any direct help with respect to procedural understanding or concepts of evidence. They are forced to think on those aspects and develop the related understanding and abilities.

There is no one unique type of practical work, around which this set of ten experimental problems and demonstrations is designed. Instead, we have designed each experimental problem so as to involve more than one type of practical work. Most of the demonstrations involve either the illustration or the observation type of practical work. The experimental problems involve investigation, skills and inquiry type of practical activities.

In case of each experimental problem, instructions on the use of instruments and the adjustment of the apparatus are given to the students in a separately provided instruction sheet. In this instruction sheet, no information is provided with respect to the measurement to be performed, its method and limitations. In most of the cases, students are expected to plan and carryout the measurement on their own.

Each experimental problem and the accompanying demonstration is innovative with respect to one or more of the following: the concepts involved, the experimental situation, the experimental method, techniques employed, procedural understanding involved and the method of presentation. We have followed the same format and the strategy of instruction for all the ten experimental problems and demonstrations.

We describe below details of a specimen Experimental Problem (No.1) and its demonstration.

5.1 Specimen experimental problem and its demonstration

For this experimental problem, we describe below the problem, experimental arrangement, students' handout, instruction sheets, the model answer and the analysis of the experimental problem. For the demonstration, we give details about the objective, experimental arrangement and the instructors' handout.

In this experimental problem, we emphasize the development of conceptual understanding, practical skills and procedural understanding. This experimental problem probes the phenomenon of electromagnetic damping and is designed to develop in students, conceptual understanding related to the concept of electromagnetic damping. The problem emphasizes the practical skills related to adjustment, control and use of instruments and concepts of evidence related to design and data handling. Here, students are given information on the use of a digital timer, adjustment of the photo-detectors and the measurement of distance. In parts A, B and C of the problem students are given some precautions and procedural instructions, and are also asked intermediate questions, which are intended to promote further thinking on those or additional precautions and procedural instructions. This experimental problem mainly involves skills and investigation type of practical work. It is innovative with respect to the experimental situation and also the measuring technique and the instrument. The experimental set-up has been completely designed and fabricated by the researcher.

In case of the demonstration the content, the design and the method of presentation are innovative. The demonstration is on the phenomenon of electromagnetic damping and its dependence on different parameters. It involves the same concepts as the main problem; the experimental situation, however, is different and relatively simple. The demonstration consists some simple illustrative activities. Students are asked questions for interlinking these activities and deriving meaningful inferences from observations.

5.1.1 Experimental Problem No. 1

5.1.1.1 The problem

This experimental problem probes the phenomenon of electromagnetic damping. For this purpose an aluminum disc is mounted on a horizontal axle around which a cord is wound. A weight hangs from the free end of the cord. If the weight is allowed to fall, it would accelerate due to gravity. As a result there would be a torque on the disc and it would undergo angular acceleration. In the experimental arrangement a pair of tiny cylindrical magnets is placed symmetrically with respect to the disc (as shown in Fig.5.1.1.1). The magnets lie along a common horizontal axis. They produce a fairly uniform magnetic field in the gap between them and a decreasing field outside the gap. Now if the weight is released in the presence of the magnets, initially the weight and the disc accelerate. Soon, however, the disc reaches a constant angular velocity, and the weight falls with a terminal velocity.

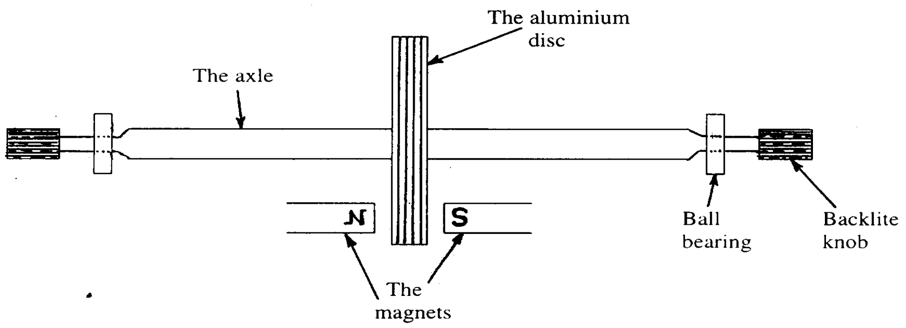

Fig. 5.1.1.1 Schematic of the disc and the magnet assembly

The constant angular velocity of the disc indicates rotational equilibrium of the disc. The accelerating gravitational torque due to the weight must be balanced by an equal and opposite retarding torque. There is a frictional torque at the supports, but it is too small. The main retarding torque arises due to electromagnetic damping. Due to the motion of the disc, it sees a changing magnetic field (which arises due to the pair of magnets). The emf induced on account of this causes eddy currents to flow within the body of the disc. These eddy currents experience a force in the magnetic field. The force and the resulting torque acts on the disc in such a way that it is retarded. This is in accordance with Lenz's law. Such is the origin of the electromagnetic damping experienced by the disc.

The terminal velocity, with which the weight falls, depends on different parameters like the geometry and dimensions of the disc and the axle, conductivity of the material of the disc, the magnitude of mass attached, magnetic pole strength of the pair of magnets, position of the magnets, the spacing between the magnets and the disc, and the frictional torque.

Two pairs of identical magnets with the same size and shape but of different pole strengths B_1 and B_2 are given. Also, a digital timer is provided to measure time.

I) In this experimental problem students are expected to observe the motion of the disc and the falling weights with and without the magnetic field. This is basically to develop an understanding of the concepts and principles related to electromagnetic damping and the motion of the disc.

II) The students are supposed to skillfully carryout necessary measurements to study the variation of the terminal velocity of the falling weight with the magnitude of the mass attached, for a given pair of magnets (with a fixed spacing between either magnet and the disc).

III) The students are now supposed to replace the pair of magnets with another pair, keeping all other parameters the same, and again note the variation of the terminal velocity with the mass attached.

IV) Using the above-mentioned data, the students are expected to determine the ratio of the magnetic pole strengths of the two pairs of magnets. Also they are expected to estimate, graphically, the frictional torque M_f (due to the frictional force at the supports).

5.1.1.2 Experimental arrangement

The experimental arrangement consists of the following two main units:

1) The disc and the magnets assembly,
2) The digital timer unit.

1) The disc and the magnets assembly

A homogeneous aluminum disc of given dimensions has attached at its center an axle which is a long (approximately 600 mm) solid brass rod of circular cross-section, as

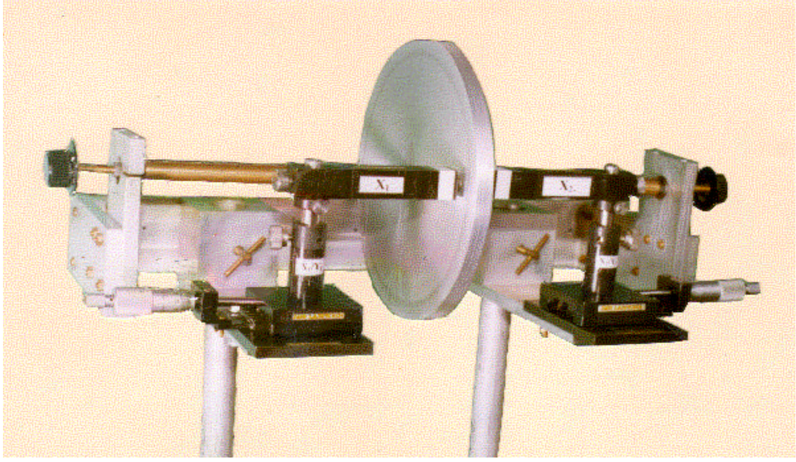

Fig. 5.1.1.2 (a) The disc and the magnets assembly

shown in Fig 5.1.1.2 (a)). It is highly machined and polished so as to have a uniform cross-section along its length. Towards both its ends the axle has a portion of narrower cross-section. This portion is threaded like a screw. The axle is mounted on the ball bearings at the point where the narrow portion begins. The ball bearings considerably reduce the friction at the supports. At the end of this screw like portion bakelite knobs are fixed. These knobs serve to facilitate rotating the axle and the disc. A terylex cord tied on one side of the axle winds or unwinds as the axle is rotated.

The stand, which supports the axle and the ball bearings, is made of non-magnetic material (either aluminum or brass). It has a set of vertically mounted clips to hold the ball bearings on each side of the axle, and also a cubic boss head arrangement to fasten it to two long (about 1.2 meters) aluminum rods, which are fixed to the ground base of the stand. A heavy iron plate is used as the ground base for the stand. The complete stand and its ground base are so designed and fabricated as to ensure that the stand is as stable as possible and will not bend on account of weights attached to the cord or extra pressure applied while either adjusting the magnets or winding the cord.

Two thick aluminum plates support the microstage holders. Each microstage holder (Fig.5.1.1.2 (b)) carries of a highly accurate and precise microstage, piston and post. The piston and post arrangement carries the mount for the magnets. A micrometer screw is provided on these holders to move the microstage and the mount and hence change and measure the spacing between the magnets and the disc.

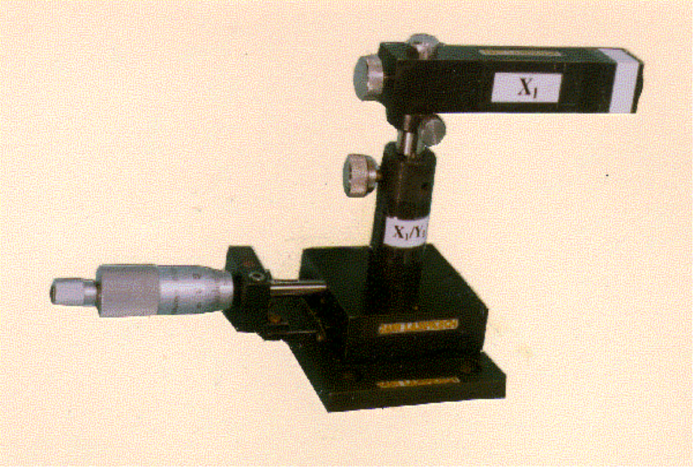

Fig. 5.1.1.2 (b) The microstage holder with mount X_1

A ring screw provided with the piston serves the purpose of a reference for alignment of the magnets. The height and the position of the magnets can be changed by changing the piston and the mount positions.

2) The digital timer unit

The digital timer unit consists of two identical C shaped detectors A and B (Fig.5.1.1.2 (c)).

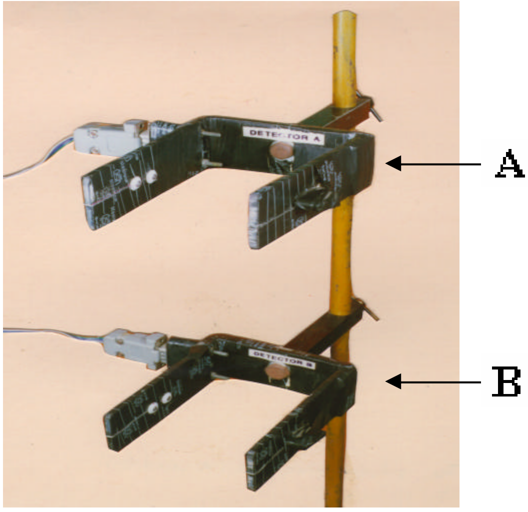

Fig. 5.1.1.2 (c) The detectors A and B

A detector consists of two photogates, each of which is a pair of a LED and a phototransistor. The output of the two photogates are ‘OR’ed to increase the sensing area (i.e. if the object crosses either of the two photogates the timer receives a pulse). A compact electronic circuit is designed, which essentially consists of a bistable circuit and a tri-state switch, to interface the detectors with a digital stopclock. This arrangement enables us to use the digital stopclock in an automatic timing mode. (For more details of the timer and the circuit, see publications). The interfacing circuit is fabricated on a small PCB and mounted inside the digital stopclock (Fig.5.1.1.2 (d)) with the connections for the detectors taken out. Either of the two detectors may be used to start or stop the timer.

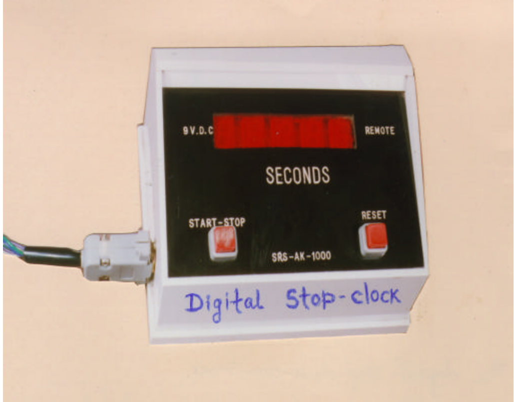

Fig. 5.1.1.2 (d) The digital stopclock cum timer

This requires proper connections of the detectors to be made, using the cord provided, with the timer. Thus when the object crosses one of the two detectors, the timer starts and when the object crosses the other, the timer stops, displaying on its screen the time interval between the start and the stop events. The detectors are mounted on a long retort stand using a boss head arrangement, which allows to change the distance between them. A reset switch is provided on the front panel of the timer unit. The least count of the digital timer used is 0.01 second, and its range is up to 999.99 second.

The complete experimental set-up

Fig. 5.1.1.2 (e) The complete experimental set-up

The experimental arrangement, as said earlier, consists of the disc and the magnets assembly and the digital timer unit. As can be seen from Fig. 5.1.1.2 (e), the disc and the magnets assembly is mounted on a long heavy stand. A set of slotted weights along with a hanger is attached to the free end of the cord. The two detectors are mounted on a long retort stand. A stainless steel pointer is also clamped to the same retort stand. A set of acrylic discs of different thickness (from 3 *mm* to 6 *mm*) is provided for the adjustment and measurement of the spacing between the magnets and the disc. Also provided are two pairs of magnets (X_1,X_2 and Y_1,Y_2), a measuring tape (2 *meter*), a meter scale, a micrometer screw gauge and pair of vernier calipers.

5.1.1.3 Students' handout

The objective

I) To study the phenomenon of electromagnetic damping of a rotating aluminium disc caused by induced eddy currents set-up within the metal disc due to its rotation (under the influence of falling weights) in a magnetic field (localised to a small portion of the disc).

II) To study the variation of the terminal velocity (of the falling weights) with the mass attached.

III) To determine the ratio of magnetic pole strength of two pairs of identical magnets and estimate the frictional torque acting on the disc at the supports.

Apparatus provided

1) A set-up consisting of a homogenous aluminium disc (capable of rotating about a horizontal axis) fixed on an axle. The axle is mounted at its ends on ball bearings, which are fixed to a holder mounted on a stand.
2) A digital timer with two photodetectors (*detector A* and *detector B*) mounted on a long retort stand.
3) Two pairs of identical magnets fixed on mounts (X_1,X_2 and Y_1,Y_2) at a time one pair may be clamped on the holders. (The pairs differ in magnetic pole strength)
4) A meter scale or measuring tape.
5) Slotted weights with a hanger (calibrated to 1% accuracy).
6) A pair of vernier callipers.
7) A micrometer screw gauge.
8) Acrylic discs of known thickness and a spirit level.

Introduction

We know that motion of a conductor across a steady magnetic field results in induced currents in the body of the conductor. These are so called *eddy currents*. As a consequence of the interaction between the magnetic field and the induced currents, the moving conductor suffers a reactive force. Thus an aluminium disc that rotates in the neighbourhood of a stationary magnet experiences a breaking force and hence a breaking torque. In this experimental set-up the disc rotates under the influence of falling weights attached at the free end of the cord wound on the axle of the disc. The breaking torque balances the torque on the disc due to the force of gravity on the falling weights. As a result the disc rotates with a uniform angular velocity and the weights move with a constant terminal velocity.

Description

The aluminium disc is mounted on an axle around which a cord is wound. A weight hangs from the free end of the cord. When the weight is released the disc (a small portion of which is moving in a magnetic field produced by a pair of magnets) accelerates and soon reaches a constant angular velocity. This uniform angular velocity of the disc corresponds to its rotational equilibrium, in which the gravitational torque is balanced by the damping torque due to the eddy currents and due to friction at the supports. As a result, the weight falls with a terminal velocity. This velocity depends, among other parameters, on the magnetic field seen by the disc, i.e. the pole strength of the pair of magnets and the spacing between the disc and the magnets. The pair of identical magnets can be mounted coaxially on the holders. The holders are provided with a micrometer screw, which allows to precisely change the spacing between the magnets of the pair.

Theory

Let, The moment of inertia of the disc = I

Mass of the weight attached = m

Moment of frictional force (frictional torque) = M_f

Magnetic strength of pair of magnets = B

Radius of the axle = r

Moment of magnetic force (magnetic torque) = M_B

Angular acceleration of the disc = a and

Tension in the cord = T

From the free body diagram for the mass m (Fig. 5.1.1.3 (a))

We have, $ma = mg - T$ or $T = mg - ma$ ....(1)

The equation for the unbalanced torque on the disc may be written as

$$I.a = T.r - M_f - M_B \quad \text{..(2)}$$

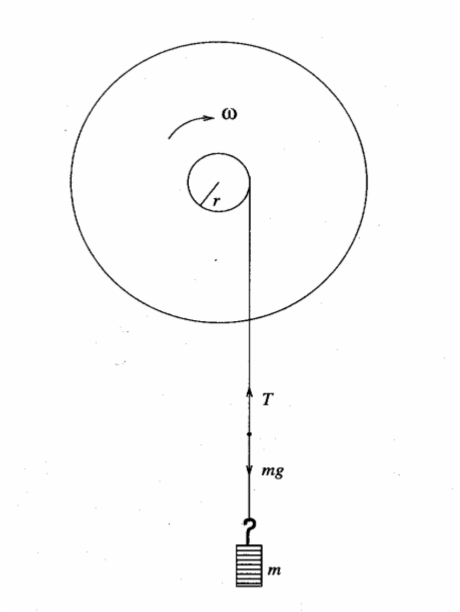

Fig. 5.1.1.3 (a) Free body diagram for the rotating disc.

Consider a disc rotating in a magnetic field, which is perpendicular to the plane of the disc. The magnetic field is confined to a small portion of the disc. An *emf* is induced in the small element moving across the field as a result of which eddy currents are set up in the disc as sketched in Fig. 5.1.1.3 (b). The interaction between the eddy currents and the field results in a breaking action on the disc. To understand this in a heuristic way we proceed as follows (detailed treatment is available in the literature).

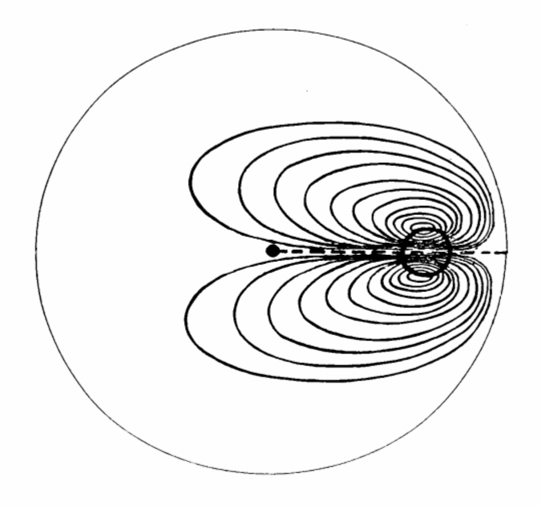

Fig. 5.1.1.3 (b) Eddy current loops.

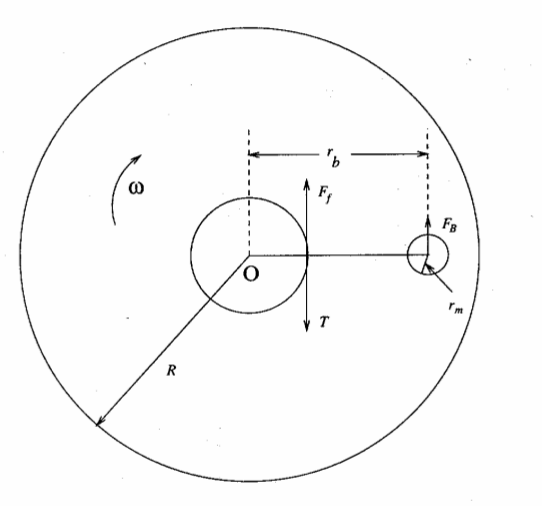

Fig. 5.1.1.3 (c) Forces on the disc.

We may take the magnetic field B *to* be confined to small circular region of radius r_m , $r_m << R$, R being the radius of the disc (Fig. 5.1.1.3 (c)). We may take B to be uniform over a distance $2r_m$. Consider the path along the diameter of the circular region. It lies on the radius of the disc and has length $2r_m$.It moves perpendicular to itself with a linear velocity $v = r_b w$, where r_b is the distance between the axis of rotation of the disc and the centre of the circular region. The motional *emf* E_b, generated on account of the rotation of the disc along the path is,

$$E_b = r_b\, w\, B\left(2r_m\right)$$

This *emf* E_b will give rise to a current i (the eddy current) along a closed conducting path within the disc of which the path in the circular region is a part,

$$i = \frac{E_b}{R^*} = \frac{2\, r_m\left(w\, r_b\right)B}{R^*}$$

where, R^* is the resistance offered by the closed conducting path. This current i experiences a side thrust F_b given by,

$$F_b = B\, i\,(\,2\, r_m\,)$$

$$= \frac{4\, r_m^2\left(r_b\, w\right)B^2}{R^*}$$

$$F_b = \left(\frac{4 r_m^2\, r_b}{R^*}\right) w\, B^2 \ldots\ldots\ldots\ldots\ldots\ldots\ldots\ldots\ldots(3)$$

Note the current element is perpendicular to B. Hence the moment of the force F_b about the axis of the disc is, $M_b = r_b\,.F_b$

$$M_b = r_b\left(\frac{4\, r_m^2\, r_b}{R^*}\right) w\, B^2$$

$$= \left(\frac{4\, r_m^2\, r_b^2}{R^*}\right) w\, B^2$$

$$M_b = C' w\ B^2$$

where

$$C' = \frac{4\, r_m^2\, r_b^2}{R^*}$$

In the calculation above we have taken a conducting path along the diameter of the circular region of radius r_m. Not necessarily all the paths will have length $2r_m$ and be strictly radially directed. The effect will however be to give an average factor C with dependence of w and B as given in the above equation for M_b . The effective torque M_B may be written as,

$$M_B = C\, w\ B^2 \ldots\ldots\ldots\ldots\ldots\ldots\ldots\ldots\ldots\ldots\ldots\ldots\ldots(4)$$

Substituting Eq. (4) in Eq.(2) and substituting for T in Eq.(2) from Eq.(1), we get

$$I\, a = \left(mg - ma\right)r - M_f - CwB^2 \ldots\ldots\ldots\ldots\ldots\ldots\ldots\ldots\ldots(5)$$

Some time after the release, the disc will reach its final constant angular velocity w_t and the mass its terminal velocity v_t. For this case, $\boldsymbol{a} = 0$ and $a = 0$, Eq. (5), Then gives,

$$v_t = w_t\, r = \left(\frac{g\, r^2}{C\, B^2} \right) \left\{ m - \frac{M_f}{g.r} \right\} \ldots\ldots\ldots\ldots\ldots\ldots\ldots\ldots\ldots (6)$$

This is the terminal velocity of the falling mass. Note v_t depends linearly on the attached mass m.

Procedural instructions

Part A

Attach a 200 *gm* weight to the free end of the cord. Wind the cord on the axle. Release the weight from an appropriate position and observe the fall of the weight, with respect to the change in its velocity as it falls.

Now clamp one pair of magnets fixed on their mounts X_1 and X_2 onto the holders provided on both sides of the disc. Adjust the mounts using the post and the piston provided to each holder so that the axes of the magnets are properly aligned and are perpendicular to the plane of the disc. A ring screw fixed on the piston serves as a reference so that another pair can be mounted in the same position.

Part B

Adjust the spacing (distance) between the magnets and the surface of the disc. The spacing on either side should be exactly the same and may vary from 0.5 *mm* to 1.5 *mm.* Measure this spacing as accurately as possible. (For this purpose you may use one of the acrylic discs of known thickness given to you and the micrometer screw of the holder). While measuring this spacing, care should be exercised so that the magnets should not touch the disc. The spacing between the disc and the magnets and the alignment and position of the mounts (magnets) once adjusted should be kept the same throughout the experiment.

Question 1. Give reasons why the spacing between the disc and the magnets, and the alignment and position of the magnets should be the same for each pair of magnets.

Part C

Wind the cord on the axle with the 200 *gm* weight attached to the free end of the cord. Release the weight from an appropriate position, which may be kept the same throughout the experiment. You may use a steel pointer fixed on the retort stand as a reference point. Observe the fall of the weight. Note the difference between the fall of weights with the magnets and without the magnets.

Now, you have to determine the time taken by the weights to fall through different distances. For measurement of time, a timer is provided along with two detectors (*detectors A and B*). (For instructions about the use of timer refer to the instruction sheet). The timer starts when the weight passes by one detector *(say, A)* and stops when the weight passes through the other *(detector B)*. Adjust the first *detector A* to a convenient distance (5 to 30 cm) below the point of release. Take a suitable distance between the two detectors *(A and B)*, measure this distance and note the time recorded by the timer as the weight is released. Repeat this for at least three more weights (ranging from 300 *gm*.to 600 *gm*). Increase the distance between the two detectors by keeping the upper detector *(detector A)* at the same position and lowering the *detector B*, by suitable increments. Record the corresponding time taken in each case for the same weights used earlier. (You are expected to take at least four sets of readings within the last 40 *cm* of the fall of weights). Tabulate your results.

Question 2. Give reason why the point of release of the weight should not be changed in each case for different masses and distances. What will be the effect if the point of release is changed ?

Part D

Plot an appropriate graph to exhibit the variation of velocity of the falling weight with distance (height) for each value of weight attached.

Question 3. Explain the variation of velocity of falling weight with distance (height) as observed from the graph.

Part E

Now, calculate the average velocity for the last 40 *cm* of the fall (which is the terminal velocity), for each weight attached, from the graph.

Part F

Replace the pair of magnets X_1 and X_2 with Y_1 and Y_2, keeping the arrangement and the spacing the same as before. Repeat parts C, D and E for this pair of magnets. Plot a graph of the terminal velocity v_t of the falling weights versus the mass attached for both the pairs of magnets.

Question 4. Explain, using the above plot, the variation of the terminal velocity with the value of the mass attached for both the pairs of magnets X_1 X_2 and Y_1 Y_2 .

Question 5. Why is there a variation in the terminal velocity with the mass attached (for a particular pair of magnets)? And why is the terminal velocity for the same mass different for two pairs of magnets X_1 X_2 and Y_1 Y_2?

Question 6. Using the above graph, determine the ratio B_1^0/B_2^0 for the two pairs of magnets X_1 X_2 and Y_1 Y_2. (Note, B_1^0 and B_2^0 are the respective magnetic pole strengths for the two pairs X_1X_2 and Y_1Y_2. The magnetic fields B_1 and B_2 are proportional to the pole strengths of each pair X_1 X_2 and Y_1 Y_2 of the magnets respectively).

Question 7. Using the same graph estimate the value of the moment of frictional force (frictional torque) M_f and explain your method.

Question 8. Describe at least two situations, where

a) An object falls with a terminal velocity.

b) The phenomenon of electromagnetic damping is applied.

Data provided

A) For the disc
  1) Material - Aluminium
  2) Thickness - 12.26 *mm*
  3) Diameter - 209.08 *mm*

B) For the axle
  1) Material - Brass
  2) Diameter - 14.92 *mm*
  3) Length (approx.) - 600 *mm*

C) For the magnets
  1) Shape - Cylindrical
  2) Material - Ceramic
  3) Diameter - 9.88 *mm*
  4) Height - 20.08 *mm*

D) For the cord
  1) Material – Terylex
  2) Cross-section – Circular
  3) Diameter – 0.59 *mm*

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5.1.1.4 Instruction sheet

A) Use of the digital timer

The timer shows reading in seconds with a least count of 0.01seconds.The front panel of the timer has two switches.

1) Reset
2) Start / Stop (Do not use this).

To reset the timer the reset switch is to be pressed. You are not required to use the Start / Stop switch provided on the front panel of the timer in this experimental problem.

For each reading reset the timer every time before releasing the weights. The timer may start in between, say while winding the cord. In order to stop the timer in such cases, interrupt the light beam in the detector B.

B) Adjustment of the photo-detectors

The photo detector arrangement consists of two photo detectors (detectors A and B). These detectors are wired to the digital timer, which measures time in seconds (with 1% accuracy). The detectors can be moved vertically with the help of bossheads, which are clamped to the long retort stand. Detector A is the one above detector B. When an object crosses the detector A the timer starts counting time and when the object crosses the detector B it stops counting. Thus one can say that detector A is the ‘start detector’ and the detector B is the ‘stop detector’. Note that when the timer is not counting, an object passing through B will not affect the timer.

C) Measurement of the distance

The distance between the marks made on the detectors is to be measured .The detectors should be clamped exactly vertically one above the other and the distance between the left marks of the detectors should be equal to that between the right marks. This distance is the correct value of the distance between the detectors.

5.1.1.5 Model answer

The numerical values given in the following text are those obtained in a preliminary test, and are reported only as a guide to the expected record of students' work.

Part A

A 200 *gm* weight was attached to the free end of the cord. The cord was wound and then released from an appropriate position. It was observed that the velocity of the falling weights goes on increasing as it falls. Thus it can be inferred that the motion of the weight and hence the disc is accelerated, since the only force responsible for the motion of the weight is the gravitational force, which is a constant force. Assuming the frictional force to be constant or zero, it can be said that the motion of the weight and hence the disc is uniformly accelerated.

A pair of magnets X_1 and X_2 is carefully fixed on the holder so that the axis of the magnets is perpendicular to the surface of the disc and both the magnets are positioned symmetrically on both the sides of the disc.

Part B

The spacing between a magnet and the disc was adjusted to 1.00 *mm*. The spacing was adjusted to be the same for the magnets, mounted on each side of the disc. This adjustment was done using an acrylic disc of thickness 3.32 *mm*. Using this disc a reference point was fixed and then with respect to this reference point the spacing was adjusted to be 1.00 *mm* using the micrometer screw fixed on the holders.

Answer to Q.1. Both the pairs of magnets are of identical dimensions but their magnetic pole strengths are different. Here we are interested in changing the magnetic pole strengths keeping the other parameters the same. This means the distance between the magnets, their position with respect to the disc and their common axis are the same for both the pairs.

Part C

A 200 *gm* weight was attached at the free end of the cord. The cord was wound on the axle and then released from an appropriate position marked using the pointer. It was observed that with the magnets, the weight seems to fall with a constant velocity, which means zero acceleration. This is unlike the earlier case where the weight falls with a constant acceleration. From this observation, it can be inferred that in this case, there exists another force acting on the disc. This force is due to the eddy currents setup in the disc and is directed so as to oppose the motion of the disc. It is linearly proportional to the angular velocity *w* of the disc, as given in the theory earlier. Now the detector A was fixed 5.4 *cm* below the point of release, which was marked and fixed using a pointer. The detector B was clamped at different distances below the detector A and the time and the distance data was measured and recorded as given in the Table 5.1.1.5(a).

Table 5.1.1.5(a) Observations of time and distance

For the pair of magnets X_1 *and* X_2

Least count of the timer = 0.01 *second*

Sr. No.	**Distance *d* *(in cm)***	**Time *t (in second)* for**				
		Mass Attached				
		200 *gm*	300 *gm*	400 *gm*	500 *gm*	600 *gm*
1	10.0	4.38	2.52	2.22	1.84	1.61
2	20.0	8.51	5.16	4.18	3.18	2.95
3	30.0	12.48	8.19	6.14	4.99	4.25
4	40.0	16.75	10.76	8.05	6.50	5.49
5	50.0	20.85	13.34	9.96	7.99	6.75
6	60.0	24.94	15.97	11.87	9.51	7.98
7	70.0	29.45	18.65	13.79	11.01	9.22
8	75.0	31.36	19.99	14.76	11.79	9.85
9	80.0	33.31	21.15	15.64	12.50	10.47

Answer to Q.2. The motion of the weights is accelerated for some distance after release and then the weight falls with a constant (terminal) velocity. Theoretically the terminal velocity as obtained from Eq. (5) is reached only at infinity. For practical purposes the terminal velocity may be said to be attained when the velocity of the mass differs from the terminal velocity by a fraction, say, less than 1/100. The distance at which this happens depends only on the mass attached. To study the motion of the falling weights, we clamp detector A (which starts the timer) 5.4 *cm* below the point of release and thereafter keep its position fixed. We clamp the detector B (which stops the timer) 10.0 *cm* below the detector A and every time we lower down the detector B by 10.0 *cm*.

Now if the weight attains the terminal velocity before it crosses the detector A, then the shifting of the point of release by some small distance may not affect the readings. But if it has not attained the terminal velocity with a different point of release, the weight will cross the detector A with different (initial) velocity. Thus for avoiding any error getting introduced due to the different initial velocities in the measurement of time, the point of release of the weights should not be changed.

Part D

From the data shown in Table 5.1.1.5(a), it can be seen that for explaining the variation of velocity as the weight falls through different distances, a graph between the time *t* which the weight takes to fall through the distance *d* (distance between the two detectors) and the distance *d* is to be plotted. The graphs of the time versus the distance for various values of the mass attached are obtained as shown in Fig.5.1.1.5 (a and b)

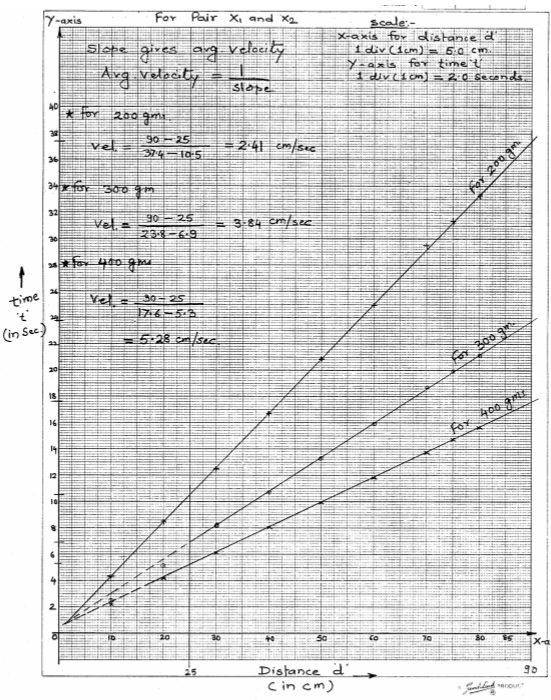

Fig. 5.1.1.5(a) Graph I of time versus distance for the pair X_1 and X_2

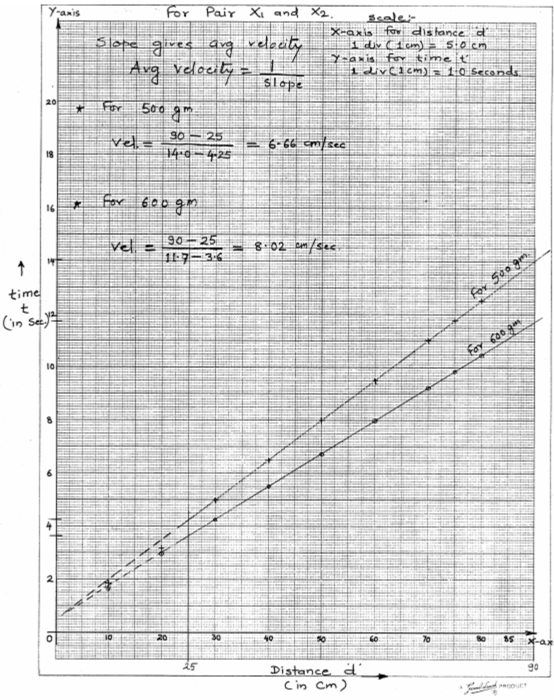

Fig. 5.1.1.5(b) Graph II of time versus distance for the pair X_1 and X_2

Answer to Q.3 The graphs of time versus the distance are for all practical purposes, straight lines. From these straight line plots for different mass attached (200 *gm* to 600 *gm*), it can be inferred that in all these cases, the weight after some distance of its fall attains and thereafter falls with a terminal velocity, which is linearly proportional to the mass attached.

Part E

Since the time versus the distance graphs are straight lines for all the values of mass attached, the terminal velocity can be determined from the slope of the straight line plots (the inverse of the slope gives terminal velocity). The values of the terminal velocities for different mass attached is shown in table 5.1.1.5(b).

Table 5.1.1.5(b) Table of mass attached and the terminal velocity

For the pair of magnets X_1 and X_2

Sr.No	Mass Attached (*gm*)	Terminal Velocity (*cm/sec*)
1	200	2.41
2	300	3.48
3	400	5.28
4	500	6.66
5	600	8.02

Part F

The pair of magnets X_1 X_2 is replaced with the pair Y_1Y_2, keeping the arrangement and the spacing the same as before. Again the distance and time data as recorded and is shown in Table 5.1.1.5(c).

Table 5.1.1.5(c) Observations of time and distance

For the pair of magnets Y_1 and Y_2.

Least count of the timer = 0.01 *second*

Sr. No.	**Distance *d* *(in cm)***	**Time *t (in second)* for**				
		Mass Attached				
		200 *gm*	300 *gm*	400 *gm*	500 *gm*	600 gm
1	10.0	3.27	2.31	1.85	1.57	1.38
2	20.0	6.12	4.18	3.31	2.78	2.43
3	30.0	8.86	6.00	4.66	3.89	3.38
4	40.0	11.59	7.70	5.96	4.94	4.28
5	50.0	14.30	9.48	7.27	6.01	5.17
6	60.0	16.96	11.16	8.53	7.01	6.02
7	70.0	19.77	12.98	9.84	8.04	6.87
8	75.0	21.05	13.76	10.45	8.52	7.27
9	80.0	22.52	14.69	11.10	9.05	7.71

The graphs between the time and the distance are plotted as shown in Fig 5.1.1.5(c and d) In this case also, the plots are straight lines and the distance after which the weight falls with a terminal velocity is different for different mass attached. The inverse of the slope of these straight lines gives the terminal velocity. The terminal velocity in each case was calculated and given in Table 5.1.1.5(d).

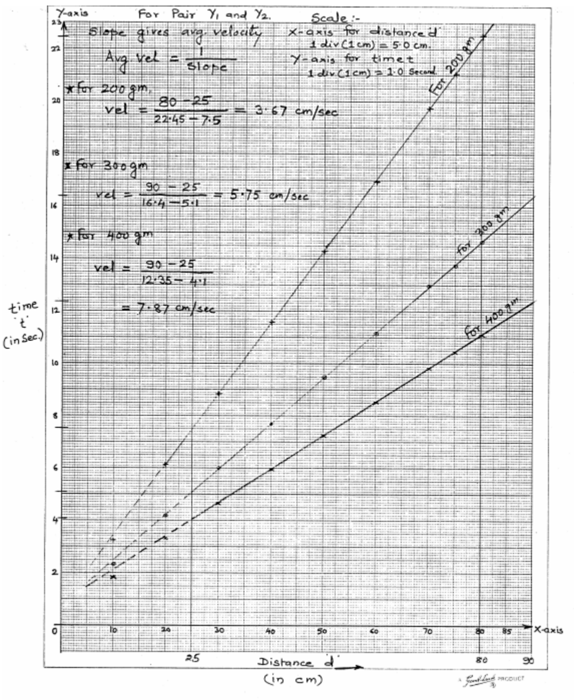

Fig. 5.1.1.5(c) Graph I of time versus distance for the pair Y_1 and Y_2

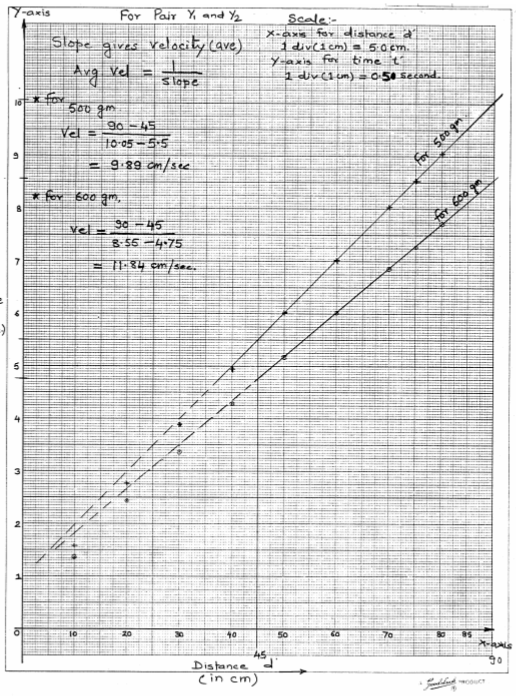

Fig. 5.1.1.5(d) Graph II of time versus distance for the pair Y_1 and Y_2

Table 5.1.1.5(d) Table of mass attached and the terminal velocity

For the pair of magnets Y_1 and Y_2

Sr.No.	Mass Attached (*gm*)	Terminal Velocity (*cm/sec*)
1	200	3.67
2	300	5.75
3	400	7.87
4	500	9.89
5	600	11.84

Now the graph of terminal velocity v_t of the falling weights versus the mass attached for both the pairs of magnets X_1 X_2 and Y_1Y_2 is plotted and we obtained straight line plots as shown in Fig 5.1.1.5(e).

Answer to Q.4. For both the pairs of magnets X_1 X_2 and Y_1Y_2, it can be seen from the graph, that the terminal velocity varies linearly with the mass attached. Both (for X_1X_2 and Y_1Y_2) the plots are straight lines with an intercept on negative y-axis.

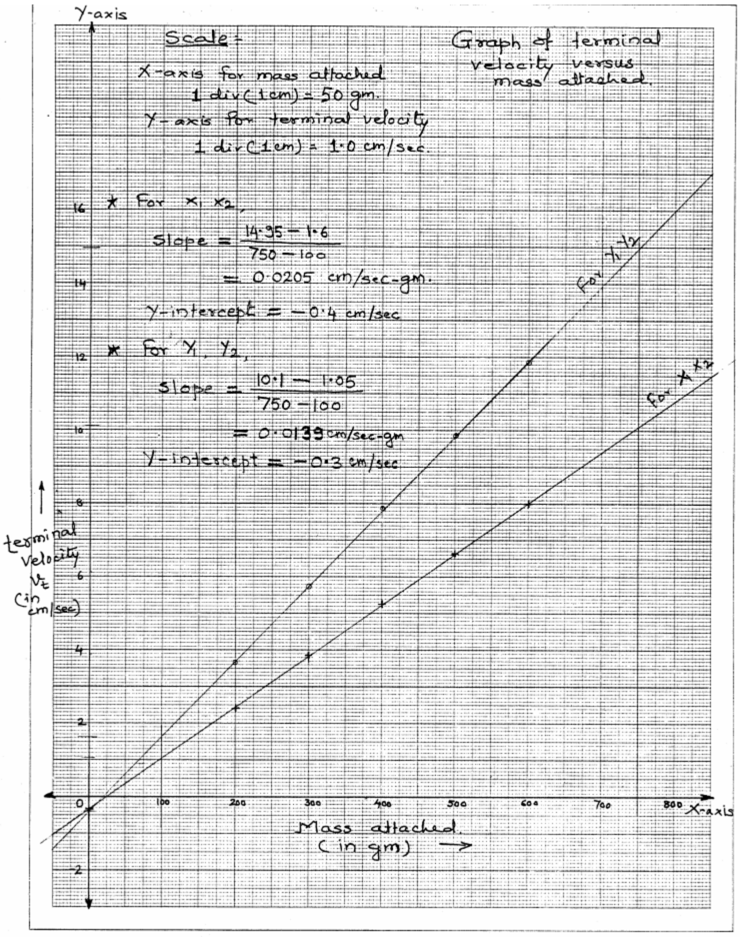

Fig. 5.1.1.5(e) Graph of terminal velocity versus mass attached

Answer to Q.5. The expression for the terminal velocity is,

$$v_t = \left(\frac{g\, r^2}{C\, B^2}\right)\left\{m - \frac{M_f}{g.r}\right\}$$

In this expression the term gr^2/CB^2 is a constant (for our situation). Thus as mass *m* is increased; the gravitational force *mg* will increase as a result of which the angular velocity *w* of the disc will increase. The damping force is proportional to *w*; hence the damping force will also increase. Since the disc moves under the influence of these two forces and as the rotational equilibrium is attained, the weight falls with a higher terminal velocity. Thus assuming M_f to be a constant, if the mass increases the terminal velocity should linearly increase for a particular pair of magnets. As can be seen from the above expression the damping force depends on the square of strength of the magnetic field *B*. Hence for the same mass attached if the field *B* is changed, then the terminal velocity will change. The pole strength of the two pairs is different. Hence the terminal velocity for the same mass is different for the two pairs X_1 X_2 and Y_1 Y_2.

Answer to Q.6. The strength of the magnetic field produced by the pair of magnets X_1 X_2 and Y_1 Y_2 is B_1 and B_2 respectively. This field is proportional to the respective pole strength B_1^0 or B_2^0. Since both the pairs are identical in all respects except their pole strengths, the ratio B_1 / B_2 is the same as the ratio B_1^0 / B_2^0.

The expression for the terminal velocity is,

$$v_t = \left(\frac{g\,r^2}{C\,B^2}\right)\left\{m - \frac{M_f}{g.r}\right\} \qquad \text{or} \qquad v_t = \frac{gr^2}{CB^2}m - \frac{M_f r}{CB^2}$$

The expression is of the form $y = mx - c$, which is the equation of a straight line. Thus, if we plot a graph of terminal velocity v_t versus the mass attached m, the slope of the straight line is gr^2/CB^2 and the negative y- intercept is $M_f r/CB^2$.

For the determination of the ratio B_1 / B_2, we will write two equations for B_1 and B_2 and take the ratio of their slopes.

$$v_{t1} = \frac{gr^2}{CB_1^2}m - \frac{M_f r}{CB_1^2} \quad \text{.............................}(1)$$

$$v_{t2} = \frac{gr^2}{CB_2^2}m - \frac{M_f r}{CB_2^2} \quad \text{..............................}(2)$$

$$S = Ratio\ \ of\ \ the\ slopes = \frac{S_X}{S_Y} = \frac{B_2^2}{B_1^2}$$

$$\text{Thus} \quad \frac{B_1}{B_2} = \sqrt{\frac{S_Y}{S_X}}$$

From the graph, $S_Y = 0.0139$ *cm/sec-gm* and $S_X = 0.0205$ *cm/sec-gm*.

$$\text{Thus} \quad \frac{B_1}{B_2} = \sqrt{\frac{0.0139}{0.0205}} = 0.823$$

It can be said that the ratio of the magnetic pole strengths of two pairs of magnets $B_1^0 / B_2^0 = 0.823$.

Answer to Q.7. As can be seen from the above expression for v_t the slope of the straight line is gr^2/CB^2 and the negative y-intercept is $M_f r/CB^2$. Thus to estimate M_f, we can take the ratio of *y-intercept* to the *slope* for both the pairs of magnets.

$$\text{y - intercept } I = \frac{M_f r}{CB^2}$$

$$\text{Slope } S = \frac{gr^2}{CB^2}$$

$$\therefore \frac{I}{S} = \frac{M_f}{gr} \qquad \therefore M_f = gr\left(\frac{I}{S}\right)$$

For pair X_1 and X_2, $g = 980$ *cm/sec*, $r = 0.746$ *cm*, $I_X = 0.40$ *cm/sec and* $S_X = 0.0205$ *cm/sec-gm*. Hence, $M_f = 1.4 \, . \, 10^4$ *gm-cm*^{2}*/sec*^{2}.

For pair Y_1 and Y_2, $I_Y = 0.30$ *cm/sec and* $S_Y = 0.0139$ *cm/sec-gm*. Hence, $M_f = 1.5 \, . \, 10^4$ *gm-cm*^{2}*/sec*^{2}.

Thus for our set of readings, the value of M_f lies between $1.4. \, 10^4$ *gm-cm*^{2}*/sec*^{2} and $1.5 \, . \, 10^4$ *gm-cm*^{2}*/sec*^{2}.

Answer to Q.8.

a) The situations where an object falls with terminal velocities are as under,

1) When a small metallic sphere is dropped in a long container filled with a highly viscous liquid. The sphere after some distance of travel through the liquid attains and thereafter falls with a terminal velocity.
2) A raindrop that falls from a large height, while approaching the ground falls with a terminal velocity.
3) A skydiver or a parachutist falls with a terminal velocity.

b) The situations where the phenomenon of electromagnetic damping is applied are as under,

1) Electromagnetic damping is employed in magnetic breaking systems, used for heavy vehicles.
2) The damping is also employed in many measuring instruments (like watt-hour meters) which involves the motion of some component of the instrument.

5.1.1.6 Analysis of the experimental problem

In parts A, B and C of the experimental problem, some precautions and procedural instructions were given to the students through the handout. Since we would like students to understand the importance of these precautions and instructions, some questions were asked, which made students think on different finer procedural details and concepts of evidences. We describe below, the learning objectives of the questions asked in the students handout for this experimental problem.

In the handout, we asked eight questions to the students, which they are expected to answer at the time of carrying out the experimental problem. Most of these questions were based on different finer procedural details and understanding the concepts of evidence. There are questions, which may involve conceptual understanding and cognitive synthesis and application of concepts in different situations. We then describe different learning outcomes of the experimental problem. These include understanding the substantive concepts, development of laboratory skills and understanding the concepts of evidence.

Learning objectives of the questions asked in the handout

Q. 1. This question is intended to check and improve the understanding of the precautions, to be executed and the importance of these precautions. It also explains the simplifications or the adjustments needed in the experimental set-up for keeping the control variables the same. In part B, where this question occurs, the procedural instructions are given, but this question is introduced to make students think on it and understand the importance of initial adjustments.

Q. 2. This question is introduced to understand the method of measurement of time and the consequences of changing the initial conditions on the measurement. It also checks and develops the ability to plan and execute the measurement and execute related precautions to keep the control variable the same. In part C, the instructions on how to carry out the measurement are given. The question is intended to make students think on them and understand and plan the measurement so as to minimize errors in the measurement.

Q. 3 and Q. 4. These questions are intended to develop students' ability to interpret straight-line graphs and use of the graphs, say, to obtain the value of a derived variable (i.e. velocity here).

Q. 5. This question is targeted to develop students' ability to explain the experimental observations or results on the basis of the theory of the experimental problem developed earlier. It also indirectly develops understanding of the concepts related to electromagnetic damping.

Q. 6 and Q. 7. These questions are intended to develop the ability to use a straight-line plot to determine the value of derived quantity by performing required mathematical manipulations. It also develops the ability to understand the importance of graphs and correlate experimental findings expressed in the form of graphs with theoretically expected results.

Q. 8. This question is intended to check and develop the ability to correlate or apply the understanding gained from the experimental problem to similar situations either already encountered or new.

Different learning outcomes of the experimental problem

We describe below briefly the different substantive concepts, laboratory skills and concepts of evidence, which we expect students either to know or to understand / develop through this experimental problem.

A) Substantive concepts

The concept of magnetic field, particularly the nature of the magnetic field produced by a cylindrical magnet, the concept of an induced emf, electromagnetic induction, eddy currents set-up in the body of a conductor, electromagnetic damping (its dependence on different parameters), rotational motion of a disc under the influence of falling weight, torque due to friction, unbalanced torque on a disc rotating about its axis, moment of inertia of a disc, tension in the string, linear velocity, angular velocity, linear acceleration and angular acceleration, terminal velocity.

B) Practical or experimental skills

1) Skill involved in adjusting the magnets so that their axes should coincide and should be perpendicular to the plane of the disc (***Alignment and judgment skill***).
2) Skill of measuring small distance between the magnet and the disc, using the micrometer screw and an acrylic sheet of known thickness, i.e. the use of micrometer screw gauge with non-zero reference. (***Skill of using an instrument in a novel way***).
3) Skill of winding the cord on the axle. (***Handling or manipulation skill***).
4) Exercise of care to maintain the point of release the same in each case by keeping the line of sight the same throughout the experiment. (***Alignment and judgment skill***).
5) Skill involved in the use of a digital timer with the photo-detector arrangement. (***Skill of using a new instrument***).
6) Skill of measurement of distance between the two detectors and also the distance between the point of release and the detector A, without disturbing the alignment of the detectors. (***Skill of measurement and control***)
7) Skill involved in the alignment of the detectors so that when the weight falls it should properly and completely obstruct the light falling on the photosensor of the detectors. (***Skill of alignment and control for measurement***).

8) Skill of replacing the pair of magnets without altering their positions and alignment. (***Skill of manipulation and control***).

9) Exercise of care for leaving the set-up undisturbed throughout the experiment, i.e. position of the retort stand on which the photo detectors are clamped should not be disturbed, weights should not be oscillating or rotating at the time of release, the set-up should be steady and perfectly stable while the measurements are being performed. (***Skill of alignment and control***)

10) Skills needed for drawing best-fit straight-line graphs using data from observation tables. (***Skill of drawing graphs and tables***).

C) Concepts of evidence

The following concepts of evidence were taken into consideration while planning the experimental problem.

I) Associated with the design

a) Choice of proper value for the distance between the disc and the magnet

b) Identifying the dependent (time), independent (distance) and the control variables.

c) Understanding the number of readings for time (dependent variable) to be taken for each distance (independent variable) to minimize the errors in the measurement.

d) Choice of proper weights (independent variable) to be attached so as to get suitable and distinct values of corresponding time (dependent variable).

e) Design a fair test to check for the correctness of the readings/results while performing the measurements.

II) Associated with the measurement

a) Selection of the proper range of weights and the heights (distance) for which the corresponding time is to be measured.

b) Choice of appropriate intervals for the measurement of distance between the two detectors and the values of the weights attached.

c) Choice of proper instrument to be used for measuring the distances (one may use a meter scale, a flexible measuring tape or a feet (30 cm) scale.)

d) Understanding the importance of initial conditions (at the time of release) so that each reading should be the same if the measurement is repeated.

III) Associated with data handling

a) Understanding the use of observation tables for organizing the results. Drawing proper tables with the values of dependent, independent, and control variables along with serial number of readings.

b) Graphs.

   1) Choice of proper axes for the variables (x-axis should be used for independent variables and y-axis should be used for dependent or derived variable). For the plot between time and height, height should be plotted on x-axis and time on y-axis and for studying variation of terminal velocity with mass, mass should be taken on x-axis and terminal velocity should be on y-axis.
   2) Proper selection of scale so that maximum portion of the graph paper should be utilized and all the points should lie on the graph sheet.
   3) Selection of proper type of graph sheet i.e. linear, semi-logarithmic or dual-logarithmic (log-log) according to the variations in the values of the parameters to be plotted.
   4) Proper selection of the ranges for determining the slope of a straight-line graph.
   5) Plotting the best straight-line graph using the linear least square fit method.

5.1.2 Demonstration No. 1

5.1.2.1 The objective

The following demonstration serves as a prelude to Experimental Problem No.1. This demonstration is designed around illustration and observation type of practical work. We have identified the concept of electromagnetic damping and its dependence on different parameters to be the key concept of the experimental problem. The objective of the demonstration is to illustrate and consolidate the understanding of this key concept. i.e. the phenomenon of electromagnetic damping. The demonstration also explains the dependence of the electromagnetic damping on the conductivity of the material of a conductor in which the eddy currents are set up and the pole strength of the magnets.

In this demonstration the fall of magnetic cylinders through hollow metallic cylindrical pipes made of aluminum, brass and PVC is observed. The motion of the cylinders in case of aluminum and brass pipes is damped on account of induced eddy currents in the pipes.

5.1.2.2 Experimental arrangement

Fig. 5.1.2.2 The experimental set-up

The experimental arrangement for the demonstration consists of three hollow cylindrical pipes made of aluminum, brass and PVC. All the three pipes are identical in dimensions. Each hollow pipe is clamped on a retort stand using a four-finger clamp and a bosshead. The pipes are arranged to be exactly vertical so as to have their axes perpendicular to the ground level. Three solid cylinders marked C_1, C_2, and C_3 are given. Two of them i.e. C_2 and C_3 are magnetized under different fields (i.e. they are magnets of different pole strengths) and the third cylinder C_1 is not a magnet. All the three cylinders are identical with respect to their dimensions and masses. Thus C_1 is not a magnet, but just a cylindrical object and C_2 and C_3 are magnets with pole strength of C_2 lower than that of the C_3. A hand-held digital stop-clock is provided to measure the time of flight of different cylinders through the pipes. A meter scale is provided for length measurements. Three plastic boxes with the sponge are provided which may be kept below each pipe so that the magnet should not fall directly on the base of the retort stand.

5.1.2.3 Instructors' handout

Introduction

The demonstration is meant to serve as an introduction to the Experimental Problem No.1. It illustrates and consolidates the understanding of the phenomenon of electromagnetic damping, which is the central concept of the experimental problem. In this demonstration, the damping of the motion of falling magnetic cylinders through hollow cylindrical pipes made of aluminium, brass and PVC is observed. The damping is caused by the eddy currents set-up in the material of the pipe. The eddy currents are induced due to the motion of the magnetic cylinders through the pipes. The demonstration also explains the dependence of the electromagnetic damping on the conductivity of the material of the pipe and the pole strength of the magnets.

Apparatus required

1) Three hollow cylindrical pipes made of aluminium, brass and PVC, each of the same dimensions and mounted on retort stands.
2) Three solid cylinders (marked $\mathbf{C_1}$, $\mathbf{C_2}$ and $\mathbf{C_3}$) identical in dimensions and masses, two of them ($\mathbf{C_2}$, $\mathbf{C_3}$) are magnets and the third one ($\mathbf{C_1}$) is not a magnet.
3) A hand held digital stop-clock.
4) A meter scale.

Data provided

A) For hollow cylindrical pipes
  a) Material – Aluminium, Brass, and PVC.
  b) Inner diameter – 16.0 *mm*.
  c) Outer diameter – 38.5 *mm*.
  d) Wall thickness – 11.2 *mm*.
  e) Length – 900 *mm*.

B) For magnetic cylinders
  a) Diameter – 12.40 *mm*.
  b) Height – 20.02 *mm*.
  c) Weight – 17.78 *gm*.

Description

Arrange the set-up as shown in Fig.5.1.2.3. Three hollow cylindrical pipes made of aluminium, brass and PVC are fixed with the clamps on the retort stands. The axis of each pipe is vertical (i.e. perpendicular to the surface of the table). A set of three solid cylinders of identical dimensions and masses marked $\mathbf{C_1}$, $\mathbf{C_2}$ and $\mathbf{C_3}$ is available. Two of these cylinders i.e. $\mathbf{C_2}$ and $\mathbf{C_3}$ are magnetic (magnets) and $\mathbf{C_1}$ is not a magnet. All the three cylinders are taken to be of same mass because the force of gravity acting on them during the fall through the pipes should be the same in each case. Also, the dimensions of each cylindrical hollow pipe are the same.

Part A

Take cylinder **C_1** (which is not a magnet) and drop it through all the three pipes. The time it takes to come out of the pipe (i.e. time of flight) in each case is observed (approximately). One concludes that this time of flight is the same in all the three cases.

Question 1. Why is the time of flight for **C_1**, the same in each pipe?

Explanation. The cylinder **C_1** falls freely under gravity in all the three cases and there is no other force acting on it in each case. The length of the pipes being the same, the time of flight is the same.

Part B

Now, take cylinder **C_2** and drop it through the aluminium and PVC pipes. Observe the corresponding time of flight in each case. It is observed that the cylinder **C_2** takes much more time in case of the aluminium pipe than in case of the PVC pipe.

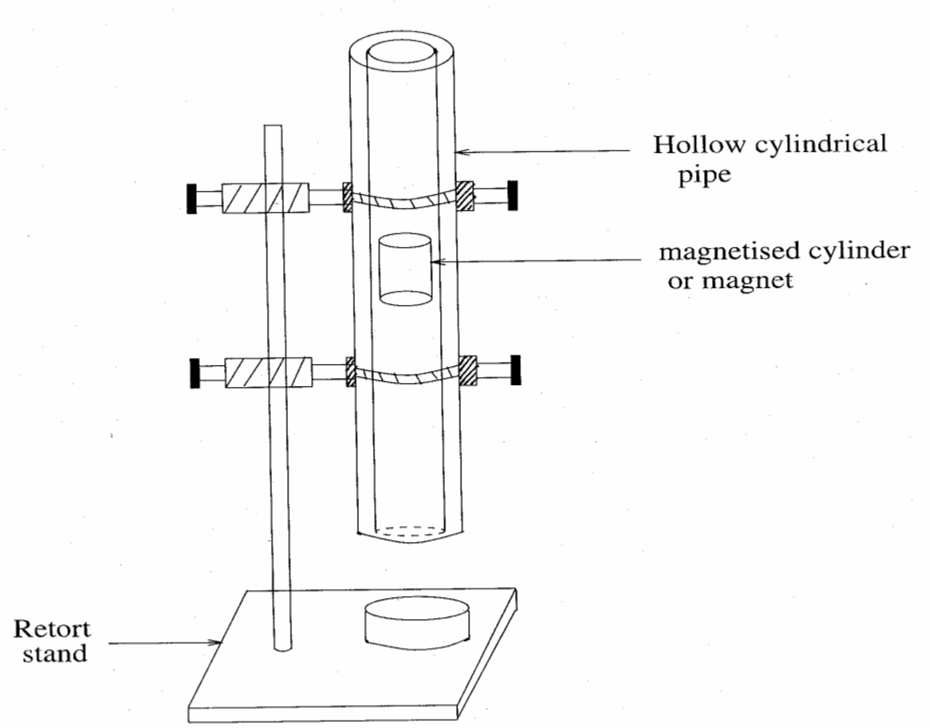

Fig. 5.1.2.3 The schematic of the experimental set-up

Question 2. Why is the time of flight for the cylinder **C_2** different for the aluminium and the PVC pipe ?

Explanation. The cylinder **C_2** takes more time in the aluminium than in the PVC pipe. This indicates that in the case of aluminium pipe there must be some upward breaking force on **C_2**, which slows down the motion of **C_2** through the aluminium pipe and hence it takes more time.

Question 3. What is the origin or the cause of the damping of the motion of $\mathbf{C_2}$, in the case of aluminium pipe ? Explain.

Explanation. The magnetic field of cylinder $\mathbf{C_2}$ (which is a magnet) as seen by each small region on the stationary conductor is changing, as the magnet is moving downward. This induces an ***emf*** and therefore currents (i.e. eddy currents) in the body of the conductor. Because of these currents the magnetic cylinders will experience a force. According to Lenz's law the direction of this force should be such as to oppose the change in the magnetic field; i.e. the force tends to retard the downward motion of the cylinder, which is the cause of the change in the magnetic field. Thus the motion of the magnetic cylinder $\mathbf{C_2}$ slows down, this is refereed to as electromagnetic damping.

Question 4.Why the time of flight for $\mathbf{C_1}$ and $\mathbf{C_2}$ in PVC pipe is the same?

Explanation. PVC is a non-conducting material. When a magnet falls through PVC pipe, eddy currents are not induced. Hence no electromagnetic damping effect is experienced by the cylinders $\mathbf{C_1}$ and $\mathbf{C_2}$.The cylinders fall freely under gravity. Their masses being the same, both the cylinders take the same time.

Part C

Now drop cylinders $\mathbf{C_2}$ and $\mathbf{C_3}$ through the aluminium pipe and corresponding time of flight is measured. It is observed that the time of flight for $\mathbf{C_3}$ is more than that for $\mathbf{C_2}$.

Question 5. Why the time of flight for $\mathbf{C_3}$ is more than that for $\mathbf{C_2}$ in the aluminium pipe? What is the likely cause?

Explanation. In case of the aluminium pipe for $\mathbf{C_2}$ and $\mathbf{C_3}$ there is a damping force, which opposes the downward motion. This damping force is more for $\mathbf{C_3}$ than for $\mathbf{C_2}$. This indicates that the magnetic pole strength of $\mathbf{C_3}$ is more than that of $\mathbf{C_2}$. Thus it may be inferred that the effect of electromagnetic damping depends on the strength of the magnetic field.

Part D

When a magnet is dropped through an aluminium pipe, it accelerates for some time and then it attains and thereafter falls with a terminal (constant) velocity. The terminal velocity depends on the magnetic pole strength and the weight of the magnet along with some other parameters. Drop cylinder $\mathbf{C_3}$ thorough the brass pipe. Measure its time of flight. Compare this with the time of flight for the same cylinder $\mathbf{C_3}$ through the aluminium pipe. It is observed that the time taken in aluminium pipe is more than that of the brass pipe.

Question 6. Why is the time of flight for **C_3** in aluminium and brass pipes different?

Explanation. Aluminium and brass both are good conductors of electric current, but their conductivity is different. The conductivity of aluminium is more than that of brass; hence the damping effect is more in aluminium than in brass.

Question 7. Mention some other parameters on which the time of flight for the magnetic cylinders in this experimental problem may depend.

Explanation. The time of flight of a magnetic cylinder may depend on,

1) The geometry of the magnetic cylinders and cylindrical hollow pipes.
2) Initial velocity of the magnetic cylinders when it enters the pipe.
3) Length of the pipe.
5) Wall thickness of the pipe.

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5.2 Other experimental problems and demonstrations

In the earlier section of this chapter, we have described a specimen experimental problem and its demonstration in detail. We feel that it is not necessary and even possible to give all such details for the remaining nine experimental problems and demonstrations developed by us. We have given the students' handout for all the nine experimental problems in **Appendix A** and the instructors' handout for all the nine demonstrations in **Appendix B** at the end of this thesis. Here, we describe briefly for each experimental problem, its brief description, the necessary experimental arrangement and the salient features. Along with each experimental problem, the objective and the brief description of each of the accompanying demonstration are also given.

5.2.1 Experimental Problem No. 2

A) Brief description

It is observed that, in most of the experimental situations, while determining the spring constant for a spring (with a spring mass system), we neglect the effect of the mass of the spring on the equilibrium extension of the spring or on the time period of oscillations for a given mass attached to the lower end of the spring. It is found that in case of soft massive springs, the mass of the spring cannot be neglected. These types of springs have extension under their own weight and therefore need a correction for this extension. Similarly, these springs can oscillate without any attached mass, which implies that the standard formula for the time period of oscillations of a spring mass system needs modifications. We have theoretically worked out the modification and corrected the formula for the determination of equilibrium extension and also the time period of oscillations. Interestingly, one finds that the mass correction factor in these two cases is not the same.

In part A and B of this experimental problem, students are supposed to determine the spring constant and the mass correction factor for the given soft massive spring and verify the modified formulas in both the static (i.e. extension) and dynamic (i.e. oscillations) cases.

A soft massive spring clamped at both the ends can be assumed to be a uniformly distributed mass system. It has its own natural frequencies of oscillations (corresponding to different normal modes) like a hollow pipe closed at both the ends. Using the method of resonance one can excite different normal modes of oscillations of the spring. In part

C, of the experimental problem, students are supposed to use a variable frequency mechanical vibrator assembly to force oscillations on the spring. They use this to excite different normal modes of oscillations of the spring and study the longitudinal stationary waves on the spring. Students also measure the frequencies of oscillations corresponding to different normal modes. From these, they determine the fundamental frequency of oscillation with both the ends fixed and compare it with the frequency of oscillations with one end fixed and the other end free as determined in part B of the experimental problem.

B) Experimental arrangement

The complete experimental arrangement for this experimental problem is as shown in Fig. 5.2.1, which is shown below. For part A and B, students are given identical soft massive springs, a retort stand with the clamp and a bosshead, weights along with their hooks, measuring tape / scale and a hand held digital stop clock. The experimental arrangement for part A is very simple, in which a spring may be clamped to the stand at its upper end. Different weights can be attached to the lower end of the spring and the extended length of the spring may be measured for different attached weights. In part B, the spring mass system may be set into oscillations and the time period of oscillations of the spring mass system may be measured for different attached weights. These measurements allow the students to determine experimentally the spring constant and also the mass correction factor in both the cases.

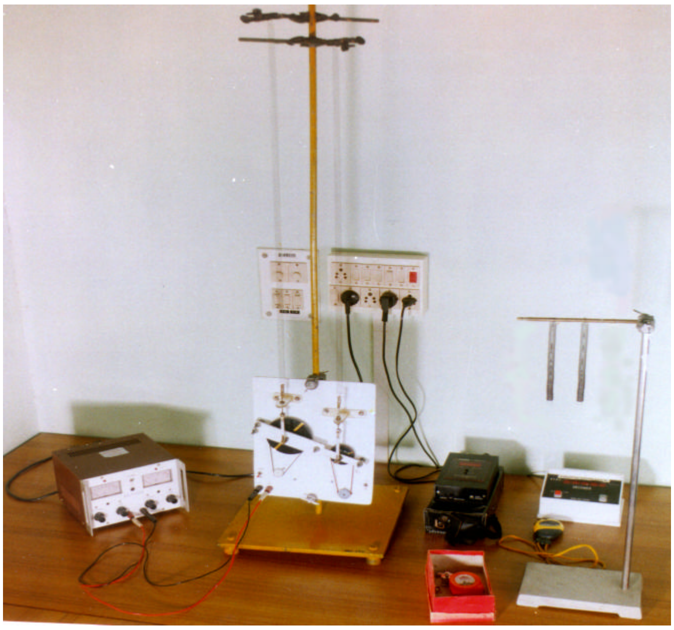

Fig. 5.2.1 The complete experimental arrangement

For part C, students are provided with a long and heavy retort stand with clamps, a variable frequency mechanical vibrator assembly, a digital tachometer, a D.C. regulated power supply and two connecting cords. In this case two identical soft massive springs are clamped at the upper end on the long retort stand. The variable frequency mechanical vibrator is fixed near the base of the retort stand. The lower ends of the springs are fixed to the vibrating strip of the vibrator. The vibrator assembly consists of two independent vibrators, identical in principle, but their vibrating frequencies are different. For vibrator A, the maximum frequency is 20 Hz and the vibrator B can go up to 80Hz. A D.C. regulated variable power supply (0 –30 V, 1A) is used to supply the necessary power to the vibrator assembly. The frequency of vibrations may be controlled and tuned by changing the voltage applied and the current. A digital non-contact type tachometer is provided to measure the frequency of vibrations i.e. forced frequency.

Students are supposed to excite different normal modes of oscillations by tuning the frequency of the vibrator. These resonant frequencies are to be measured and from this data, by plotting a graph, the value of the fundamental frequency is to be determined.

C) Salient features

In this experimental problem, the development of laboratory skills involved in adjustment, measurement, use of apparatus, judgment and control are emphasized along with the procedural understanding and different concepts of evidence. This problem is designed basically to verify and support experimentally, a modified version for a well-known formula. It also is a unique experimental situation, which demonstrates the stationary longitudinal waves on a spring system, which otherwise are always observed indirectly. This problem is designed to develop in students, concepts of evidence required for design, measurement and data handling. It also helps students foster different cognitive abilities like interpreting and inferring.

In this experimental problem, students are given instructions on the use of a digital hand held tachometer, variable frequency mechanical vibrator assembly, D.C. regulated power supply and the digital stop clock. They are also given some simple procedural instructions. In the students' handout, five questions are asked, which are designed around the concepts of evidence related to design and data handling, and conceptual understanding. The problem involves inquiry, skills and investigation type of practical work.

We describe below the learning objectives of the questions asked in the handout. Q. 1 and 2. are intended to develop an understanding about selection of variables and choice of scale while plotting a graph. It also demands the ability to explain the behavior or the interdependence of the parameters plotted. It also helps in using and interpreting the data presented in the form of a graph to derive the meaningful results. Q.3 is intended to develop an understanding about the techniques and methods of measurements and their advantages. Q.4 helps students to develop the procedural understanding especially the concepts of evidence related to the design of an experiment. Q.5 is intended to develop an ability to synthesize and apply acquired conceptual understanding to a new situation in order to explain the theoretical basis of observed behavior.

We feel that it is not necessary to give here all the details about different learning outcomes (as given for experimental problem No. 1) for this experimental problem. We found that the substantive concepts involved in this experimental problem, are elementary concepts in mechanics, especially in simple harmonic oscillation, waves and static and dynamic behavior of a spring mass system. The laboratory skills involved are of the following types: 1) Handling or manipulation 2) Alignment or judgment 3) Use of instruments 4) Measurements and control 5) Drawing graphs and tables.

Thus this experimental problem is designed to develop in students laboratory skills, procedural understanding and concepts of evidence associated with design, measurement and data handling.

5.2.2 Demonstration No. 2

A) The objective

The following demonstration serves as a prelude to Experimental Problem No. 2. For the delivery of this demonstration we follow the same format as is used for demonstration No.1. The demonstration is delivered in an interactive manner, in which the instructor asks questions to the students and gets them answered from the students. He may provide some hints if found necessary. This demonstration is designed around illustration and observation type of practical work.

The demonstration illustrates and explains the concept of stationary waves in the transverse mode and dependence of the number of harmonics (loops) on the tension in the string and the length of the string.

B) Brief description

In the experimental set up for this demonstration, a long metal rod is attached to a fixed frequency vibrator, which vibrates with mains frequency i.e. 50 Hz. Five elastic strings are tied to this vibrating metal rod and the other ends of the strings are clamped on the aluminum stand as shown in Fig.5.2.2 The strings can be stretched and the tension in the string may be adjusted using the clamping screws.

In this experimental set up, we found that an elastic string gives a fairly steady and visible stationary wave pattern. It is observed that with the elastic strings we can simultaneously observe on different strings, stationary waves corresponding to fundamental to fifth harmonic. Hence, in spite of the fact that the mass per unit length of the elastic strings changes with its stretching, we have used the elastic strings for this demonstration. In this demonstration by adjusting the amount of stretching of the string one may excite different normal modes of vibrations of the string. The instructor is supposed to demonstrate the stationary wave pattern on the string. For this demonstration six questions are designed which illustrates concepts like stationary waves, resonance, node and antinode. The dependence of number of harmonics on the tension in the string and the length of the string is also explained.

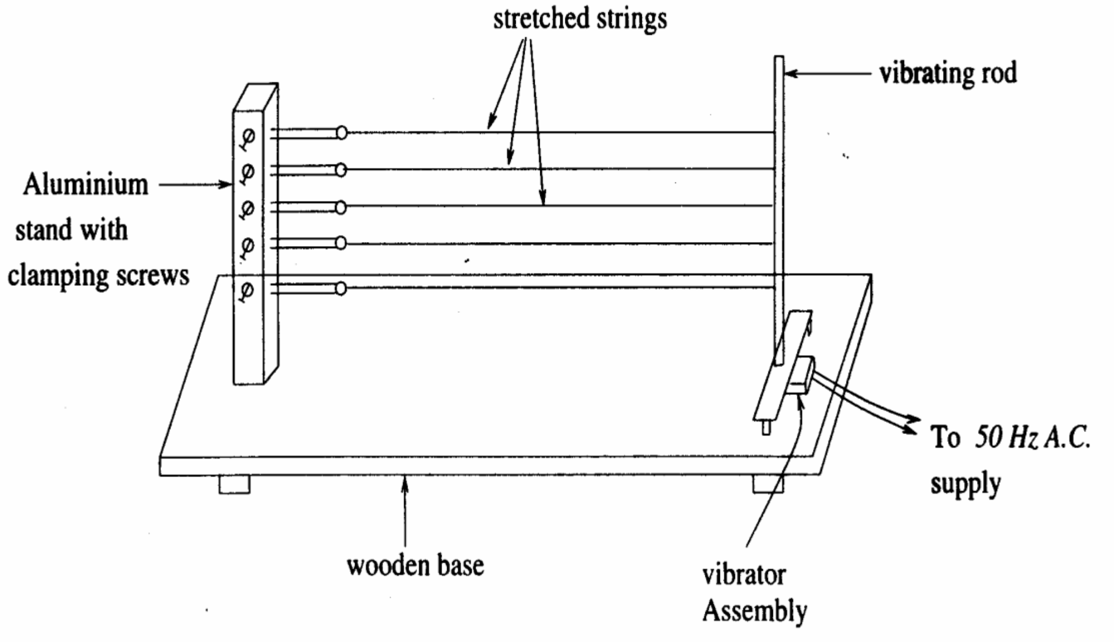

Fig. 5.2.2 The demonstration set-up

More information about the questions and the explanation along with the other details of the demonstration are included in the instructor’s handout given in the Appendix B.

5.2.3 Experimental Problem No. 3

A) Brief description

As we know the operational amplifier (Op-Amp) is a very useful device for constructing different analog or digital circuits. Its unique characteristics (i.e. high input impedance, low output impedance and high open loop gain) make it even more suitable in constructing circuits to be used for performing different mathematical operations. In this experimental problem, a circuit of a tunable sharp filter is given to the students. The circuit is deigned using three Op-Amps, two of which are used as integrators and the third one as a unity gain inverter. This circuit filters out only those sinusoidal waves, which match with its tuned frequency. The tuned frequency of the filter may be changed by altering the values of resistors and capacitors.

In Part A of this problem, students are supposed to study a Op-Amp based tunable filter circuit. In this they observe the output waveforms and amplitudes for different input waveforms (i.e. sine, square, triangular, ramp, etc.) of different frequencies and amplitudes near and below the theoretically calculated tuned frequency of the filter. In Part B, the students are supposed to Fourier analyze a square waveform using sharp Op-Amp filter circuit tuned at a fixed frequency. In this Part, the tuned frequency of the filter is fixed whereas the input frequency is changed to infer about the frequency ratios and the amplitude ratios for the different sinusoidal components. That is, the students have to change the input frequency of the square wave keeping the input voltage (i.e. amplitude) constant and when any harmonic of this frequency matches with the tuned frequency of the filter, they get voltage maxima at the output. This method of Fourier analysis is permitted in our case since we note that for square waves the amplitudes a_1, a_3, a_5, a_7,……………for different harmonics depends only on the value of V_o i.e. the maximum amplitude of the wave to be analyzed.

In Part C of the problem, the students are supposed to design an appropriate method to Fourier analyze a triangular waveform and determine the amplitudes and frequencies of different sine and cosine (if any) components present in the waveform.

B) Experimental arrangement

The experimental arrangement for this problem is as shown below in Fig. 5.2.3. Three operational amplifier (IC 741) circuit boards are provided with different connecting sockets. These boards can be used to connect the Op-Amps in the desired configuration. On these circuit boards, fixed value resistors and capacitors are provided, which may be connected in the feedback or the input circuit. A Γ15V d.c. regulated power supply is available to provide the necessary power to the Op-Amps. A function generator is provided which may be used to apply different waveforms at the input of the filter. A dual trace cathode ray oscilloscope (CRO) with auto measurement facility is provided to observe the waveforms and carry out the desired measurements. Two digital multimeters are provided which can be used for the measurement of frequency or the amplitude (i.e. the voltage) of the waveforms. A set of connecting cords and B.N.C. connectors are made available for the connections to be made on the circuit boards.

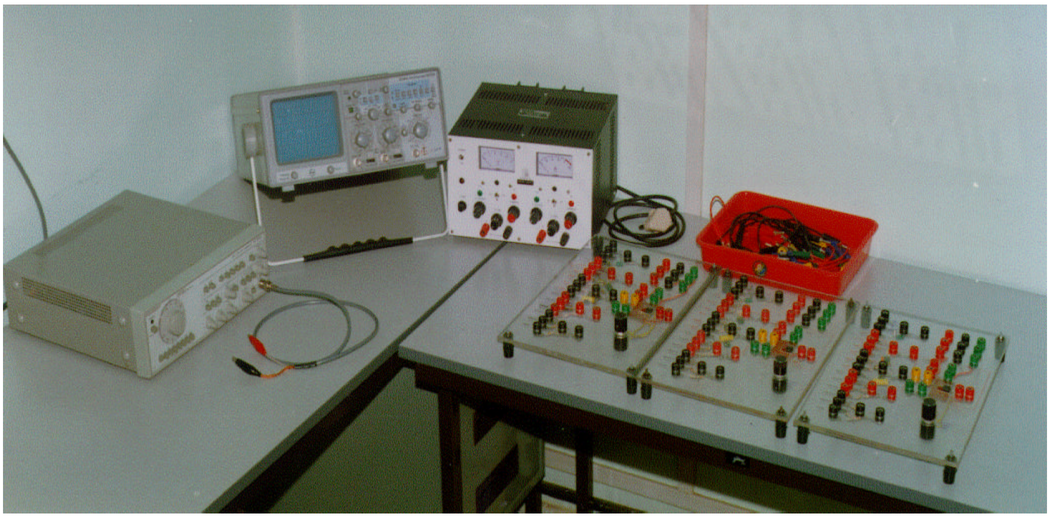

Fig. 5.2.3 The complete experimental arrangement

C) Salient features

In this experimental problem the development of concepts of evidence associated with design and procedural understanding is emphasized along with the skill involved in the use of instruments. Students are supposed to design an experimental procedure to Fourier analyze the waveform and perform the required measurements to determine the frequencies and amplitudes of the Fourier components present in the given wave form.

This experimental problem is designed, to introduce a technique of Fourier analysis to the students and also to develop the problem solving ability in experimental physics. This problem is mainly based on the problem solving or investigation type of practical work, but it also involves skill and exploratory type of practical work. In Part A of the problem, students are supposed to explore and study the input-output behavior of a filter circuit tuned at a fixed frequency. This also involves skills needed to use different electronic instruments to perform the desired measurements.

In this problem, the students are given instructions on the use of Op-Amp circuit boards, dual trace CRO, d.c. regulated power supply, function (signal) generator and digital multimeters. They are not given any procedural instructions; instead, they are supposed to design their own method of Fourier analysis. In this problem three questions are asked which are mainly based on concepts of evidence related to design and procedural understanding.

Thus this experimental problem is designed to develop problem solving ability, concepts of evidence associated with design and procedural understanding along with the skill involved in the of use of instruments. It also introduces a technique of Fourier analysis using a simple circuit.

5.2.4 Demonstration No. 3

A) The objective

This demonstration serves as a prelude to Experimental Problem No. 3. This demonstration is delivered to students in an interactive manner. It is designed around illustration and observation type of practical work.

In the experimental problem, students are supposed to Fourier analyze a square and a triangular wave using a sharp filter circuit constructed using operational amplifiers (Op-Amps). We found that for the students it is difficult to understand the use and working of the filter circuit, which uses three Op-Amps, two of which are used as integrators and the third one as unity gain inverter. Hence we have designed this demonstration, which aims at introducing to the students the use of the new device, i.e. Op-Amp and familiarizing them with the two circuits made of Op-Amps, namely, a unity gain inverter and an integrator.

This demonstration explains the input output characteristics and the principle of working of these two circuits. It also explains the concept of gain, (i.e. voltage gain) inversion, integration, amplification and attenuation.

B) Brief description

The experimental set-up for this demonstration consists of one Op-Amp (IC 741) circuit board, one dual trace CRO, one d.c. regulated power supply, one signal generator, connecting cords and B.N.C. connectors. The Op-Amp circuit board consists of a 741 IC Op-Amp, with the connections taken out as terminal and a set of fixed value resistors and capacitors. The Op-Amp can be connected in different configurations using these resistors and capacitors provided on the board. A dual trace CRO is used to observe the input or output waveforms and to perform voltage and frequency measurements. A d.c. regulated power supply is used to provide the necessary power to the Op-Amp IC. A signal generator is used to take out different waveforms to be applied as the inputs to different circuits.

In part A, B and C of the demonstration the input-output relations and the working of an inverting amplifier is studied. In this study, the students are experimentally shown and explained, the gain dependence on the value of feedback resistor R_f for a fixed value of input resistance R_{in}. Then the working of a unity gain inverter is explained to students wherein $R_f = R_{in}$. Students are also given information on an inverting attenuator for a fixed frequency.

Then in parts D, E and F of the demonstration a simple ideal Op-Amp circuit for an integrator is explained to the students. Students are given information on how it works as an integrator. The input and output relationship is explained and actually demonstrated on CRO for different input signals i.e. d.c., square, sine and triangular. It also explains how the same circuit acts as an active low pass filter.

5.2.5 Experimental Problem No. 4

A) Brief description

In this experimental problem, students are supposed to study two different configurations of a magnetic circuit. Through this problem, we introduce and explain the basic concepts like magnetic flux, electromotive force, magneto motive force, magnetic circuit and reflected impedance. We know that in case of a transformer core, the magnetic flux generated by the current in the coils is confined to the core due to its high magnetic permeability and absence of air gaps. The transformer core used in this experimental problem presents an interesting example of a simple magnetic circuit. In Part A of the problem, a configuration of a two loop magnetic circuit is considered in which two coils are wound on the central leg on an ordinary laminated iron core. The two coils i.e. primary and secondary are wound with 1:1 turns ratio and 300 turns each of 23 *SWG* copper wire. The cross sectional area of the central leg is twice that of the extreme legs. Students are supposed to pass a current through the primary and perform the necessary measurements of currents and voltages with different load resistance in the secondary circuit. They are supposed to explain the variation of current and voltage in the primary due to different loading at the secondary and hence explain the concept of reflected impedance.

In Part B of the problem, a more involved and interesting configuration of a magnetic circuit is considered, in which three coils are wound on three legs of an ordinary laminated iron core. In this case also, the cross sectional area of the central leg is twice that of the extreme legs. Three coils i.e. a primary, left secondary and right secondary are wound on each of the three legs with the turns ratio 1:1:1 and 80 turns of 15 *SWG* copper wire. Students are supposed to establish a current in the primary coil using an external source and the analysis of currents in the primary and both the secondary coils is to be done for different loads connected in both the secondary circuits. Students are also supposed to verify and explain theoretically the expected current and voltage relationships with different loading at the secondary coils.

B) Experimental arrangement

As described earlier, in Part A of the problem a simple configuration of a magnetic circuit is considered which is designed around a three legged transformer, in which two coils of copper wire each of 300 turns are wound on the central leg of the laminated iron core. The cross sectional area of the central leg is twice that of the extreme legs. One of the coils may serve as a primary and the other secondary. This transformer is fixed on a wooden board and the connecting terminals for the coils are provided on the board. Three high watt fixed value resistors are provided on the board, which may be used for the measurements or to limit the current. Also a 6 *Volt*, 15 *Watt* bulb is provided with its connecting holder. An 18 - 0 - 18 *Volt*, 2 *Amp* step down

Fig. 5.2.5 The complete experimental set-up

transformer is used to supply the necessary current in the circuit. Digital multimeters are provided to measure the voltages and currents. The complete experimental arrangement for this experimental problem is, as shown in Fig. 5.2.5.

For Part B of the experimental problem the magnetic circuit is designed around a three-legged transformer core. As described earlier, the core is a normal laminated iron core wound with 80 turns of 15 *SWG* copper wire on each leg. The cross sectional area of the central leg on which the primary coil is wound, is twice that of either of the side legs on which the secondary coils are wound. The connecting terminals are provided for each coil. A 6 *Volt*, 2 *Amp*, supply drawn from a step down transformer is provided to establish the necessary current in the primary coil. A 6 *Volt*, 15 *Watt* bulb is provided, which may be used as a load for the demonstration. A resistor ladder is provided, which consists of a set of resistors mounted on a wooden board with their connecting sockets. The resistors may be connected in series or in parallel as per the requirement. Digital multimeters are provided to measure currents and voltages. Two rheostats with three stages of resistance 10 *W*, 25 *W* and 50 *W* with 5 *Amp* current capacity are provided which may be used as a variable load in the secondary circuits. Also provided are the connecting cords.

C) Salient features

This experimental problem is designed to develop conceptual understanding in the field of dynamic electricity and magnetism; particularly, concepts like magnetic flux, electro-motive force, magneto-motive force, magnetic circuits and reflected impedance. It builds students' understanding about the principle and the working of a transformer on the basis of simple concepts and laws.

In this problem, the emphasis is on the development of conceptual understanding rather than on procedural understanding and hence concepts of evidence. Also, the problem involves relatively simple laboratory skills with respect to use of instruments. It is designed basically to verify and support experimentally, the theoretically predicted relationships between the currents and voltages in case of two simple configurations of magnetic circuits. It also brings out the concepts of back electromotive force and reflected impedance. The problem also helps students develop different cognitive abilities like application, synthesis, interpreting, and inferring.

In this problem, as seen from the handout, students are given a detailed theoretical analysis for the currents and voltages in case of both the configurations of the magnetic circuits. The theoretical analysis also consists of different situations, which may arise with different loading at the secondary circuits. Students are given necessary information on the different instruments and apparatus, i.e. transformer boards, resistor ladders, rheostats, and digital millimeters in an instruction sheet. As seen from the handout, in this problem no questions are asked, but students are supposed to explore and verify the theoretically predicted relationships between different parameters. This experimental problem involves mainly investigation and partly exploratory type of practical work.

5.2.6 Demonstration No. 4

A) The objective

This demonstration is designed to serve as a prelude to the Experimental Problem No. 4. The format of presentation of this demonstration is same as that of the earlier demonstrations i.e. the instructor questions the students and presents the demonstration in an interactive manner. This demonstration involves mainly the observation type and partially the illustration type of practical work.

The demonstration uses a two loop magnetic circuit to explain how the changing magnetic flux linked with a coil gives rise to an induced emf. It also directly or indirectly explains the concepts like, magnetic flux, induced emf, magnetic circuit and the reflected impedance.

B) Brief description

The experimental setup essentially consists of a specifically designed three legged transformer in which two coils of copper wire each of 300 turns are wound on the central leg of the laminated iron core. The cross sectional area of the central leg is twice that of the extreme legs. One of the coils serves as the primary and the other secondary. This transformer is fixed on a wooden board and the connecting terminals for the coils are taken out. Three high watt fixed value resistors are provided, which may be used to limit the current in the circuit. A 6 *Volt*, 15 *Watt* bulb is provided with its connecting holder. An 18-0-18 *Volt*, 2 *Amp* step-down transformer is used to supply the necessary current in the primary circuit. In this demonstration, the circuit connections are made as shown in Fig.5.2.6. The primary coil is connected to an a.c. source (36 *Volt*) in series with a bulb and two resistors. Initially, we keep the points A and B unconnected and put

ON the power to the circuit. We observe that the bulb doesn't glow. We explain through questions, why the bulb does not glow, where the applied voltage gets dropped and the order of magnitudes of currents and voltages across the primary coils.

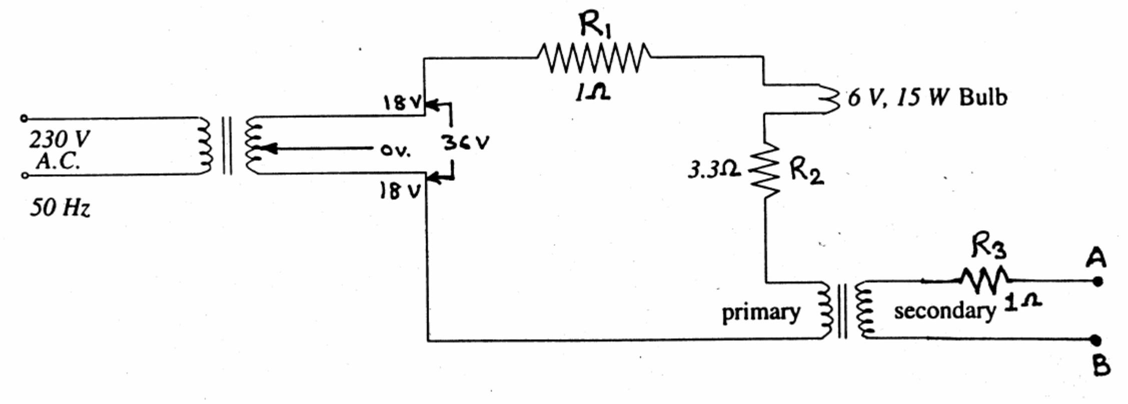

Fig 5.2.6 The circuit diagram

We then measure the induced emf (i.e. voltage) across the secondary coil. We find that this voltage is as large as the primary voltage.

We then short the secondary coil and find a glow in the bulb. We measure the currents and voltages in the primary and secondary circuits, and thus explain the concept of the back emf and reflected impedance. We also explain the dependence of the turns ratio of the primary and the secondary coil on the reflected impedance.

More information about the questions and explanations may be obtained from the instructors' handout given in the Appendix B.

5.2.7 Experimental Problem No. 5

A) Brief description

As we know a physical pendulum is an extended physical object of an arbitrary shape that can oscillate about a fixed axis. In case of a physical pendulum, the shape of the pendulum does not have to be regular. However, knowledge of the distribution of mass is essential since the center of gravity must be known. The physical pendulum used in this experimental problem consists of a cylindrical threaded brass rod (actually a long screw) and a square shaped nut. The pendulum is mounted on the knife-edges fixed to an aluminum stand. One can change and measure the distance x between the point of suspension and the upper end of the rod by turning the nut or the threaded rod.

In Part A of the problem, students are expected to study the variation of the time period of oscillations of the physical pendulum, with the variation of the distance of the axis of rotation from the center of mass of the pendulum. This distance is related to x.

Thus in this Part, students change the distance x and measure for various values of x the corresponding value of time period of oscillations T.

In Part B, students are expected to use the data recorded above and determine the local value of the acceleration due to gravity g. While determining g, students are supposed to take into account the correction due to the presence of the nut, because of which there is a slight shift in the position of the center of mass of the pendulum, as the distance x is changed.

In Part C, of the problem, the magnetic dipole moment of a small magnet embedded at the lower end of the pendulum, oscillating in a magnetic field, is determined by measuring its effect on the time period of oscillations of the pendulum. The given physical pendulum, with a small magnet embedded at its lower end is mounted on the knife-edges. Another strong cylindrical disc magnet is mounted on a vertically adjustable stand kept just below the equilibrium position of the pendulum. Because of the presence of magnetic field of the disc magnet, the pendulum experiences an attractive force, the effect of which gets added to the effect of acceleration due to gravity and thus the time period of the physical pendulum is decreased. This altered time period of the pendulum is measured for different distances between the two magnets, and thereby the magnetic moment of the magnet embedded at the lower end of the pendulum is determined.

B) Experimental arrangement

The complete experimental arrangement for this experimental problem is shown in Fig. 5.2.7. As described earlier, the physical pendulum used in this problem, consists of a cylindrical fully threaded brass rod and a square shaped nut. The pendulum can be mounted on the knife-edges provided on the aluminum stand. A small cylindrical magnet is embedded at the lower end of the pendulum rod. The axis of this magnet coincides with the axis of the pendulum rod and the density of the material used for the magnet is found to be very close to the density of the brass. Hence we found that actual center of mass of the rod coincides with the midpoint of the rod.

The time period of oscillations of the pendulum may be measured using the timer. The timer consists of a digital stop-clock, a control unit and a photo-detector. The photo-detector is mounted on the aluminum stand so that when the pendulum oscillates, the pointer attached to the square nut obstructs the light beam of the photo-detector, which supplies a necessary signal to the control unit. The control unit is programmed to display the time period for the third oscillation of the pendulum after resetting the timer.

Fig. 5.2.7 The complete experimental arrangement

A strong cylindrical disc magnet is fixed on a non-magnetic stand, the height of which can be changed either by adjusting the base table using an adjustable screw or more precisely by using the micro-stage with a micrometer screw. The micrometer screw may be used to measure accurately the distance between the lower end of the pendulum and the disc magnet. A set of acrylic discs and cylinders of different thickness is provided, which may be used as a reference for the measurement of the distance. A metallic cone is provided to adjust the position of the cylindrical disc magnet so that the axis of this magnet coincides with the axis of the pendulum, when the pendulum is in equilibrium position. A spirit level and a micrometer screw gauge are also provided.

C) Salient features

In this experimental problem, there is emphasis on the development of all three aspects of practical physics, namely, conceptual understanding, the laboratory skills, and procedural understanding along with different concepts of evidences. The concepts to be understood are the small oscillations, the physical pendulum, the moment of inertia, the parallel axis theorem, the magnetic field of a bar magnet along its axis and off the axis. The laboratory skills involved are of the type, handling or manipulation, adjustments, measurements, use of apparatus, alignment, judgment and control, and drawing graphs and tables. The concepts of evidences involved are more of design, measurement and data handling type.

In this problem, students are asked to estimate the error getting introduced in a derived variable on account of the errors or uncertainties in the individual measurements. This helps students develop the understanding of estimation of errors and importance of significant figures, while reporting the laboratory work.

In the handout of the problem, students are given a detailed theoretical basis of the experimental situation and the problem. They are supposed to understand this theory and apply it for the determination of the required parameter. The students are also given detailed instructions on the use of different instruments and about the experimental set-up in a separately provided instruction sheet. They are given almost all the necessary procedural instructions but are forced to think on different concepts of evidences and take decisions about the design, measurement and data handling. For example, no exact numerical value of the independent variable is suggested and students are asked to select a proper value to obtain the best result.

This experimental problem mainly involves inquiry and skills type of practical work, partially involves investigation type. From the handout it may be seen that students are supposed to answer six questions during their laboratory work on the problem. These questions are designed around plotting and interpretation of graphs, obtaining the required result from the graph, the conceptual understanding involved in the precautions to be executed while performing measurements and the application to a new experimental situation.

The digital timer used in the experimental problem has been designed and calibrated by the researcher. The calibration of the timing device was carried out using a highly accurate digital storage type oscilloscope. The frequency, its stability and the overall reliability of the crystal oscillator were studied. We found that the idea of introducing the magnetic interaction and measuring the effect of this interaction on the time period of oscillation of the physical pendulum is interesting and innovative. Even though a rigorous theoretical analysis of the problem may be complex, we have made some simplifying assumptions, using which the experimental problem has been successfully designed.

5.2.8 Demonstration No. 5

A) The objective

This demonstration is designed to serve as a complementary prelude to Experimental Problem No.5. It is presented in an interactive manner, like the earlier demonstrations. It involves illustration and observation type of practical work.

The demonstration illustrates the oscillations of a physical pendulum and explains the dependence of its time period on the distance between the point of suspension and the center of mass of the pendulum. It also explains how this period is altered in the presence of an external magnetic field for a ‘magnetic’ physical pendulum. This demonstration is thus designed to introduce, illustrate and explain the above-mentioned key concepts involved in the Experimental Problem No.5

B) Brief description

In this demonstration, the experimental arrangement consists of a physical pendulum (a solid brass sphere attached to one end of a solid cylindrical stainless steel (s.s) rod), which can oscillate about a given axis. The pendulum is supported on two pointed screws fixed to a C-shaped stand. A nut mounted on the pendulum rod rests on the screws. The nut may be clamped to the s.s. rod of the pendulum which can move up and down on the rod. This allows us to change the distance between the center of mass of the pendulum from the axis of rotation. A small cylindrical magnet is embedded in the brass sphere so that the axis of this magnet coincides with the axis of the cylindrical s.s. rod. We call this pendulum, a magnetic physical pendulum. A digital timer is provided along with a C-shaped photo-detector, which can be used to measure the time period of oscillations of the pendulum. Also provided is a strong cylindrical disc magnet mounted on a non-magnetic stand with an adjustable height. This magnet may be mounted below the equilibrium position of the pendulum and the magnetic field produced by this magnet is assumed to be uniform over a horizontal plane for some distance (20 *mm*), from the axis of the magnet. A 150 *mm* metal measuring scale and a one *meter* long measuring tape is provided to measure distance.

In this demonstration, first of all, the dependence of the time period of oscillations T of the physical pendulum on the distance l of the center of mass of the pendulum from the axis of rotation is observed and explained. For this we actually change the position of axis of rotation and hence change the distance l and measure corresponding time *T*. We then introduce the strong magnet below the pendulum. We observe that the time period of oscillations for the same distance *l*, changes with the introduction of the disc magnet. We explain the cause of this change. We then increase the gap between the pendulum and the magnet in uniform steps and study its effect on the time period of oscillations. We also observe that the change in the time period *T* is not linearly proportional to the gap between the pendulum and the magnet.

5.2.9 Experimental Problem No. 6

A) Brief description

In Part I of this experimental problem. Students are expected to study the motion of spherical ball rolling down on a straight plastic track with a U-shaped cross section, inclined at an angle by analyzing its position versus time behavior.

A two-meter long plastic track is mounted on an aluminum base; on this plastic track the spherical ball can roll down touching the edges of the track. A digital timer may be used to measure the time taken by the ball to roll through a prefixed distance. Students have to measure the time *t* the ball takes to roll through the different distances *S* for two different values of the angle of inclination of the track with the horizontal. From this data of *S* and *t*, the students are expected to study the motion with respect to its velocity and acceleration and determine the acceleration of the ball (which is a constant) for both the inclinations. They are also expected to take into account the rolling motion of the steel ball and determine the local value of acceleration due to gravity *g*. Also, they are supposed to estimate the percentage error in the values of acceleration of the ball and the acceleration due to gravity.

In Part II, of the experimental problem, the students are expected to study the motion of a freely falling spherical ball and determine the acceleration due to gravity *g*. In this Part, the students use a spherical steel ball for which the air resistance is very small and hence we neglect the air resistance. The students let the ball fall freely only under the influence of force of gravity. They record the time *t* the steel ball takes to fall through a prefixed distance *S*. Thus for different distances, the *S* and *t* data is recorded. From this *S* and *t* data, the students are expected to determine the local value of acceleration due to gravity *g*. They are expected to estimate the percentage error involved in the determination of the value of *g*.

B) Experimental arrangement

The complete experimental arrangement for Part I of the experimental problem is as shown in Fig. 5.2.9 (a).

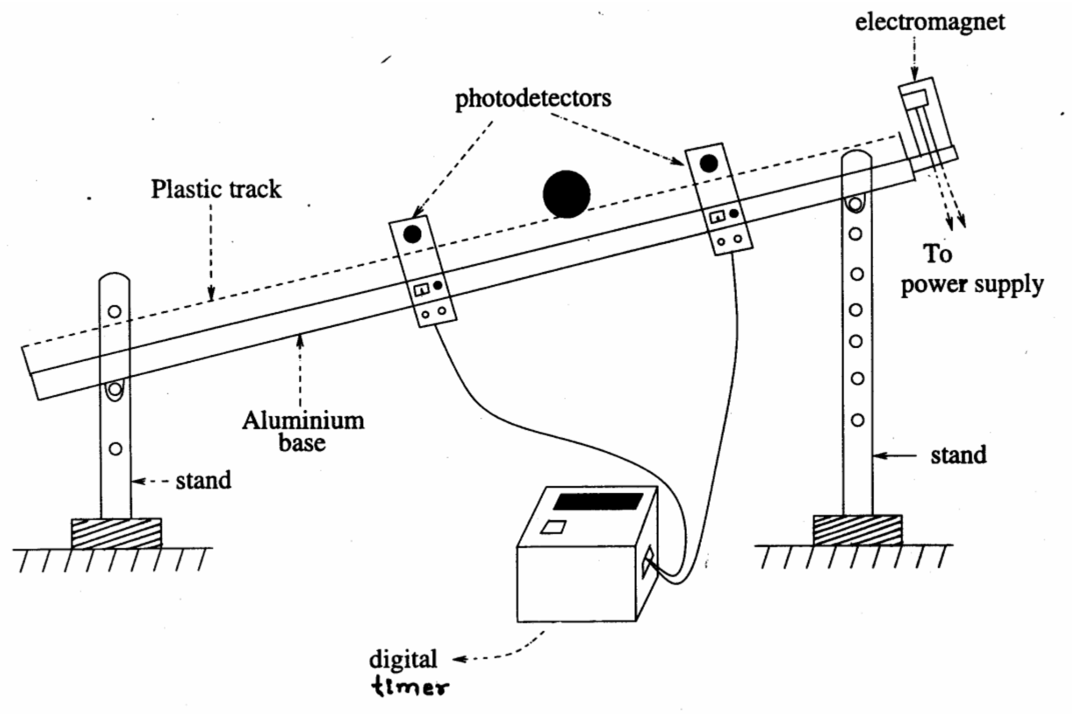

Fig. 5.2.9 (a) The complete experimental arrangement for Part I

In the experimental set-up a two-meter long aluminum base is mounted on two stands of different and adjustable heights so that the track makes an angle q with the horizontal. The inclination q may be changed by changing the height of the stands. A two-meter long U-shaped plastic track is fixed on this aluminum base. An electromagnet is fixed to one end of the track, which holds the ball and releases it from the same initial position each time. A d.c power supply is used to provide the necessary power to the electromagnet.

Two movable photo-detectors are mounted on the aluminum base. The position of the detectors, may be changed by moving the detectors along the length of the track and may be fixed using the screws on both the sides of the detectors. These detectors are connected to the digital timer. The digital timer measures and displays time the ball takes to roll down through the distance between the two detectors. The distance between the detectors may be adjusted and measured using a measuring scale fixed on the aluminum base and the wire (pointer) fixed on the detector. Students may keep the position of detector A (which starts the timer) fixed at a convenient distance from the electromagnet and change the position of the other detector B (which stops the timer), for the measurement of time for different distances. Two highly polished solid spherical steel balls are provided. Also provided is a meter scale and a measuring tape.

The experimental arrangement for Part II of the experimental problem is as shown in Fig. 5.2.9 (b)

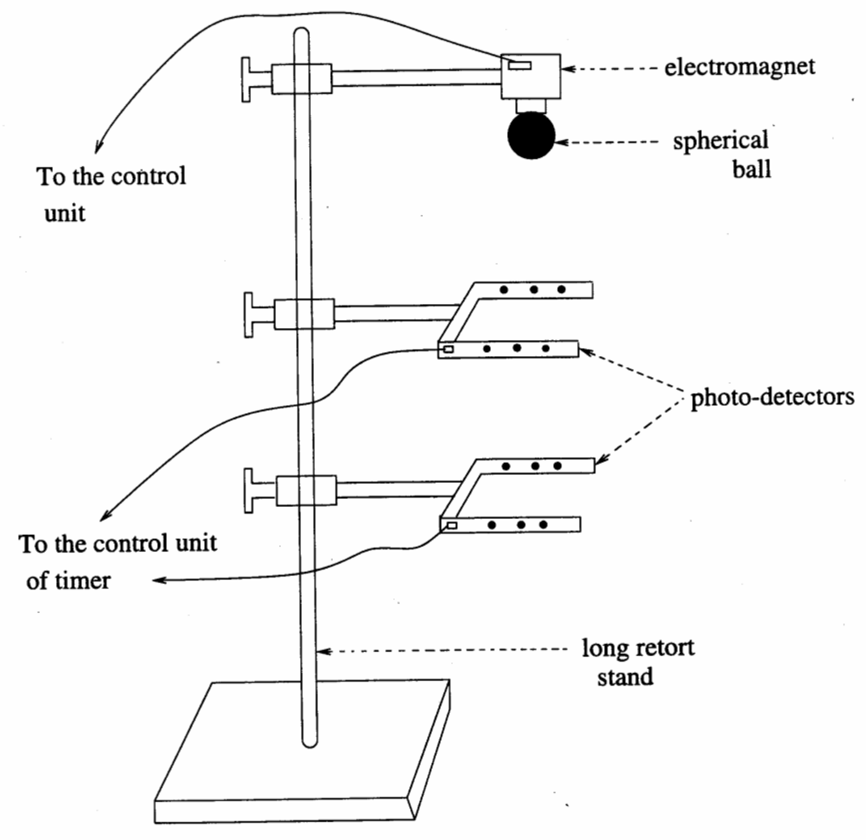

Fig. 5.2.9 (b) The complete experimental arrangement for Part II

The experimental setup consists of a long retort stand on the top end of which a small electromagnet is clamped, to hold the ball. Pressing of the switch of the control unit cuts off the power supply to the electromagnet and the ball gets released. The electromagnet is purposely used so that the ball gets released from the same position each time. For the measurement of time, a digital timer is provided which consists of a digital stop clock, a control unit and two C-shaped photo-detectors along with a frequency meter to calibrate the digital timer. The position of photo-detectors can be changed using a boss head and a clamp. Again in this case also, the detector A (which starts the timer) can be clamped just below the electromagnet and the other detector B (which stops the timer) can be clamped at any convenient distance from the detector A. The detectors detect the crossing of the ball and the digital timer displays the time the ball takes to fall through the distance between the detectors. Markings are made on the detectors, which can be used to measure the distance between the two detectors. A measuring tape is provided for the measurement of different distances.

C) Salient features

This experimental problem is designed to develop in students, mainly procedural understanding and concepts of evidence and partially laboratory skills and conceptual understanding. In this problem, the students are asked to estimate the error in the determination of a derived variable on account of the errors or uncertainties in the individual measurements. This helps the students develop understanding of error estimation and importance of significant figures. Some procedural instructions are given to the students through the handout. They are also given the information on the use of instruments, description of the apparatus, a brief the introductory theoretical basis of the problem.

In both the parts of the problem very little or no information is given about the concepts of evidence associated with measurement and data handling. The students are supposed to design the most accurate method to determine the value of a derived variable i.e. acceleration a or g. This problem also develops in students, different cognitive abilities like application, synthesis, interpreting and inferring. The laboratory skills involved are relatively simple and are of the type, handling or manipulation, measurements, use of apparatus, adjustments, alignment, judgment and control.

The conceptual understanding involved is simple and is mainly from mechanics, like motion of a spherical object on an inclined plane, rolling of a sphere, motion of a freely falling object, velocity, acceleration, damping, frictional forces etc.

As said earlier, in this problem there are two separate parts (Part I and Part II). In both the parts, the students are expected to study the motion of an object by understanding the distance and time behavior. They are expected to determine experimentally the value of acceleration due to gravity g along with the percentage error in the value of g. As seen from the handout the students are asked seven ‘intermediate’ questions. Most of these questions are designed around the concepts of evidence associated with data handling. They involve use of graphs, plotting of a graph, interpretation of the plot, and advantages of the graphical method to determine a derived parameter. There is a question on the estimation and minimization of errors in the result of an experimental problem. This experimental problem is mainly designed as a skill, observation and illustration type of practical work. It also involves partially the investigation type of activity. Thus the objective of this experimental problem is to develop 1) concepts of evidence associated with measurement and data handling 2) the understanding of estimation of errors and reporting of laboratory work 3) conceptual understanding and 4) the laboratory skills.

5.2.10 Demonstration No. 6

A) The objective

This demonstration is designed to serve as a prelude to Experimental Problem No.6. The format of presentation of this demonstration is the same as that of the earlier demonstrations except that, the number of questions asked to the students is less and more emphasis is given on the explanation by the instructor. This demonstration is designed as an illustration and observation type of practical work.

This demonstration is designed to introduce to students, the use of a new instrument, that is, a digital timer. The objective is to explain the use and principle of operation of a digital timer for measurement of the time interval between two events. The use of the timer is demonstrated in two different experimental situations. Also the mechanism of sensing the passing of ball through the photo-detector is explained and concepts like accuracy, precision, and calibration are discussed.

B) Brief description

In this demonstration the use of digital timer in two different experimental situations is explained. In case of the Parts A, B and C, the timer is used to measure the time a ball takes to roll down an inclined U-shaped plastic track for a prefixed distance. In Part D, the timer is used to measure the time the ball takes to fall freely through a prefixed distance, under the influence of the force of gravity.

In the experimental set-up for the parts A, B and C, a two-meter long aluminum base is mounted on two stands of different heights. A two-meter long U-shaped plastic track is fixed on this aluminum base. An electromagnet is fixed to one end of the track, which holds the ball. A d.c. power supply is used to provide the necessary power to the electromagnet. Two photo-detectors are mounted on an aluminum base, which can move along the length of the aluminum base. These detectors are connected to the digital timer. The digital timer measures and displays the time the ball takes to roll down through the distance between the two detectors. In Part A, the use and adjustments of the detectors and the timer is demonstrated and through a question the principle involved in sensing the passing of a ball through the photo-detector is explained. Then the time measurement is repeated for three to four times keeping the photo-detector arrangement and the inclination the same. Using this data the concepts of accuracy, precision and calibration are explained. Students are also explained the method of calibrating the digital timer.

The experimental arrangement for Part D, of the demonstration consists of a long retort stand with a heavy base on which an electromagnet and two G-shaped photo-detectors are clamped. In this case each photo-detector consists of three photo-gates or photo-pairs, i.e., a pair of an LED and a phototransistor (unlike the earlier case where there is only one photogate in each detector). This is done to increase the sensitive area of the detector. The detectors are properly aligned and connected to the digital timer. The ball is attached to the electromagnet and then released electronically. The ball falls through the two detectors and crosses their sensing area and the timer displays the time interval between the crossings of the ball through the two detectors. This measurement is repeated for different distances between the two detectors and thus the use and principle of working of the digital timer is explained.

5.2.11 Experimental Problem No. 7

A) Brief description

We found that, in the field of electricity and magnetism, one of the most difficult problem for students is the visualization of *lines of forces* and the *equipotential surfaces*. In this experimental problem, we study the nature of electrostatic potentials and the equipotential surfaces for various electrode configurations. For this an electrolytic tank is used, in which the electrodes of different shapes may be arranged. By applying the potential difference between the electrodes, an electric field is constructed inside the tank as an alternating current field. The equipotential curves are studied with the only condition that there is symmetry along the vertical axis. For plotting the equipotential curves, students are expected to identify the locus of points, which lie at the same potential with respect to the reference. The potential distribution can be compared with the solution of Laplace equation (in two dimensions) for the specified configuration and conditions.

Students study the equipotential curves for geometries like 1) two parallel plates 2) one point electrode placed on the angle bisector of a L-shaped electrode and 3) two concentric cylinders. Using the two concentric cylinders, students are expected to study the uniqueness theorem. Also the technique of method of images is to be studied by using the equipotential curves for a point electrode placed in front of a long conducting metal plate.

B) Experimental arrangement

The experimental arrangement for this problem is very simple. It consists of a specially designed acrylic tank (of dimensions 50 x 75 x 7 *cm*). This acrylic tank has a thick and hard base plate on which a large laminated graph paper is pasted. The tank is properly leveled using the acrylic bushes fixed at its bottom. An electrolyte prepared dissolving some potassium chloride (KCL) in water is introduced in the tank. The electrolyte may fill the tank up to half of its height. This electrolyte provides a low resistance path for the current, when the metallic electrodes of different shapes are placed in the tank and an a.c. potential difference is applied between them.

A set of metallic electrodes is provided. This set consists of plates, hollow cylinders, solid cylinders and L-shaped electrodes. The solid cylinder (actually a s.s. rod) may be treated as a point in two dimensions. A digital multimeter is provided along with the probes, which is to be used for the measurement of potential difference. A variable a.c. (50 *Hz*) power supply is provided which has outputs in steps of 1.5 *Volt* up to 9.0 *Volt*, and then the 12 *Volt* output. This power supply is used to establish the necessary potential difference between the electrodes. Two variable resistors are available, which may be used to adjust the potential applied at different electrodes. Also provided are connecting wires and a measuring tape or measuring scale.

C) Salient features

This experimental problem emphasizes the development of conceptual understanding much more than the development of procedural understanding, understanding of concepts of evidence and the practical skills. This problem is designed to explain to the students, the concepts like, the lines of force, equipotential curves or surfaces, and the uniqueness theorem. It also illustrates the principle of method of images, which is one of the most useful technique in electrostatics for predicting the field lines or the equipotential curves for complex distribution of charges. In this experimental problem students plot the equipotential curves for different electrode configurations and develop an understanding about the method or the technique of plotting equipotential curves. The power of this method is in arriving at the euipotential curves for an arbitrary electrode configuration for which a simple analytic solution of Laplace equation cannot be easily obtained. Students are given information on the use of the instruments like, digital multimeter, a.c. power supply. In this problem, as seen from the handout in the appendix, four questions are asked. All the four aim to develop conceptual understanding. Out of these four questions, three require students to predict the expected equipotential curves or the alteration in the observed equipotential curves. The fourth question is based on the uniqueness theorem.

This problem helps students to develop a link between the theory and the experiment. Here students are expected to compare the experimentally observed equipotential curves with the theoretically predicted curves. This experimental problem mainly involves the exploratory and verification type and partially involves investigation type of practical work. It develops relatively simple and less complex concepts of evidences and laboratory skills. The laboratory skills involved are of the type handling and adjustment, measurements, use of apparatus, alignment control and drawing graphs. The concepts of evidences involved are of the type, which are associated with the measurement and data handling.

Thus this experimental problem is mainly designed to develop in students the conceptual understanding related to the introductory concepts in electrostatics and to introduce an innovative technique for plotting equipotential curves.

5.2.12 Demonstration No. 7

A) The objective

This demonstration is meant to serve as a prelude to the Experimental Problem No.7. The objective of this demonstration is to explain to the students 1) the experimental arrangement with its basic necessities, 2) the method or technique of plotting the equipotential curves using the electrolytic tank and 3) the equipotential curves for a dipole geometry. This helps students visualize the lines of force for a dipole geometry. This demonstration is also presented in an interactive manner and is designed as a skill, illustration and observation type of practical work.

B) Brief description

The experimental arrangement for this demonstration is identical with that of the experimental problem. The set-up consists of a specially designed acrylic tank of dimensions (50 x 75 x 7 *cm*). This acrylic tank has a thick base plate on which a large laminated graph paper is pasted at its bottom. The tank is properly leveled using the acrylic bushes fixed at its bottom. In this tank an electrolyte solution is prepared using potassium chloride (KCL) and water. This electrolyte fills the tank up to half of its height. A set of three identical metal solid cylindrical electrodes (actually stainless steel rods) is provided. A digital multimeter is provided along with the probes, which is to be used for the measurement of a.c. voltage (i.e. the potential difference). A variable a.c. (50 *Hz*) stabilized power supply is provided which has fixed outputs in steps of 1.5 *Volts* up to 9 *Volts* and then the 12 *Volts* output. This power supply is used to establish the necessary potential difference between the electrodes. Also provided are connecting wires and a measuring tape or measuring scale.

In this demonstration, first the instructor explains the experimental arrangement along with the finer adjustments and precautions to be executed. The experimental arrangement necessary for plotting the equipotential curves for a dipole geometry is shown. Then the method or the technique (which is to be used in experimental problem) for plotting the equipotential curves is explained and demonstrated. Also the proper method of using the digital multimeter and the power supply is explained to the students.

Through this demonstration, some simple questions about the method and the arrangement are answered. Also the students are asked to draw the expected eqipotential curves for the dipole geometry of electrodes. Actual measurements are done and by finding the locus of points, which lie at the same potential, equipotential curves are drawn for the dipole geometry.

More information about the questions, explanations and the instructions may be obtained from the instructor’s handout given in the Appendix B.

5.2.13 Experimental Problem No. 8

A) Brief description

We know that, ordinary light sources emit unpolarized light, which means that in the case of such light the electric vectors are oriented in random directions, uncorrelated with each other. Light in which all the photons have their electric vectors oriented in the same direction is called the plane-polarized light. The polarization of light may be achieved using different methods. In part A and B of the problem, students are expected to first determine the transmission axes of the given polarizer and analyzer using a reference polarizer for which the transmission axis is known. This is achieved by a comparison method and plotting a graph. In part C, the students are expected to study the relationship between the intensity of light incident on the photo-detector and its output current for any one of the given photo-detectors. They use the law of Malus for this purpose. They are expected to plot an appropriate graph to explain the observed relationship. Actually, for the given photo-detector, there is a linear relationship between the light intensity and the output current, for the given range of intensities.

In part D, the students study the reflection of polarized light from the surface of a transparent prism. In this they use the plane-polarized light with the direction of polarization (i.e. direction of E-vector) parallel to the plane of incidence (i.e. say, P-component) and study the variation of reflectance or reflectivity with the angle of incidence. From this using the Brewster's law, they are expected to determine the refractive index of the material of the prism.

Then in Part E, too, the students are expected to study the variation of reflectance or reflectivity for the surface of the prism, with the angle of incidence, but in this case, for a plane polarized light with the plane of polarization perpendicular (i.e. normal) to the plane of incidence (i.e. say S-component)

B) Experimental arrangement

The experimental arrangement for parts A, B and C is very simple. In this, a red He-Ne laser source, a polarizer, an analyzer and a photo-detector all are mounted on the optical bench. The laser beam passes through the polarizer, the analyzer and is then incident on the sensitive area of the photo-detector. A digital multimeter is used to measure the output current of the photo-detector.

For part D and E, the experimental arrangement is as shown in Fig. 5.2.13.

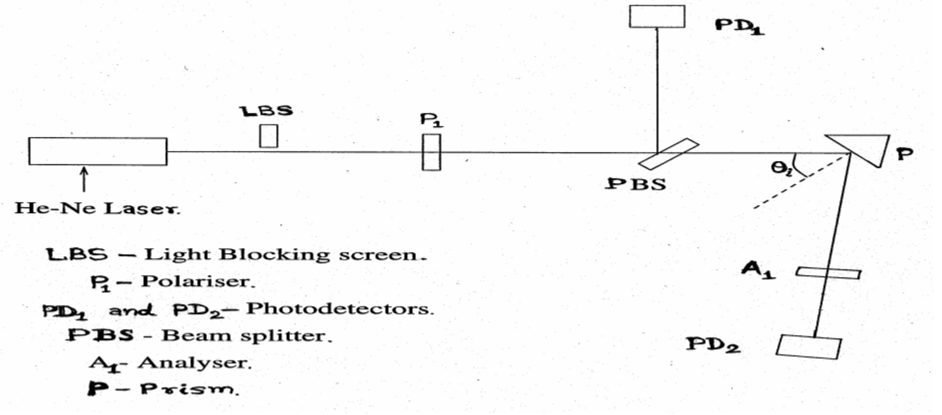

Fig. 5.2.13 The schematic of the experimental arrangement

A He-Ne laser source is mounted on a stand with adjustable height. The light emitted by the laser source is unpolarized. A light-blocking screen is provided which can be used to block the laser beam whenever it is not necessary. This light-blocking screen is mounted on an optical bench. The polarizer is used to polarize the light with the plane of polarization in a particular direction. The polarizer is mounted on a holder with markings on a vertical circular degree scale disc, which may be used for the adjustment and the measurement of angles. Also, an extra reference polarizer is provided for which the transmission axis is known.

A plane beam-splitter is clamped on a holder and is mounted on the optical bench. The beam splitter is used to split a single laser beam into two beams. The angle of incidence should be exactly 45 degree for the beam splitter to reflect 50 % intensity and transmit 50 %. A photo-detector is used to monitor the variation of the intensity of light reflected from the beam splitter. This is necessary because the output power of the laser source may fluctuate from time to time, and needs to be monitored and requires appropriate correction in the calculation of the experimental results.

A right angle glass prism is mounted on a holder, which is fixed to the prism table of the diffractometer arrangement. This holder is provided with a universal tilt mechanism. Using the two leveling screws this holder may be leveled and aligned properly. The height of this holder may be changed. This prism holder is fixed to a horizontal circular degree scale, which can be rotated. An analyzer and a photo-detector are mounted on the circular moving arm of the diffractometer arrangement, which is basically spectrometer but without the collimator and telescope arms. One may use the scale on the central circular portion of the diffractometer arrangement to measure angles more accurately. The analyzer is used to study the state of polarization of light reflected from the surface of the prism. The photo-detector is used to measure the intensity of reflected light. Both the photo-detectors have identical characteristics. Two identical digital multimeters are used to measure the output currents of the photo-detectors. Also provided are a magnifying reading torch, a spirit level and lens cleaning tissues.

C) Salient features

This experimental problem is designed around the concept of polarization of light by a reflection from the surface of a transparent medium. In this problem, the students are given preliminary tasks in which first they determine the unknown transmission axes of the given polarizer and the analyzer. Also they study the relationship between the intensity of light incident on the photo-detector and its output current. Then they study polarization of light by reflection from the surface of a transparent prism.

In this problem, all the three aspects, i.e. conceptual understanding; procedural understanding, and concepts of evidence and laboratory skills are equally important and hence are equally emphasized. The problem is designed to develop in students all the three aspects. The conceptual understanding here pertains to concepts from optics, particularly, from polarization of light. The main concepts and laws involved are, polarization of light, characteristics of light emitted from a laser source, intensity, plane of polarization, plane polarized light, polarization by reflection, law of Malus and Brewster's law.

Procedural understanding and concepts of evidences associated with design, measurement, data handling and analysis are more emphasized in this problem. The laboratory skills involved are of types handling or manipulation, alignment or judgment, use of instruments and tools, measurement and control, drawing graphs and observation tables. This problem also helps students in the development of different cognitive abilities like designing, application, synthesis, interpreting and inferring.

In this problem, students are given detailed instructions on the use of apparatus and tools; this includes information on the use of He-Ne laser source, diffractometer arrangement, beam-splitter, photo-detector and a pair of polarizer and analyzer. Some introductory procedural instructions are given to the students through the handout, which carries very little information on concepts of evidence. Four questions are included in the handout. Q.1 is designed to check the understanding of appropriate use of a graph and drawing conclusions from the graph. Q.2 is also based on plotting of a graph, and on the ability to choose appropriate parameters or quantities to be plotted making use of the theory to the problem. Q.3 again is designed around the plotting of graphs but the importance is given to the ability of explaining the observed relationship from the graph. Q.4 is designed to develop an ability of comparing two curves and drawing inferences from the comparison. This experimental problem is designed around mainly the illustration, skill and investigation type of practical work.

5.2.14 Demonstration No. 8

A) The objective

This demonstration is designed as a prelude to the Experimental Problem No.8. It is designed with two objectives, the first is to introduce to students use of different instruments and optical components and explain related precautions and the second is to demonstrate polarization of light (emitted by a laser source) after a reflection from the surface of a transparent prism. This demonstration directly or indirectly explains different concepts involved in the problem. This demonstration is presented partially in an interactive manner and is designed around the illustration and observation type of practical work.

B) Brief description

In part I of this demonstration, the use of different optical components (along with their mounts) and instruments is illustrated and explained to the students. The students are supposed to use these optical components and instruments in the experimental problem. We find that they hardly know anything with respect to the method of operation and use of these components and instruments, and also the necessary precautions to be exercised. These components and instruments include a He-Ne laser source, diffractometer arrangement, plate beam splitter, photo detector and an analyzer-polarizer pair. In case of each of these components the demonstration explains the use, specifications, method of operation and the necessary precautions along with the mounting instructions.

In part II of the demonstration the concept of polarization of light is explained and the polarization of beam of unpolarized light emitted by as the laser source after a reflection from the surface of the prism is demonstrated. In this the unpolarized light emitted by a laser source is incident on the surface of the transparent prism at different angles of incidences and the state of polarization of the reflected light is studied using an analyzer and a white screen. The state of polarization of reflected light when the light is incident at Brewster's angle is also demonstrated.

More information about the questions and their explanations along with the other details of the demonstration may be obtained from the instructors' handout given in the Appendix B.

5.2.15 Experimental Problem No. 9

A) Brief description

As we know, in the case of formation of primary rainbow, the sunlight incident on a raindrop is refracted at the first surface, reflected at the back surface and refracted again as it emerges in to the air. Dispersion occurs as the sunlight propagates through the drop. When this process occurs in a large number of raindrops, a primary rainbow is produced in the sky. A secondary rainbow occurs with two internal reflections.

When the white light is incident on a suspended drop of a liquid, the suspended drop will produce different order rainbows as a result of two refractions and K (K = 1, 2, 3, ...) internal reflections of light. The first order rainbow corresponds to one internal reflection. The second order rainbow corresponds to two internal reflections. Thus the K^{th} order rainbow corresponds to K internal reflections. Each rainbow is due to white light rays incident on the drop at a well determined angle of incidence, which is different for each rainbow. Each rainbow contains all the colors of the spectrum of the incident white light.

In this experimental problem, students are expected to study the different order rainbows formed in a drop of different given liquids. In part I of this problem, students are expected to study the formation of different order rainbows in a suspended drop of water and measure the angular positions of different order rainbows. These rainbows can be observed directly by the eye and their angular positions can be accurately measured using the telescope in conjunction with the spectrometer’s circular scale. From this, the variation of total deviation of the incident light for different orders with the number of orders is determined and studied.

Also, as we know the deviation of light, when light enters in a medium of refractive index m is proportional to m and the wavelength of light l. In part II of the problem, the students are expected to obtain the rainbows with different liquids and measure the deviation for a second order rainbow for different liquids. Then by comparison method, the students are expected to determine the unknown refractive index of the given liquid A.

B) Experimental arrangement

In this experimental problem, the students are given a high power (150 *Watt*) tungsten filament bulb as a source of white light. This bulb is mounted inside a wooden box. Four windows are provided to take out the desired amount of light. The height of these windows may be adjusted as required. A cooling fan is fixed inside the box to avoid any damage to the box by excessive heating. A power supply is used to provide the necessary power to the tungsten filament bulb. This power supply has one common and five variable output terminals. The intensity of light emitted by the bulb may be changed by connecting the bulb to different output terminals of the supply.

A spectrometer is provided with a circular degree scale disc and two windows for measurements of angle. In this case, the mounting of the collimator arm is modified to increase the range of movement of the telescope arm. The collimator has adjustable slits on both the sides along with the regular lens arrangement. This is used to illuminate only half of the liquid drop. The telescope does not have the regular lens arrangement, instead, the eyepiece is replaced by a pinhole and the objective is replaced by a magnifying lens of suitable focal length. This is done to get the magnified image of the liquid drop.

A specially designed syringe holder is provided to hold the syringe in the symmetric position. This holder is mounted on the prism table. The holder is so designed that when the syringe is properly clamped and the liquid drop is obtained, the drop is seen from all angular positions of the telescope and that also exactly at the center of the field of view of the telescope.

A set of four syringes, small beakers and pettri dishes is provided. Beakers are used to keep different liquids. Pettri dishes can be mounted on the plane platform of the prism table and used to collect the liquid, which trickles down from the syringe. Four different liquids, i.e. water, glycerin, clove oil and liquid A, are provided. A magnifying reading torch is provided, which may be used for reading the circular scale.

C) Salient features

This experimental problem is designed to explain the formation of different order rainbows on the basis of reflection, refraction and dispersion of light when it is incident on a suspended drop of liquid. In this problem the development of conceptual understanding and the laboratory skills are more emphasized than the procedural understanding and the concepts of evidences. The conceptual understanding involved is from the field of optics like reflection, refraction, dispersion of light, refractive index, wavelength of light etc.

The laboratory skills involved are of the type alignment, judgment, use of apparatus, handling and manipulation, measurement and drawing graphs. The procedural understanding and the concepts of evidences involved are associated with measurement and data handling.

In this problem, the theoretical basis of the formation of rainbows is explained to the students through the students' handout. The students are also given instructions on the use and alignment of the tungsten filament bulb, its power supply and the spectrometer. Some instructions on procedural aspects and concepts of evidences are given to the students. This is intentionally done since the procedural understanding involved in this problem is relatively simple and hence not given an important place as compared to the conceptual understanding and the laboratory skills.

In this problem, four questions are asked to the students. These questions are mainly designed around the development of abilities related to the plotting of graphs, explaining the observed behavior through the graph, choice of proper parameters to be plotted (on the basis of the theoretically expected results) to get the desired results, estimation of errors and application of the understanding to design a new situation for the required purpose or the task.

This problem is designed mainly around skill and illustration and partially around investigation type of practical work.

5.2.16 Demonstration No. 9

A) The objective

This demonstration is meant to serve as an introduction or a prelude to Experimental Problem No.9. In this demonstration, the use of apparatus is explained and demonstrated to the students and hence this has less interactive component, but the format of presentation is identical to the earlier demonstrations. This demonstration is designed around illustration and observation type of practical work.

In this demonstration the use of a spectrometer is demonstrated and explained. In the experimental problem we use a spectrometer, in which the regular arrangement of the collimator, telescope and prism table is modified. This modification is explained to the students. The demonstration explains the concept of least count, and the necessary adjustment and alignment of the source of white light, the collimator, the liquid drop and the telescope. How to use the adjustable slit to illuminate half of the liquid drop is shown and finally the different order rainbows in case of the water drop are demonstrated to the students.

B) Brief description

In part A of the demonstration, the students are shown a regular spectrometer and also the given modified spectrometer. They are then introduced to the use of spectrometer, its main parts with their uses, optical components used and the method of measuring angular position of the telescope. Then the modification incorporated in the given spectrometer is shown and explained to the students along with its need. Also the use of this modified spectrometer is explained.

Question one is introduced to explain the concept of the least count of a measuring instrument. In part B of the demonstration, the alignment and adjustment necessary for observing the different order rainbows is explained. In part C, the different order rainbows formed due to a water drop are demonstrated to the students; the angular positions of these rainbows, the observed spectrum, the position of red and violet ends and the relative intensities are also shown.

More information on this demonstration giving finer details may be obtained from the instructors' handout given in the Appendix B.

5.2.17 Experimental Problem No. 10

A) Brief description

When light from a distant source (or a laser source) passes through a narrow slit and is then intercepted by a viewing screen, the light produces on the screen a diffraction pattern. This pattern consists of a broad and intense central maximum and a number of narrower and less intense maxima on both the sides. In between the maxima are the minimas. A similar diffraction pattern may be observed using a plane diffraction grating. In case of the diffraction grating, the maxima produced are intense and widely separated.

In this experimental problem, the diffraction pattern observed due to a plane diffraction grating is observed and analyzed to determine the wavelength of the light emitted by the laser source. A precision circular aperture is used to study the diffraction pattern due to a circular aperture. In this case, the diameter of the circular aperture is to be determined.

A two-dimensional plane diffraction grating (which is actually a combination of two, one dimensional plane diffraction gratings) is used to get a two-dimensional diffraction pattern. Using the appropriate formulas, the grating spacings (i.e. the distance between two consecutive lines or slits) of both the gratings are to be determined. Also the angle of inclination between the two gratings is to be determined.

B) Experimental arrangement

The experimental arrangement consists of a 2-meter long optical bench along with four mounts. Different optical components can be mounted on these four mounts. A

He-Ne laser source may be mounted on one of the mount, preferably on the extreme left mount. Other three mounts may be used to clamp, either the diffraction grating, the light blocking screen, the precision circular aperture or the white screen. The position of any of the mounts may be changed along the length of the optical bench. A micro-stage is provided for each mount to change its position in a direction perpendicular to the length of the optical bench. One can use a measuring tape to measure the distance between the optical components and the screen.

Four plane diffraction gratings with different grating spacings are provided. Also provided are two 2-dimensional plane diffraction gratings, which are made by combining two independent one-dimensional plane diffraction gratings. A white screen is provided to observe and record the diffraction pattern. Two precision circular pinholes are provided. These pinholes are mounted on the holders, which can be directly clamped to the mounts of the optical bench. A light-blocking screen is used to block or interrupt the laser beam when it is not required. A 5 *meter* long measuring tape, a 30 *cm* measuring scale and a traveling microscope is provided, which may be used appropriately (if justified) to measure the different distances. A magnifying reading torch is provided to record and note down the readings.

C) Salient features

This problem is designed to study and analyze the diffraction of light (emitted by a laser source) by one dimensional plane diffraction gratings, a circular aperture and a two-dimensional plane diffraction grating.

In this problem, the development of all the three aspects i.e. conceptual understanding, procedural understanding (and concepts of evidences) and the laboratory skills is equally important and hence this problem is designed with an objective to develop all these abilities and understandings in students. In this problem, students develop an understanding about the diffraction of light due to plane diffraction grating, a circular aperture and a 2-dimensional plane diffraction grating. The procedural understanding and the concepts of evidence involved are simple but important to be developed and are associated with design, measurement and data handling. This problem help students to develop different cognitive abilities like application, interpreting, designing and inferring. This problem has more stress on laboratory skills like, handling or manipulation, adjustment, measurement, use of apparatus, alignment, judgment and drawing graphs and tables. In this, the estimation of errors and other related aspects is also emphasized and students are asked to determine the error and discuss the sources of errors and precautionary measures to minimize these errors.

In this problem, the necessary theoretical relations are given to the students. Instructions on the use of different apparatus are provided to the students through the instruction sheet. Also some simple instructions on the procedural aspects and concepts of evidences are given. Five questions are asked, which are designed around the understanding about plotting of graphs, estimation of errors, procedural understanding and the application of the conceptual understanding in a new situation to predict the unseen pattern or effect.

This experimental problem is designed around skills, illustration and investigation type of practical work.

5.2.18 Demonstration No. 10

A) The objective

This demonstration is designed as a prelude to Experimental Problem No.10. This demonstration explains the diffraction of light emitted by a laser source using a single slit and a plane diffraction grating. The objective of the demonstration is *i*) to explain the characteristic properties of light emitted by a laser source. *ii*) to introduce and illustrate the concept of diffraction due to a single slit and a plane diffraction grating and *iii*) to observe the diffraction pattern due to different plane diffraction gratings and explain the dependence of angle of deviation q_m corresponding to different maximum intensity points for different orders on the grating spacing. *d*. This demonstration also explains the idea of 2-dimensional diffraction.

This demonstration is presented in an interactive manner and is designed around illustration and observation type of practical work.

B) Brief description

The experimental set-up for this demonstration consists of a 2-*meter* long optical bench with four mounts. These mounts can be moved along the length of the optical bench and thus can change the position of different optical components mounted on them. A red He-Ne laser source is clamped on one mount and other three mounts can be used to clamp any of the optical components. A holder is provided to mount different gratings. A white screen is provided to observe and record the diffraction pattern.

First of all, the students are introduced to the new device i.e. a laser source. The difference between the light emitted by a laser source and a mercury vapor lamp is explained. A single slit (with adjustable slit width) is introduced in the path of the laser beam. The diffraction pattern obtained on the white screen due to this single slit is shown to the students. Also some basic information about the intensity distribution in the diffraction pattern is given to the students. Also the variation of the angular position of m^{th} order minimum with the slit width is explained and demonstrated.

The diffraction due to a plane diffraction grating with 15000 lines per inch (LPI) is demonstrated and explained with respect to the angular positions of different order maximas. Also how the diffraction pattern gets altered when the above grating is replaced by a grating having 6000 LPI (and also the gratings having 2500, 300 LPI) is demonstrated. The principle of obtaining the two dimensional diffraction pattern is illustrated and explained.

CHAPTER VI

The Course and Evaluation of the Project

The description of a set of ten innovative experimental problems and demonstrations formed the subject of the chapter V. In the present chapter, we turn to the evaluation of the research project. The project was evaluated through a course on experimental physics designed and tried out by us. The chapter has two sections, one is on the course on experimental physics and the other on the evaluation of the project through the course.

Section 6.1 describes the objectives of the course, plan and contents of the course, the sample group and its selection, the course administration and finally the limitations of the course. Section 6.2 first presents the methodology of the evaluation of the course and hence the project. It then describes various tools of the evaluation and analysis of students' performance. We discuss three quantitative tools of evaluation, i.e., 1) tests on conceptual understanding, 2) tests on procedural understanding and 3) experimental tests, and two qualitative tools: 4) a questionnaire on attitudinal and other affective aspects and 5) a feedback questionnaire. The discussion covers the design and administration of, the marking scheme, if any for and the analysis of students' performance in the case of each of the tools. The chapter concludes with a summary of the evaluation results.

6.1 The course on experimental physics

As described in chapter IV of this thesis, the evaluation of the whole research project was through the course on experimental physics, which grew from the package of ten innovative experimental problems and their accompanying demonstrations developed by us. We also developed the instructional strategy for the delivery of these experimental problems and demonstrations to the students. All this work was described in chapter IV and chapter V and the appendixes.

The design of the course was presented in Section 4.3 of chapter IV. As said there the course was formulated as a remedial course in experimental physics for the +2 and undergraduate students in India, typically at the end of their first or second year B. Sc. courses. It had a single group design with equivalent pre and post tests given at the beginning and the end of the course. Between the tests the students 'solved' the ten experimental problems. A demonstration relevant to particular experimental problem was given to the students as a prelude to each experimental problem. While the details of the course are given in the following pages, what was explained in Section 4.3 may be summarized here. No control group design was considered, as it would have been difficult to implement it in practice and as we were mainly interested in the students' change in behavior due to our course and not in its comparison with the traditional method. We thus felt that the single group design was adequate.

The pre and post tests served to evaluate the course and thereby the whole project. A statistically significant enhancement in the scores of the students between the pre and the post tests indicated the effectiveness of the course and hence of the developmental project. The evaluation through the tests had three components: i) Tests on conceptual understanding ii) Tests on procedural understanding and iii) Experimental tests to measure the performance of the students in 'solving' an experimental problem.

The scores on the three tests corresponded to three qualitative dependent variables, whereas the independent variable was the laboratory training imparted in the course. The null hypotheses explained in Section 4.3, corresponded to no significant difference in the scores of the three variables on account of the treatment. These quantitative measurements and tests were complemented by two different qualitative instruments of evaluation, namely, 1) a questionnaire on the students' attitudinal and affective change in behavior and 2) an open-ended feedback questionnaire filled by the students.

In the following sub sections, we describe the objectives, plan and the contents of the course, the sample group and its selection and administration of the course. The Section 6.2 is devoted to the evaluation of the course and the analysis of the results of the evaluation.

6.1.1 Objectives of the course

As described in Section 4.3, the course had the main objective: To evaluate the effectiveness of the developments carried out in this research project. One other auxiliary objective was served by the course. This was to check the feasibility of converting our package of experimental problems and demonstrations into a deliverable unit that can go into our present educational system as a remedial course in experimental physics to supplement regular laboratory training in physics, and to check its suitability for the target group and acceptability by the student community. The tests and the questionnaire serve to evaluate the course with respect to the main objective. The auxiliary objective was mainly served by the students' feedback session.

6.1.2 Plan and contents of the course

As described earlier, we have converted our package of experimental problems and demonstrations into an intensive course on experimental physics, in which, students are expected to work on ten experimental problems. Each experimental problem is supported by a related demonstration, given as a complimentary prelude to it. Since only one experimental set-up could be fabricated on account of practical and monetary limitations for each of the experimental problems, we were constrained to take only twenty students for one batch with a pair of students working on each experimental problem as per the instructional strategy developed in the research project. It was felt that at least a sample of 40 students was required to make the tests and the data reliable and valid to draw conclusions from them using statistical analysis. We, therefore, decided to conduct the course in two batches. Each batch had 20 students making the total number of participants 40 and the sample size sufficient for meaningful statistical analysis.

We took First Year (F.Y.) and Second Year (S.Y.) B.Sc. students as participants for this course. This decision was taken mainly because, as explained in Section 4.3, our target group of students was undergraduates studying physics. We wanted the participants' group to be homogenous with at least three years of exposure in physics laboratory training.

A set of pre tests was designed to be given at the beginning of the course. This set of pre tests consisted of two paper and pencil type written tests on two dependent variables, i.e., levels of students' conceptual and procedural understanding as described earlier. There was also an experimental pre test (Test I), in which students were supposed to solve a given experimental problem. This was designed around the third dependent variable: i.e. the practical or experimental skills. It should, however, be noted that an experimental test gives a composite measure which includes the effect of conceptual understanding, procedural understanding and problem solving ability along with experimental skills in an integral, non-separable way. This set of pre tests was basically intended to know and check student's initial level of preparation with respect to different dependent variables after the regular physics laboratory training for three years, during their studies at the +2 level and the first year of the B. Sc. programme.

We also designed a set of post tests based on the same dependent variables described earlier, which was administered at the end of the course. The difficulty level of the post tests was kept to be more or less the same as that of the pre tests. Also the number of questions, the basic ideas, and the concepts of evidence and substantive concepts addressed to in the questions were kept the same for corresponding pre and post tests. Care was thus taken to see that corresponding pre and post tests were equivalent to each other, so that difference in the score between a pre test and the corresponding post test is essentially due to the treatment, i.e. due to the training, and not due to difference between the tests. The set of post tests was designed to check the improvement in students' performance with respect to the three dependent variables after a treatment in the form of the course.

During the course, the students were allowed to work in the laboratory from 9:00 Hrs to 18:30 Hrs. It was seen that as far as possible the laboratory had a 'free' atmosphere wherein students were encouraged to carryout independent and self-designed experimental work. This was part of the instructional strategy. The long laboratory hours ensured that the students were not constrained by the time factor.

In this course, the first two days were devoted for pre tests and introductory lectures. These lectures were given as a general laboratory orientation as well as an introduction to some specific aspects of experimental physics. In these lectures the students were taught methods and theory of estimation of errors, use of significant figures, reporting of laboratory work, methods of data collection and analysis, use, plotting and interpretation of graphs, use of observation tables, concepts of evidence related to measurement, design and data handling, and different principles and techniques of various electronic measuring instruments. From the third day onwards for ten days the students were asked to 'work on' or 'solve' ten experimental problems. On each of these days the students were given a handout on a given experimental problem and a corresponding instruction sheet along with the required experimental set-up and apparatus. The instruction sheet guides the students on the use and specifications of the apparatus, and provides safety instructions and necessary data and tables. On each day, a related demonstration was given individually for a pair of students by an instructor before the students were given the handouts for the experimental problems. These demonstrations were delivered in an interactive mode as described in the instructional strategy earlier. In case of the experimental problems, the students were not given any direct guidance by the instructor with respect to any procedural aspect of the experimental problem. They were given help about the use of new instruments, and provided with the instruction / users manuals for sophisticated instruments. The necessary books and references were made available to them so that they could understand the theoretical basis of the experimental problems in a better way. Direct help, however, was avoided as said earlier.

During the last three days, there were enrichment lectures, discussions on experimental problems and demonstrations and some repetitions. A set of post tests was also administered in these last two days. A students' feedback session was held on the last day, i.e., on the 15th day before the valedictory function of the course. In this course no written material including the tests and the handouts was given to the students for taking it home everyday. All the material handed out to them was taken back at the end of each session along with their answer sheets.

6.1.3 Sample group and its selection

As described earlier, for this course we selected 40 students from the first year (F.Y.) and second year (S.Y.) of the B.Sc. course of the University of Mumbai. These students had physics as one of their major subjects. This ensured that each student had undergone at least three years of physics laboratory training. We selected twenty students for the first batch and twenty students for the second batch. The selection procedure was as described below.

We sent an advertisement of the course on experimental physics to different colleges in Mumbai in the month of January 1999. Interested students from F.Y and S.Y. B.Sc. were asked to individually apply for the course. We received about 105 applications before the last date for receiving the applications, which was 25th March 1999. In the requirement we had asked for the students' academic record including performance at Standard X and XII examinations along with a short write up explaining their interest in experimental physics. This write up helped us to check the students' interest in and the motivation towards experimental physics. From 105 applications, only a group of forty was to be selected. The selection was made on the basis of performance at the Standard X and XII examinations and the students' write up about experimental physics. Equal weightage was given to all the three factors. We selected 17 students from the F.Y. and 23 students from the S.Y. B.Sc. course. There were 18 female and 22 male students. All the selected students had a good academic record and came from fifteen different colleges in Mumbai. As said earlier, they already had undergone three or four years of regular physics laboratory training in different colleges.

6.1.4 Course administration

We conducted the course on experimental physics in two batches at the Homi Bhabha Centre for Science Education (HBCSE), Tata Institute of Fundamental Research (TIFR), V. N. Purav Marg, Mankhurd, Mumbai, India. The course was conducted for the fires batch from 12th April to 28th April 1999 and for the second batch from 30th April to 17th May 1999. In both the batches we had a mix of students from F.Y. and S.Y. of B.Sc. course. All these students had physics as one of the major subjects in their B.Sc. course. We charged students nominal fees of Rs. 100/- as registration charges. Students were provided accommodation on HBCSE campus. Although this was optional and all the students were from Mumbai, we found that about half of the students from each batch preferred to stay on the campus. Also the library and the canteen facilities were made available to the students. The researcher worked as one of the resource persons for the course. There was one more resource person from HBCSE. Both of us were available for both the batches. We invited two external resource persons for each of the two batches. Thus in all for each batch there were four resource persons or ‘instructors’. These invited resource persons were basically physics teachers, with substantial teaching experience at the undergraduate level. We invited different speakers to deliver enrichment lectures and lectures on various aspects related to physics laboratory training.

As described earlier, the course was designed to include the set of pre and post tests within the span of 15 days. Out of these fifteen days first two days were spent on the pre tests, introductory lectures following registration and a small inaugural function. For next ten days the students worked on ten different experimental problems. The last three days were devoted to a set of post tests, enrichment lectures, discussions on the experimental problems, repetitions of some parts of the problems, explanations, a students’ feedback session and a valedictory function. The programme, the contents, the speakers and even the timings were identical for both the batches.

On the first day of the course after the registration at 9.30 hrs there was an introductory session, which was meant to introduce, to the students, the resources persons and the plan and contents of the course. This introductory session was followed by a lecture on ‘Exciting and important experiments from the history of physics’.

Immediately after this lecture, with just 15 minutes tea break, the students were given a questionnaire on attitudinal and other affective aspects, which asked for their free opinion or response to different items in the questionnaire. They were given one hour for this purpose. This was followed by a one and half hour long pre test on procedural understanding. On the same day after the lunch an experimental problem on 'an electronic black box' was given individually to all the students as an experimental pre test (Experimental Test I). This was a three hours long test, in which all the students were given an identical set-up and were expected to solve the same experimental problem.

On the second day morning, the students were asked to appear for a two hours long pretest on conceptual understanding. Thus we administered a set of three pre tests consisting of two paper and pencil tests and one experimental test and also one questionnaire, at the beginning of the course.

The course or 'the treatment' actually started on the second day afternoon with three lectures and general instructions. The general instructions were given on different aspects of laboratory work in physics and the contents and the format of the course. Lectures were delivered by experts on different aspects of experimental physics. This included methods and theory of estimation of errors, the importance of significant figures, reporting of laboratory work, methods of data collection and analysis, use, plotting and interpretation of graphs and observation tables, concepts of evidence associated with design, measurement and data handling and the principles and techniques of basic electronic measurements and instruments.

During first two days the students were given the tests (individually) and lectures in a group of twenty students. On the second day, the students were grouped to form ten pairs. This was done completely on a random basis without any regard to academic and behavioral factors. From the third day onwards, the students worked in pairs. They worked on ten experimental problems for ten days. Since there were four instructors, we called eight students i.e. four pairs at 9:00 Hrs and gave them four demonstrations, one each by the four instructors till 9.30 Hrs. The next four pairs were called at 9:30 Hrs. and given demonstrations till 10:00 Hrs. The remaining two pairs were called at 10.00 Hrs. and given demonstrations by two of the instructors. We took precaution to ensure that each student got the same time, i.e. 6:00 hours, for working on an experimental problem. It was ensured that for each experimental problem a related demonstration was given in an interactive mode as described in the instructional strategy. Each demonstration was given to a pair of students individually by different instructors as a complementary prelude (introduction) to the given experimental problem. All the demonstrations were 30 minutes long. Students were not given any written material on the demonstrations, but during the demonstration enough time was given for thinking and discussion related to the demonstration.

All the students were made to work on all the ten experimental problems. On each day after the demonstration, the students were given the handouts, the instruction sheets for their allotted experimental problems along with the answer sheet. They were not allowed to take the handouts out of the laboratory and all the handouts were taken back at the end of each day. We took precaution that no student could be prepared in advance for a particular experimental problem on a particular day. For this we allotted the experimental problem to each pair of students in a schedule that ensured random order. On each day in the morning, the students were given only after they arrived in the laboratory, the allotted experimental problem on which they were supposed to work on that day. We took every possible precaution that no student used any unfair means for solving the problems.

Through the handouts on each experimental problem the students were guided to think and take decisions about different aspects of procedural understanding in particular and the experimental physics in general. As per the instructional strategy, for these ten days, no direct guidance was provided to the students by the instructor with respect to procedural understanding or concepts of evidence. The students were provided help by the instructor about the use of a new instrument or once in a while on the theoretical basis of the experimental problems. They were given the necessary books, references and user manuals for different instruments used for each experimental problem. Thus in these ten days the students were trained strictly as per the instructional strategy developed for the delivery of the experimental problems and the related demonstrations. The students were provided a ‘free’ laboratory atmosphere in which they were encouraged to carryout independent and self designed experimental work.

On the thirteenth day of the course, in the morning, we arranged an enrichment lecture on ‘Powers of ten’ (Orders of magnitudes). On the same day we had a detailed discussion on all the ten experimental problems. This discussion continued for about six hours with in-between breaks. On the fourteenth day, the morning was free for students, when they repeated some sections of a few problems and had discussions with the instructors on different experimental problems and demonstrations. The actual course or the treatment was over after this session.

In the afternoon of the fourteenth day, the students were given an experimental post test (Experimental Test II) on ‘an electronic black box’. In this test the students had to solve an experimental problem, related to the corresponding pretest problem, but one that was a bit longer and somewhat higher in difficulty level than the pre test. The method to be used for this test was the same. The students were given four hours for solving this experimental problem. The same test was given individually to each of the students. We had arranged twenty identical experimental set-ups for this test as in the case of the pre test.

On the fifteenth day of the course, in the morning, the students were given the same questionnaire on attitudinal and affective aspects, as was given before the treatment. They were supposed to give their free opinions and responses to the different questions. They were given one hour for this purpose. With a 15 minutes tea break after administering the questionnaire, the students were given a post test on procedural understanding. They were given one and half hour for this test. The difficulty level of this test was intentionally kept the same as that of the corresponding pre test and most of the questions were designed on the same concepts of evidence with only the contexts changed or modified.

After this test we had a 45 minutes lecture demonstration session. In this session the researcher introduced some simple concepts in electricity, magnetism and optics, discussed and showed some related demonstrations. This session was intentionally kept as a relaxing session, after having two tests in the morning. On the same day, after the lunch, the students were given a two hours long post test on conceptual understanding. Thus we administered at the end of the course a set of post tests essentially equivalent to pre tests administered at the beginning of the course. No student was allowed to take home any test paper in pre and post tests. These papers were taken back at the end of the allotted time.

Before the valedictory function, the students were asked to give their feedback about the course. For this we gave them a feedback questionnaire consisting of eight specific points on which they were asked to write and give reasons.

It is important to note that the students were carefully accommodated in the two batches, so that students from the same college were in the same batch. This was done to ensure that there should be no passing of information about the experimental problems or the tests from one student to another. Interestingly we found that no student from the first batch was known to any of the students from second batch till the batches came for the course and hence it became possible for us to use the same tests for both the batches without losing reliability and validity.

6.1.5 Limitations of the course

We describe below some limitations of the course on experimental physics, which we designed and conducted for investigating the effectiveness of the experimental problems, demonstrations and the instructional strategy as developed in our research project.

From the point of view of physics educational research, the course, as a means to evaluate the research project had the following limitations:

1) Because of practical constraints, the sample size could not be larger than 40.
2) Ideally, a control group design should have been used (as explained earlier, this was not practical and, we believe, not strictly necessary).

The other limitations of the course arise from its suggested replicability as a remedial course in experimental physics at the undergraduate level. They are as follows:

1) The most important limitation is with respect to the number of students. It is difficult to accommodate a larger group of students for this course. This would be possible only with larger infra-structural facilities, staff and instruments and the apparatus.
2) The ratio of students to the instructor has to be low, since as per the strategy, the demonstrations are to be given individually for each pair of students.
3) Such courses need to be conducted at a stretch continuously for at least 10 to 15 days. Hence it is not easy to use them for regular college laboratory training, but if they are conducted during vacation periods, they may serve a very important purpose of supplementing the regular physics laboratory training.

6.2 Evaluation of the project

As said earlier, we designed and conducted the course on experimental physics, with the main objective to evaluate the effectiveness of the research project presented in this thesis. This meant the effectiveness of the experimental problems and demonstrations as well as that of the instructional strategy developed by us. The course itself was evaluated using pre and post tests on different aspects of laboratory training. The design of the course was presented in the earlier section. In the following section we describe the methodology of evaluation of the course and present results of the evaluation carried out and the analysis of the results.

6.2.1 Methodology of evaluation

As described in Section 4.3 of chapter IV, the evaluation of the research project was through the course on experimental physics, which evolved out of the package of ten experimental problems and demonstrations developed by us. The course was given to a sample group of 40 undergraduate students of University of Mumbai. The effectiveness of the course with respect to laboratory training was evaluated using a single group pre and post tests designed. Our reasoning is that if the course was found to be an effective tool of improvement in the target group's performance in laboratory work, then the research project had fulfilled its objectives. It is for this purpose that the package of ten experimental problems and demonstrations developed in the research project was used in conjunction with the instructional strategy for their delivery also developed by us. The latter was developed on the basis of the conceptual framework described in chapter III. It was described in chapter IV and is reflected in the experimental problems and demonstrations described in chapter V.

As described in Section 4.3, the design of the evaluation of the course was as shown below:

Pre tests ® **Treatment (A course on experimental physics)** ® **Post tests**

The treatment was the course on experimental physics consisting of ten experimental problems, which the students worked on. As reported earlier, each experimental problem had a corresponding demonstration as an introduction to it.

We did not consider a control group design, since as said earlier, it would have been difficult to implement in practice, and secondly, we were interested primarily in the students' behavior on account of our course and not in its comparison with the traditional method. We thus felt that the single group design was adequate. (A consequence of this approach is that our course, if found effective, may be considered complementary and not as an alternative to the traditional mode of physics laboratory training at the undergraduate level. It could be used as a remedial course.)

The evaluation of the course through pre tests given at the beginning of the course and post tests given at the end had three quantitative components: i) Tests on conceptual understanding ii) Tests on procedural understanding and iii) Experimental tests to measure the performance of the students in ‘solving’ an experimental problem.

The first two correspond to a single variable each, namely, the level (or score) of a student’s conceptual understanding and the level of his/her procedural understanding respectively. The third is centered around the variable ‘experimental skill’, but is not a single variable measure; rather it is a composite measure of the experimental skills, problem solving ability, conceptual understanding and procedural understanding. It is difficult to isolate the contributions of each of the four variables to this composite measure. The three components give three null hypotheses, which were stated, in Section 4.3 of chapter IV. These three quantitative components were complimented by two qualitative instruments; one was a questionnaire on attitudinal and other affective aspects, given both before and after the treatment, and the other was a feedback questionnaire with open-ended questions answered by the students at the end of the course.

The sample, as said earlier, was a group of 40 students studying physics as one of their subjects as part of their undergraduate studies in colleges affiliated to the University of Mumbai. They were studying in the first year (F.Y.) or second year (S.Y.) of the B.Sc. course and had three or four years of physics laboratory training.

The pre and post tests in conceptual and procedural understanding were designed to be equivalent, i.e. they had the same number of items, the same difficulty level and identical coverage of topics. They were administered under identical conditions. The pre and post experimental tests (Experimental Test I and Experimental Test II) also were equivalent. The difficulty level of post test was intentionally kept somewhat higher. The two tests involved, had identical format and approach and the post test had to have an element of compensation for the advantage offered to the students because of the identical format and approach.

The average levels of the performance of the students in each of the components were noted. The difference between the pre and post test average course for each component was tested for statistical significance. The inferences drawn from this quantitative analysis was supported by the qualitative analysis of the questionnaires.

Together both of these analyses allowed us to conclude about the effectiveness of the course and thereby the entire research project.

We describe in the following subsections the various components of evaluation referred to above and the results obtained from them.

6.2.2 Description of tools and analysis of students' performance

In this section, we describe various tools, which we have used for the evaluation of the course and thereby the present research project. We also give detailed quantitative and qualitative analysis of the students' performance in the pre and post tests.

We discuss three quantitative tools of evaluation, i.e., 1) tests on conceptual understanding; 2) tests on procedural understanding and 3) experimental tests and two qualitative tools, 4) a questionnaire on attitudinal and other affective aspects; 5) a feedback questionnaire. The discussion is on the design and administration, the marking scheme and the analysis of students' performance for each of the tools.

6.2.2.1 Tests on conceptual understanding

We designed a pair of pre and post tests to test the students' performance with respect to the conceptual understanding involved in the experimental problems and demonstrations. Both the tests had 26 questions. These were mainly of the objective type, although a few questions were open ended and not of the objective type.

A) Design and administration

As said above there were 26 questions in both pre and post tests. Twenty-three out of these were of objective type and the remaining three were open ended. In these three questions the students were supposed to draw or complete a given figure or a given schematic ray diagram. Each of the objective questions had five options with the correct answer (one or more) to be ticked. These tests were essentially concept based and the questions had to be 'context linked', i.e. all the questions asked in these tests, had a direct relation, a link or an application to the concepts involved in the experimental problems. This was necessary, because we wanted to check as to what extent the experimental problems, i.e. the 'contents' of the course helped the students to develop related conceptual understanding.

The contexts or the situations around which the questions were framed were new and novel, although the concepts were related to the experimental problems. We took care that there was one to one correspondence between the questions from the pre test with those from the post test. The question wise difficulty level of the two tests was the same, although the questions were based on different situations. All the questions in the pre and post tests were based on 'substantive' or 'declarative' concepts (and their applications) from mechanics, optics, electricity and magnetism.

We validated these pre and post tests through a detailed discussion of these tests with physics teachers, colleagues and two experts in science education. Another means that we used for validation was introspection based on our experience with International and Indian National Physics Olympiad Programmes. The discussions with teachers, colleagues and experts helped us to design different situations, to keep the difficulty level the same and to prepare the marking scheme.

We administered the pre test on the second day of the course, before the actual treatment started and the posttest on the last day of the course after the 'treatment'. Every student was given a separate question paper on which he / she had to write his / her name and college etc and put his / her signature. In each case the students were given two hours to answer the given twenty-six questions. They were specifically instructed to tick the appropriate answers, which may be more than one to some questions. The question paper itself served as an answer sheet and no separate answer paper was provided. Rough sheets were given to the students for carrying out the necessary rough work. These rough sheets were to be returned after the allotted time. The question papers were taken back from the students after the test so as to ensure that they did not pass these on to the students of the next batch.

In these tests, we extensively used figures and diagrams to clearly explain the situation of the problem to the students. Thus most of the questions were supported by schematics or figures. The pre and post tests on conceptual understanding are reproduced for reference in the Appendix C of this thesis.

B) Marking scheme

In these tests, most of the questions were objective type, hence making the marking scheme for the pre and post test was a relatively simple job. As said earlier, each test had 26 questions, out of these 3 were open ended and 23 were of the objective (multiple choice) type. In the open-ended questions, it was required to draw or complete a figure or a schematic ray diagram.

In the marking scheme, five points were assigned for the correct answer for all those questions, which had only one correct answer. We decided not to have negative marking for these questions. We gave ten points each for two specially designed questions. One of this, Q.2, had four correct options and in the other, Q.26, students were supposed to draw two different ray diagrams. We used negative marking for those questions for which there were more than one correct answer. There were four such questions and the marking was such that an answer with all correct options got full points. For every wrong option 20% of the total points for the question were subtracted and for every correct option (100 / N)% points were added, where N was the total number of correct options. The total points allotted to the tests, i.e. to all the total twenty-six questions together were 140 (= 24 x 5 + 2 x 10).

These tests were graded by only one evaluator, since it involved mostly objective type questions. (For other tests, which involved open ended, essay type of questions, there were at least two evaluators. This was a measure to reduce the effect of subjectivity.) The marking or grading scheme was exactly the same, even question wise, for both the pre and the post tests. For both the cases the maximum number of points was 140. The students were not informed about the marking scheme of the pre and post tests before the course concluded.

C) Analysis of students' performance

The students' performance in the pre and post tests was graded as per the marking scheme described earlier. Students were given points out of a maximum of 140. In the tables below the actual scores, not percentages are given. Table 6.1, shows the actual average score of the group of 40 students in the pre and post tests.

Table 6.1 Scores of the sample group for the tests on conceptual understanding

Sample size	Pre-test mean (Std. dev.)	Post-test mean (Std. dev.)	Difference in the mean	Coefficient of correlation	t-value	Probability
40	35.9 (17.6)	54.3 (15.0)	18.4	0.66	8.9	Less than 0.001

From this table it can be seen that there was an improvement in the students' performance in the post test as compared to that in the pre test. The average score of students in the pre test was 35.9 with a standard deviation of 17.6, whereas the average score of students in the post test was 54.3 with a reduced standard deviation of 15.0. The performance improved from pre to post test by an average positive difference of 18.4 points.

We tested the difference between the means for statistical significance. Since the pre and post tests were on the same group, the t-value for the difference was calculated using the correlated means formula:

$$t = \frac{M_2 - M_1}{SE_D}$$

where, SE_D is the standard error of the difference between correlated means and is given by,

$$SE_D = \sqrt{(s_{M1})^2 + (s_{M2})^2 - 2\, r_{12}\, s_{M1}\, s_{M2}}$$

where, s_{M1} and s_{M2} are the standard errors of means of the initial and final tests means and r_{12} is the coefficient of correlation between scores made on initial and final tests.

The number of degrees of freedom in the evaluation was 39. With this the t-value turned out to be 8.9, which was statistically significant at 0.1% level (probability less than 0.001 for one tailed distribution).

We have also analyzed the performance of different relevant groups in the tests. The table 6.2 gives the frequencies of the groups made, these were male and female students and students from the first and the second year respectively.

Table 6.2 Group wise frequencies of students

Gender \ Year	First Year (F.Y.) (Group A)	Second Year (S.Y.) (Group B)	Gender wise total
Male (Group D)	12	10	22
Female (Group C)	5	13	18
Year wise total	17	23	40

Table 6.3 Scores of year wise groups

	Group A (F.Y.)	Group B (S.Y.)	Difference of A and B (A – B)	t-value	Probability
Pre-test mean (Std. dev.)	38.7 (19.3)	33.8 (16.3)	4.9	0.87	0.38
Post-test mean (Std. dev.)	55.3 (15.1)	53.5 (15.2)	1.8	0.38	0.70
Difference of mean	16.6	19.7			
Coefficient of Correlation	0.78	0.57			
t- value	5.6	6.4			
Probability	Less than 0.001	Less than 0.001			

Table 6.3 gives the data for the groups A and B made year wise. The t-values for the difference in the average test scores were calculated using the correlated means formula. The t-values for the difference in the average scores between the groups A and B were calculated with the independent means formula, as there was no correlation between the groups, they were independent. The levels of significance were determined for the difference between the test scores using a one tailed distribution and for the difference between groups using a two-tailed distribution. As one can see there was no statistically significant difference between the groups either for the pre tests or the post tests. (The probabilities were as high as 38% and 70% respectively). On the other hand the difference was significant for the mean test scores in the case of both groups A and B. Thus both the groups showed improvement.

Table 6.4 Scores of gender wise groups

	Group C (Female)	Group D (Male)	Difference of C and D (C – D)	t-value	Probability
Pre-test mean (Std. dev.)	30.7 (14.6)	40.1 (19.0)	- 9.4	- 1.7	0.09
Post-test mean (Std. dev.)	52.1 (15.1)	56.1 (14.4)	- 4.0	- 0.8	0.41
Difference of mean	21.4	16.0			
Coefficient of correlation	0.63	0.67			
t- value	7.1	5.5			
Probability	Less than 0.001	Less than 0.001			

Table 6.4 is similar to table 6.3. It gives data for groups C and D, corresponding to the division of the sample according to gender.

As one can see that the performance of the male students was better in both the tests than that of the female students. In the pre test the difference between the groups was significant at 10% level (probability 9%) and for the post test it was not significant even at 10% level. What is noteworthy is that the female students improved in the case of conceptual understanding more than the male students and almost caught up with them.

To sum up, after the treatment (the course), there seems to have been statistically significant improvement in the performance of all the students and of the students considered year wise and gender wise. Thus the course may be said to have improved the students' understanding of the substantive concepts involved in the experimental problems and demonstrations. In particular, in conceptual understanding the female students seem to have gained more than the male students.

6.2.2.2 Tests on procedural understanding

We intentionally designed a separate pre and post test package on procedural understanding. To recall, procedural understanding corresponds to the understanding of the concepts of evidence, which were listed in chapter III. The concepts like accuracy of an instrument, its error, reliability, the significant figures, the ranges of readings that can be taken by an instrument, the range that is required in the experiments, the intervals between the readings, precautions to be exercised, interpreting graphs, planning of presentation and graphs etc. form and integral part of performing an experiment. Usually, their significance is subsumed and therefore lost under the rubric of 'experimental skills'. Gott and Duggan have given them separate, autonomous status with the name 'procedural understanding'. According to them, this understanding mediates between conceptual understanding and the actual experimental skills, like manipulations of instruments and apparatus, coordination, working with specific instruments, constructing, fabricating etc. It is the procedural understanding, which utilizes skills to verify, elucidate further or discover knowledge or 'physics', i.e. conceptual understanding.

Usually, procedural understanding is judged through experimental tests, through observations by the instructors or examiners. Since we feel it is a kind of understanding of concepts in its own right, it should be tested separately. Since it is 'conceptual in nature', we thought a paper and pencil test with appropriately framed questions based on experimental situations should be used to test it. Such test had the added advantage; it was procedural understanding not in a specific context, but in a 'general form'. We devised separate paper and pencil pre and post tests on procedural understanding. These tests included questions based on experimental situations explained in the text about how, why and what of the design, measurement and data handling in the given situation. Specifically, these included devising a procedure for measuring a particular parameter, choosing appropriate instruments, determining the range and accuracy required, exercising precautions, controlling certain parameters, changing certain parameters, estimating errors, reducing systematic errors, detecting mistakes and misconceptions with respect to accuracy, precision, errors and significant figures, devising appropriate tabular and graphical representations, interpreting graphs, and so on.

A) Design and administration

In case of the both the pre and post tests on procedural understanding, we set twelve questions. In each test, first eight questions were of descriptive or essay type and were based on different aspects of procedural understanding as explained above. The next two questions were based on understanding of significant figures and interpretation of graphs respectively. The last two questions were objective type with one or more correct answers. These were on graphs and their interpretation. In case of both the tests all the twelve questions were 'context free', i.e., these questions had no direct bearing on the specific experimental problems included in the course.

In both pre and post tests, Q. 1 and 2, were based on concepts of evidence associated with design and measurement and the related procedural understanding. Q. 3 and 4 were based on the concepts of evidence associated with data handling and proper use of graphs in coordination with the underlying theory. Q.5 was based on procedural understanding associated with design and measurement, whereas Q.6 was based on the concept of least count, Q.7 involved concepts of evidence associated with measurement, Q.8 involved concepts of evidence associated with design. Q.9 and 10 were based on the understanding of significant figures and their propagation in calculations. Finally Q.11 and 12 required understanding and interpretation of linear graphs.

All the questions in the post test were based on the same concepts of evidence and aspects of procedural understanding as the corresponding questions from the pre test, but the experimental situations were different. Care was taken to keep the difficulty level the same for both the tests. These tests were validated through discussion with experts and also through introspection based on our experience with the International and Indian National Physics Olympiad Programme.

The pre test was administered on the first day of the course and the post test was administered on the last day of the course. In each case, the students were given one and half hour to answer the given twelve questions. Each student was given a separate answer sheet. Students were provided extra sheets for necessary rough work. The question paper, the answer sheet and the rough sheets were all taken back at the end of the allotted time for both the pre and post tests. The question papers of the pre and the post tests on procedural understanding are given for reference in Appendix C of this thesis.

B) Marking scheme

Most of the questions in these tests were descriptive and hence preparing the marking scheme was somewhat difficult in this case. We took the help of two expert teachers for preparing the marking scheme. On account of contents difference, length of expected answers and differing difficulty levels, it was necessary to give different weightages to different questions. The detailed model answers for each question were prepared and analyzed, and accordingly the points to be allotted to each of the questions were decided. The total (maximum) points allotted to the test were 105.

The allotted points for different questions of the pre test were as follows. Q.1 - 18 (12 +3 +3) points, Q.2 - 11 (6 +3 +2) points, Q.3 - 7 points, Q.4 - 7 (1 +3 +3) points, Q.5 - 13 (5 + 5 +3) points, Q.6 - 5 points, Q.7- 8 (3 + 5) points, Q.8 - 11 (5 +2 +2 +2) points, Q.9 - 9 (1.5 x 6) points, Q.10 - 7 (3 + 4) points, Q.11 - 4 points and Q.12 - 5 (1 x 5) points.

The marking scheme of the post test was almost the same except with a few minor changes. The allotment of points for the post test was as follows Q.1 - 18 (12 +3 +3) points, Q.2 - 11 (6 +3 +2) points, Q.3 - 8 points, Q.4 - 7 (3 +4) points, Q.5 - 12 (5 +5 +2) points, Q.6 -5 points, Q.7 - 7 (3+4) points, Q.8 - 12 (4 + 4 + 4) points, Q.9 - 9 (1.5 x 6) points, Q.10 -7 (3+4) points, Q.11 - 6 (3 +3) points and Q.12 - 3 (1 x 3) points.

Thus both the tests had a total of 105 points for the given twelve questions. We used negative marking only for one question, i.e., for Q.11, which was a purely objective (multiple choice type) question with only one correct answer.

Students were not informed about the marking scheme either of the pre test or the post test.

C) Analysis of students' performance

We evaluated the students' answer scripts to both the pre and post tests as per the above marking scheme. In this case, since most of the questions were of the essay or descriptive type, we decided to have the scripts marked by two different evaluators to enhance validity and reliability of the data generated. We requested an experienced physics teacher from a local undergraduate college to mark the answer scripts in both the tests. He was given the detailed marking scheme and the model answer. No marking was done on the students' answer scripts; instead, the marking was done on a separate marking sheet. The researcher was the other evaluator. The evaluation was done independently without interruption by the two evaluators. The mean of the point scores given by the two evaluators to each student was used for further analysis of the students' performance.

Table 6.5 Scores of the sample group for the tests on procedural understanding

Sample size	Pre-test mean (Std. dev.)	Post-test mean (Std. dev.)	Difference in the mean	Coefficient of correlation	t-value	Probability
40	29.2 (12.6)	47.4 (15.8)	18.2	0.79	11.9	Less than 0.001

Table 6.5 gives the mean scores on the pre and post tests obtained by the sample students group. The numbers are actual point scores and not percentage. The maximum points for both the tests were 105. The difference in the score between the pre and post test was 18.2 and is significant at a level much better than 0.1%, the probability for the t-value 11.9 with 39 degrees of freedom being less than 0.001 for a one tailed distribution. Clearly the group has shown improvement in procedural understanding as a result of the course.

Table 6.6 Scores of year wise groups

	Group A (F.Y.)	Group B (S.Y.)	Difference of A and B (A – B)	t-value	Probability
Pre-test mean (Std. dev.)	31.6 (10.8)	27.5 (13.7)	4.1	1.0	0.31
Post-test mean (Std. dev.)	52.8 (14.8)	43.8 (15.3)	9.0	1.9	0.07
Difference of mean	21.2	16.3			
Coefficient of correlation	0.77	0.78			
t-value	9.4	8.1			
Probability	Less than 0.001	Less than 0.001			

Table 6.6 and 6.7 give the group wise analyses, table 6.6 for groups A and B as per the year of study and table 6.7 for groups C and D as per gender. Groups A and B do not differ significantly on the pre test (probability 31%), but do differ on the post test (probability 7%) at 10% significance level. It is noteworthy that on both the tests the first year group shows 'better procedural understanding'. Also, the first year group has gained more from the training. The increase in their mean score is 21.2 (with t-value 9.4, significant at better than 0.1% level), whereas the increase in the score of the second year students is 16.3 (with t-value 8.1, also significant at better than 0.1% level).

Table 6.7 Scores of gender wise groups

	Group C (Female)	Group D (Male)	Difference of C and D (C – D)	t-value	Probability
Pre-test mean (Std. dev.)	24.9 (12.0)	32.8 (12.2)	- 7.9	- 2.0	0.05
Post-test mean (Std. dev.)	41.3 (12.9)	52.5 (16.5)	- 11.2	- 2.3	0.02
Difference of mean	16.4	19.7			
Coefficient of correlation	0.78	0.77			
t-value	8.3	8.8			
Probability	Less than 0.001	Less than 0.001			

Male students score better than female students both in pre and post tests of procedural understanding. The difference between the two groups is significant at 5%

level. Both groups, however, show substantial improvement after treatment. The males gain more than the females. The improvement is significant at a level better than 0.1% for both the groups.

To sum up, in procedural understanding students show substantial improvement after the course. The first year students score better and show more improvement than the second year students. Similarly, male students score better and show more improvement than the female students.

The important and concrete inference from this analysis would be that the developments carried out in this research project, namely, the experimental problems, demonstrations and suitable instructional strategy for them, if delivered to the students through a course on experimental physics, help students to gain in procedural understanding, i.e. the understanding of different concepts of evidence associated with design, measurement and data handling.

6.2.2.3 Experimental tests

The third component the comprehensive evaluation of the course on experimental physics devised by us and thereby the whole research project was an experimental test, the first two being the tests on conceptual and procedural understanding respectively. The tests on conceptual and procedural understanding were both paper and pencil tests and the only way to evaluate the experimental skills of the students who took the course was through an experimental test. Of course, as said earlier, the performance in experimental skills cannot be isolated as in the case of conceptual and procedural understanding. Any experimental test evaluates experimental skills in an integral way together with the conceptual and procedural understanding. In the following discussion on design, administration, marking skills and analysis of results of the experimental test this point may be taken note of. The experimental test was administered to the students both before (pre test) and after (post test) the course.

A) Design and administration

As said above the experimental test was administered both as a pre test and a post test. These pre and post tests had to be fairly, although in practice not exactly, equivalent. We therefore chose a common format for both the pre and post tests. This was the well known black box problem. We employed the electronic version in which a simple electronic circuit consisting of only resistors and semiconductor junction diodes was concealed in a black box. The circuit was a three or four terminal network and only these terminals provided external contact to the network. The students were supposed to determine the circuit and its components, by studying the current-voltage (I-V) characteristics of different possible combinations of the out coming terminals. For this purpose they had to use only the given instruments, which they could connect to the terminals.

One advantage of the black box format was that the same experiment could be given to every student, which is not in the case in conventional experimental tests. There every student, say in a typical batch of 20 students who give the test, gets a different experiment. From the point of view of a fair test this is not proper, as different experiments can hardly be considered to be equivalent in difficulty level. We, however, ensured that though each student was given equivalent experimental problem, the ‘same’ experimental problem was not given to all the students from a batch giving the test. This was easy to achieve in the black box format, since the values of the given components in the circuit were different for different students. The difficulty level, therefore, of the experimental problem was practically the same for all the students.

A three terminal black box was given as a pre test and a four terminal black box was given as a post test. The difficulty level of the post test was somewhat higher than that of the pre test. This was so since it involved compared to the pre test, more experimental work and the study of I-V characteristics of more combinations of terminals. For the post test, we therefore decided to allow four hours for students to solve the experimental problem, where as for the pre test the students were given only three hours. The post test was intentionally kept at a higher difficulty level, because for the post test the students had gone through the pre test earlier and hence the basic method of solving the problem was known to them. The ‘higher difficulty level’ compensated for this knowledge.

In these tests, each individual student was given a problem sheet. This problem sheet gave the aim of the experimental test, the list of apparatus provided, instructions, description of the apparatus, the statement of the problem and the data of forward characteristics of a typical P-N junction diode (which might be required in solving the problem). In both the tests, the students were given necessary instructions only on use of instruments and not on procedural stages or concepts of evidences. It is important to note that, the approach and the procedure involved was nearly the same for the pre and post tests.

The black box experiment effectively combines practical skills such as performing measurements, coordination of different motor operations, plotting appropriate graphs etc. with the abilities associated with problem solving like devising a fair test and monitoring whether the conclusions are valid, devising a systematic procedure which will enable one to string the fair test for identifying individual components to unravel the unknown circuit. Problem solving here involves logical reasoning coupled with the understanding of concepts of evidence (the procedural understanding). All this was considered for evaluating the students' performance. Also, the students were asked to report in a systematic manner all the steps they devised and followed. Students' reporting skill of laboratory work was also an important aspect of evaluation. It must be emphasized here that our evaluation differed in another major aspect from the conventional evaluation of an experimental test. No examiner observed the student during the experimental work with a view to evaluate him / her. The scoring of students' performance was on the basis of only their reports. That is why they were asked to report whatever they did. The instructions were devised to help students to do this. This approach, essentially borrowed from the practice at the experimental tests conducted during the International Physics Olympiads and referred to earlier, removes a great deal of arbitrariness in the conventional evaluation, which arises from the subjective way in which the examiners grade the students while observing their practical work and occasionally asking them questions.

The pre test, i.e., the Experimental Test-I, was administered to the students on the first day of the course. Every student was given the set of necessary apparatus, the problem sheet, the answer sheet, rough sheets and graph papers. All the sheets and graph papers were taken back at the end of the allotted time. The post test, i.e. Experimental Test-II, was administered in a similar manner on the 14th day of the course. The only difference in this case was that, as said earlier, a four terminal black box was given instead of a three terminal black box and four hours were given instead of three hours for completing the test.

In both the tests, students were instructed that the circuit inside the black box is made up of at least three electronic components of the type, resistors and P-N junction diodes. The students were asked to 1) study I-V characteristics of all possible combinations of the out coming terminals A, B and C (for a 3 terminal black box) and

A, B, C and D (for a 4 terminal black box), 2) plot appropriate graphs and explain the I-V characteristics, 3) identify the type of components and the complete circuit inside the black box and its connection with the connecting terminals, 4) determine the value of resistance of the resistors, if any and 5) determine the minimum potential difference across a P-N junction diode, if any when it begins to conduct. For this the students were provided given the forward characteristics of a typical P-N junction diode of the type used in the circuit inside the black box.

We found it necessary to clearly state the kind of components used in the black box circuit. If we did not do this and limit the kinds of components used to simple ones, the problem becomes much more open ended, even non-unique, time consuming and extremely difficult. Our experience with the black box type of experiments and our studies with the Olympiad and other group of students helped us in this respect. Further, we found that it was necessary to give broad procedural steps 1) to 5) listed above to guide the students and keep them on track and not to allow them enter into unfortunate blind alleys.

The problem sheets for the pre test (i.e. Experimental Test-I) and the post test (Experimental Test-II) are reproduced for reference in Appendix C of this thesis.

B) Marking scheme

A marking scheme was carefully devised to evaluate the students' performance with respect to different aspects and abilities mentioned earlier, which this test was supposed to evaluate. While devising the scheme, we took the help of two experts in physics laboratory training and teaching of experimental physics. We identified various stages and aspects of the solution of the experimental test according to their model answer, which they were asked to provide. We then decided the relative weightage to be given to different stages and aspects. In the scheme that evolved points are given for various aspects like the range of values of the quantities, choice of scale of a graph, identification of types of variables etc.

The amount of experimental work, the time allotted and the difficulty level of the post test were greater than the pre test. This was necessary since, as explained earlier, after the pre test, students become familiar with the method of solving the problem, which was common to both the tests. The marking scheme for both the tests was more or less the same.

In both the cases, students were given points out of a total of 135. Out of the 135 points, 24 points were given for plotting and explaining graphs and the I-V characteristics obtained. The number of graphs to be plotted was more than one and hence each of the graphs was given equal weightage. This weightage was different in the pre and post tests, since they involved different number of graphs. The 24 points were subdivided and allotted for specific graph plotting tasks like, choice of variables, scale and axes, proper use of the graph sheet etc. Then 24 more points were assigned to data collection, measurements performed and identification of components between the individual combinations of terminals. These 24 points covered different tasks like specific measurements and data collection, interpretation of data and graphs, logical reasoning and correct identification of the components connected between different combinations of terminals. Determination of the resistance value of resistors present in the circuit took up 12 points. The distribution of these 12 points, took into account the number of resistors, the percentage accuracy of determined values of the resistance and the method and approach used to determine the value of the resistance. Five points were allotted to determination of the correct value of the minimum potential difference across the P-N junction diode when it began to conduct. The distribution of these 5 points was done on the basis of number of diodes, the percentage accuracy of the determined value of voltages, and the method used.

Ten points were assigned to identification of the complete correct circuit and its connection to the different outcoming terminals. The finer distribution of these ten points were different for the pre and post tests, since both involved different number of terminals and different level of complexity of the circuit. Reporting or presentation of the laboratory work was given 20 points, which covered proper use and drawing of tables and diagrams and general reporting and the mode of presentation. Twenty points were allotted to the method and approach, practical skills and understanding of concepts of evidence not covered so far (for example, choice of correct external circuit, correct values of external resistors, applied voltage etc.) and finally 20 points were allotted to the abilities and aspects related to experimental physics like, understanding and application of the necessary theory and concepts, confidence shown in handling a problem, drawing correct circuit diagrams, collection, organization and analysis of data, and overall ability of handling successfully the given experimental problem.

C) Analysis of students' performance

The evaluation was carried out as per the above-discussed marking scheme. To enhance the reliability and validity of the generated data, the scoring of students' performance was independently carried out by two different evaluators. We requested an experienced undergraduate physics teacher from a local college to score the students' performance in both the pre and post tests. He was given the detailed marking scheme and the model answer. No marking was done on the students' answer sheets; instead, the marking was done on separate marking sheets. The researcher was the other evaluator. The evaluation was carried out by the two evaluators independently. We used, in further analysis the mean of the scores given by the two evaluators to each student.

Table 6.8 shows the performance in the experimental tests of the students in sample group who took the course. The scores given are actual scores out of a maximum of 135. It is evident that the whole group has shown considerable improvement, the difference in the means between the post and pre tests being + 27.9 corresponding to a t-value of 9.3 which is statistically significant at a level better than 0.1%. It may be noted that for working out the t-value we used the correlated means method, since the same group took both the pre and post tests.

Table 6.8 Scores of the sample group for the experimental tests

Sample size	Pre-test mean (Std. dev.)	Post-test mean (Std. Dev.)	Difference in the mean	Coefficient of correlation	t-value	Probability
40	28.0 (18.4)	55.9 (18.0)	27.9	0.45	9.3	Less than 0.001

Table 6.9 is meant for comparison of groups A and B of the students in their experimental test scores. To recollect, group A corresponds to students studying in the first year of their B.Sc. course and group B corresponds to those studying in the second year. For this comparison, the groups being independent, the independent means method is used for obtaining the t-value. The t-value for the difference in means between the groups A and B for the pre test is small and negative and not significant even at 10% level, whereas for the post tests it is 3.4 and significant at better than 0.1% level. These shows that the students of group A have benefited from the course much more than students of group B, as far as the experimental tests are concerned. Both groups,

however, have shown improvement in their scores from the pre test to the post test at a level of significance much better than 0.1%. (The t-values for these calculated using the correlated means method are 8.9 and 6.2 respectively).

Table 6.9 Scores of year wise groups

	Group A (F.Y.)	Group B (S.Y.)	Difference of A and B (A – B)	t-value	Probability
Pre-test mean (Std. dev.)	26.5 (18.1)	29.1 (18.9)	- 2.6	- 0.44	0.66
Post-test mean (Std. dev.)	65.9 (18.4)	48.6 (14.0)	17.3	3.4	0.001
Difference of mean	39.4	19.5			
Coefficient of correlation	0.50	0.61			
t-value	8.9	6.2			
Probability	Less than 0.001	Less than 0.001			

Table 6.10 gives the comparison between groups C and D, which corresponds to the female and male students. In the pre test there was no statistically significant difference between the two groups (Note the male and female groups are independent and the t-values are computed accordingly). In the post test, however, the two groups significantly differ at a level better than 0.1%. This means that the male students have benefited much more from the course, as far as experimental tests are concerned, than the female students. Both the groups, however, show statistically significant improvement from the pre test to the post tests (at a level much better than 0.1%).

Table 6.10 Scores of gender wise groups

	Group C (Female)	Group D (Male)	Difference of C and D (C – D)	t-value	Probability
Pre-test mean (Std. dev.)	25.7 (15.9)	29.9 (20.3)	- 4.2	- 0.73	0.47
Post-test mean (Std. dev.)	46.8 (15.0)	63.4 (17.1)	- 16.6	- 3.2	0.003
Difference of mean	21.1	33.5			
Coefficient of correlation	0.34	0.51			
t-value	5.1	8.4			
Probability	Less than 0.001	Less than 0.001			

The number of female students is more at the S.Y. B.Sc. level (13) than at the F.Y. B.Sc. level (5). In fact at the S.Y. B.Sc. level there is a majority of females, 13 out of 23. This explains why in the procedural understanding and experimental tests S.Y. B.Sc. students show less improvement than F.Y, B.Sc. students, since in these tests it is the male students and not the female students who do better.

To summarize, as far as the performance in the experimental tests is concerned, both F.Y. B.Sc. and S.Y. B.Sc. student groups, both the female and male student groups and similarly the sample group as a whole show statistically significant improvement. One may definitely conclude that the course leads to a significant improvement in the students' performance in the experimental tests. Further, if comparison is made, it is seen that the F.Y. B.Sc. students benefit more then the S.Y. B.Sc. students and the male students benefit more than the female students.

6.2.2.4 A questionnaire on attitudinal and other affective aspects

As mentioned earlier, the evaluation of the students' performance in the course on experimental physics which was carried out through the three types of tests discussed in the previous section, was supported by a questionnaire specially designed by us to study the changes in the attitudinal and other affective aspects of behavior among the students who took the course. We concentrated on behavior related to laboratory training in physics. The questions included in the questionnaire did not, however, pertain to any specific aspect of the course; they pertained to the students' perceptions with respect to physics as a subject and physics theory and physics practicals in comparison with each other, their liking of these and the value they attach to these. We sought also their opinions with respect to gender differences. There was a separate section on experimental physics seeking the students' perception regarding what experimental physics contributes to and their own performance. These questions were supplemented by appropriate personal information obtained from the students.

A) Design and administration

The questionnaire, as said above, was on attitudinal and other affective aspects. These are not subject to quick change. In the cognitive domain repeating an item may not be desirable, as the students may remember the question and its answer. In the affective domain, on the other hand, the memorization aspect is not relevant and in fact, it may be desirable to repeat an item and compare the student's responses before and after the treatment, though as said above one does not expect a major change in the responses. We therefore gave the same questionnaire to the students before and after the course. They were given enough time to complete the questionnaire on both the occasions.

In the first part, the students were asked to fill personal information like name, class, gender, college and subjects of study. Additional personal information like their academic record at the Secondary School Certificate Examination, Higher Secondary School Certificate Examination and the first year Science Examination was available in a compiled form through their applications for the course. The next part of the questionnaire which we referred to as “general information” was devoted to questions probing which subject the students liked most and why, what their career plan was, which subject according to them was taught best and whether the students’ liking for physics (theory and experiments) was due to experience in their schools / colleges or otherwise. This part also included items on the gender perception of the students, whether according to them male or female students prefer physics as a subject and prefer and perform better in theory or in practicals.

The third part of the questionnaire covered the students’ interest and their perception of utility, importance and difficulty in physics as a whole and in its theory / practical components. The part also served for comparison between theory and practicals. This part was given the heading “the subject”, whereas the last part titled “experiments” sought to elicit the students’ opinions regarding various aspects of experimental work, why they are important, what they develop, why they are interesting and so on. This part also checked how the students assess their own performance in the laboratory.

The questionnaire was validated by discussing each item with 1) senior colleagues in physics and 2) a senior colleague who has years of experience in preparing and dealing with questionnaires and who works in areas of cognitive science and gender studies. Also, the questionnaire was tried with a group of students similar to the sample group. This helped us to remove linguistic ambiguities and also omit or modify certain options.

The questionnaire is reproduced in the Appendix C of this thesis. It was administered on the first and the last days of the course. There were in all 28 items. As said earlier, the students were given enough time (one hour) to complete the questionnaire. Most questions were of either multiple-choice type with 3, 4 or 5 options or of 5-point scale type. For the latter type, the students had to give the extent to which they agreed with or liked an item, with 1 as the highest and 5 as the lowest rating on the scale. For a number of items the students had to give reasons for their choice or rating. These reasons were classified by us. The analysis is given in the next section.

B) Analysis and results

As said above the students' responses for every item were compiled for both pre-course and post-course administering of the questionnaire and these were compared. First, what we did was to obtain the frequencies of various options for each item. We supposed pre-course response frequencies as the "norm" and compared the post-course frequencies with the "norm" using chi-square tests. As said earlier, we did not expect substantial changes in the frequencies from pre to post-course questionnaire. We therefore identified those items in which there was a 10% or greater change in an option for an item and were further studied. Incidentally, by and large these were also the items for which the chi-square test gave reasonable (5% or better) statistical significance.

Characteristics of the sample student group

The personal information collected through the questionnaire and the students' application forms allowed us to identify the academic characteristics of the sample group of students. Out of the 40 students in the group, 23 were from the Second Year B.Sc. and 17 form First Year B.Sc. class. These are the 13th and 14th years of the students' academic life. In the group there were 18 female students (5 from the First Year and 13 from the Second Year) and 22 male students (12 from the First Year and 10 from the Second Year). Except 2 all the students had scored more than 75% marks in their Secondary School Certificate Examination (S.S.C.), a public examination taken at the end of the 10th year (Std. X) of their schooling. The median was in fact 80% or above. In Mumbai city higher secondary school and colleges admission to the science stream (out of three possible streams at this stage, namely, arts, commerce and science) demands typically 75% or more marks at the S.S.C. examination. In that sense these were typical students. The next stage is the Higher Secondary School Certificate (H.S.S.C.) Examination, again a public examination taken at the end of the 12th year (Std. XII) of a student's schooling. The students of the science stream are eligible to go for professional courses like medicine and allied fields like dentistry or pharmacy or like various branches of engineering including computer science. The students' marks in the science subjects in this examination often determine their eligibility for the professional courses and hence this examination is highly competitive. Consequently, typical students get fairly high percentage of marks in the science subjects (physics, chemistry, mathematics and /or biology) in this examination even if they go for the undergraduate science (B.Sc.) course and not for the professional courses (for which the percentage of marks demanded may be higher than 85%). In the present situation the fact that our undergraduate students (studying the First or Second Year B.Sc.) had mostly with two exceptions a percentage of 65% or more in their science subject at the H.S.S.C. examination was not surprising or even unusual but rather typical. In fact, the median of the group's score was 75% and yet the group could be said to be about above average among all the undergraduate students studying science in Mumbai colleges. The S.Y. B.Sc. members of these groups had a varying percentage in physics at their F.Y. B.Sc. final examination from 41% to 89%, the median being 60%. This further confirms that the student group was just about above average among undergraduate science students in Mumbai. Compared to all undergraduate students in the city, i.e. including those who study any of arts, commerce and science subject, these students, however, would form a well above average group.

Semi qualitative analysis of the questionnaire

1) All the students said that they liked, among the various subjects they study, physics the most. The reasons they gave, for this, were that they found the subject exciting, challenging, related to life, conceptual and for some, even more scoring than other subjects and for some, a doorway to astronomy. All the students wish to continue with physics at the Master's level. Some wish to take up a job after the Master's. A large majority, however, wishes to continue further and go for research in physics. There was no variation between the pre course and post course opinions of the students' in this regard (Item 1 to 4).
2) According to the students, there is no difference in their performance in physics between male or female students. However, a sizeable section did say before the course that females preferred theory and males experiments. After the course, however, the students were distinctly egalitarian in this regard, with 28 out of 40 saying that there is no difference (Items 5 to 7).

3) With respect to performance in overall physics, however, the reverse was true. The number of students saying that there is no gender difference reduced from 31 to 26. This was probably on account of the actual performance in the experimental physics course; here the male students did better than the female students. (See results of the experimental tests in the earlier section) (Item 8).
4) Most students said that, among all science subjects they had studied in schools / colleges, physics was taught the ‘best’. Here one is not sure whether the assessment is objective or whether the students give a socially acceptable opinion since they liked physics or had chosen to attend a course in physics. There was no pre or post course difference in this regard (Item 9).
5) With regards to the students’ liking of physics theory, many attributed it to positive school / college experience including good teaching. Many, however, were mavericks who said it was either self-study or projects and external experience and not the school / college environment which resulted in their liking. About 10% students pointed out the negative influence of school / college teaching, especially, the examination orientation of the studies and lack of encouragement from teachers. With regards to practicals some honestly said that they did not have any other experience than the school / college practicals. There was no pre or post course difference in the students’ opinions in this regard (Item 10 and 11).
6) Practically all the students find physics interesting (18/40) or very interesting (21/40). Similarly all of them feel that physics is important (26/40) or very important (14/40) and that it is useful (14/40) or very useful (23/40). Majority of the students find physics neither easy nor difficult (23/40), some find it easy (7/40), but a sizeable number (11/40) acknowledge that it is difficult (although they may say that it is useful, important and interesting); only one student finds the subject very difficult. These frequencies did not vary before and after the course (Item 12 to 15).
7) Majority of the students found theory and experiments equally interesting and the frequency for these items remained the same before and after. Similarly, some students did say that they like either theory more (7/40 after the course) or experiments more (10/40 after the course). The frequencies for these choices were marginally different (10/40 and 8/40) before the course, with the choice tilting in favor of experiments after the course. (Item 16).
8) Practically all students felt that theory and experiments were equally important and this perception remained the same after the course. With regards to perception of

utility, however, there was some change; there were 20 who thought theory and experiments were equally useful and 14 who thought theory to be less useful before the course; these frequencies changed to 28 and 8 respectively after the course. Thus the students probably realized the interdependence of theory and experiments to a greater extent after the course and this resulted in a change in their perception (Item 17 and 18).

9) The students' perception with respect to whether they do theory or experiments better showed some change after the course. The frequencies were 15 and 21 in favor of theory before and after respectively; 8 and 7 for doing both equally well before and after respectively; and 15 and 10 in favor of experiments before and after respectively. One may say that their perception in this regard changed to be a more 'realistic' and less 'romantic' one on account of the course. The course probably resulted in their being aware of the 'rigors' of doing experimental work (Item 19).

10) When asked how the students rate themselves as 'experimentalists', a significant majority (27/40) take up a safe choice 'average', 5 out of 40 take the position 'below average', an equal number take the position 'good' or 'above average', and only 2 out of 40 confidently rate themselves as 'excellent'. No body however rates oneself as poor. This perception did not change after the course (Item 27).

11) Most students (27/40) again take a safe middle course of having learnt 'something', when asked about how they felt at the end of an experiment. Here 11 out of 40 felt a positive (more than average) sense of achievement and 2 felt 'great'. It is significant that no student had a negative sense of achievement. This perception of students remained the same before and after the course (Item 28).

12) Practically, all of them (except 4/40) felt that theory and experiments are closely related. At the end of the course every body (40/40) had acquired this perception (Item 20).

13) To the question to what extent experiments are necessary for learning physics, 27/40 answered that they were essential and 12/40 answered that they were necessary before the course. These frequencies changed to 35/40 and 4/40 after the course. In a sense the course 'convinced' the students that experiments are an integral part of a student's learning physics (Item 21).

14) Before the course 8/40 students opined that either no or a little theory was required for carrying out experiments. These frequencies declined to 4/40 after the course, whereas the frequency for the positive perception in this regard (theory was required

considerably or necessarily for experiments) changed from 31 to 35 out of 40 after the course (Item 22).

15) Before the course out of 40 students 32 felt that practicals develop practical skills and concepts equally, 4 felt that they develop only practical skills and 3 felt that they develop only concepts. After the course these frequencies changed to 36, 3 and 1 respectively. One student who felt before the course that practicals developed neither practical skills nor concepts changed his opinion completely after the course (Item 23).

16) Next we analyzed the students' liking and confidence on a 5 point rating scale with respect to six different aspects of doing experiments. These were a) practical skills and measurements b) design of a new experiment c) relation with theory d) reporting of data e) analysis of data and f) inferences and conclusions from the experiments. We found that the frequency pattern for practical skills did not change after the course for liking, but it changed for confidence, moving up the scale. The frequency pattern did not change after the course, significantly either for liking or confidence in the case of design of new experiments, relation with theory and drawing inferences. In the case of reporting and analysis of data, however, it seemed that the students' liking increased especially in case of analysis, after the course. The confidence frequencies for both these aspects more or less stayed the same. It must be noted that on the whole the students' grading for both liking and confidence with the respect to all the six items (a, b, c, d, e and f) were on the positive side (very high, high or average) and not on the negative side (low or very low). Very few students graded their liking or confidence with respect to the various aspects low (Items 24 and 25).

17) The students were expected to grade importance-wise five possible reasons for their interest in experimental physics. Majority seemed to favor all reasons and graded them highly. There was however, not any significant change before and after the course with respect to three of these reasons, namely, development of ability to work with hands, understanding physics better and learning to use different instruments. With respect to the other two reasons, namely, experiments offer an enjoyable mode of learning physics and offer an opportunity to realize theory in practice, however, there was a change in the students' grading before and after. There perception after the course moved towards more positive rating (Item 26).

Conclusions from the questionnaire

As said earlier, behavioral changes in the attitudinal and affective domain are rather slow and one did not therefore expect substantial changes in this domain as a result of the treatment, i.e. the course on experimental physics. The analysis of the questionnaire has confirmed this. Some items did show changes in the frequencies for various choices made by the students. These were items, which had a direct or considerable bearing on the students' actual experience of the course. Items, which did not show changes in the frequency pattern, were not so directly related to experiments. For example, they were related to the students' intrinsic liking of physics, their perception of the importance and utility of physics and the relation between theory and experiments, the students' liking and confidence in certain specific aspects of experimental physics, their perception of gender difference with respect to preference to physics as a whole or to theory or experiments. Items related to the students' previous experience in their school or college, also, were stable. Probably because the students felt ethically committed to non-criticism of their own institutions, majority of them were positive about this experience and did not change their opinions after the course. Some students did, however, write negatively about their experience and they too did not change their opinions after the course. Also with respect to items of self-assessment, the students took up a safe option, namely the middle or average position.

On the whole it seems that the students felt that their liking and confidence in doing experiments increased on account of the course. Although, as said above, in certain aspects of experimental physics there was no change in the frequency pattern. The course convinced more students that experiments are an integral part of learning physics, that theory is essential for understanding and doing experiments, and that the experiments contribute not only to building up practical skills but also to developing concepts.

In two cases, the changes were rather unexpected. More students said after the course than before that theory and experiments were both equally useful. It could have been expected that after the course more students would opt for 'experiments are more useful than theory', but this did not happen. Similarly, more students thought after than before the course that they did theory better than experiments. This means that their opinions became more sober, tampered with experience, realistic after the course. They did, however, feel that experiments were more interesting than theory in somewhat greater number, after the course than before.

It is also to be noted that their perceptions about physics in general and about experimental physics in particular were definitely positive, although these did not show changes in frequencies. Also, as noted earlier, items bearing on their experience of the course, showed not large but significant changes in the frequencies pointing towards a positive impact of the treatment (the course on experimental physics). At the end of the course the students were given a feedback questionnaire with open, essay type of questions. The analysis of this questionnaire confirmed the positive impact. This analysis is discussed in the next section.

6.2.2.5 Analysis of students' feedback

The three-component evaluation of students' performance in the course on experimental physics was supported by certain qualitative tools. One of them was the questionnaire on attitudinal and other affective aspects of behavioral change, which was discussed in the last section. One more qualitative tool to support the main evaluation tools was the feedback we sought from the students on the last day of the course. The feedback from the students was in the form of written answers to eight essay type questions. The students were given adequate time to complete their answers. Appendix C also reproduces the feedback questionnaire.

Analysis of the feedback

A) The first three questions in the questionnaire were on experimental problems, which experimental problem they liked most, liked the least and found the most difficult. The students' answers to these questions were varied. Table 6.11 gives the frequencies for various experimental problems mentioned by the students in the above categories. The distribution of frequencies is fairly even for the 'most liked' category. In a sense, this is very satisfying for the researcher, because every experimental problem is liked by some students and the number of such students is more or less constant. The possible exception is the Experimental Problem No. 9, the 'rainbow', which does involve fairly tedious experimental adjustments. Only 2 students liked it most. This may be said to be consistent with the fact that as many as 17 found it the most difficult (which was not an unexpected result) and 10 liked it the least. Two students stated that they could not single out an experimental problem that they liked the most; they liked all the experimental problems. Seven students listed two experimental problems in the most liked category. Experimental Problem No. 8 was this way liked the most by four students. Diffraction study using a laser source was liked the most by 8 students; it may be said to be the most popular experimental problem.

Table 6.11 Frequencies of students' responses

Sr. No.	Experimental Problem	Most liked	Least liked	Most difficult
1	No. 1 (Electromagnetic damping)	3	1	0
2	No. 2 (Soft springs)	4 (+2) = 6	0	0
3	No. 3 (Fourier analysis)	5 (+1) = 6	2	4
4	No. 4 (Magnetic circuits)	4 (+1) = 5	0	3
5	No. 5 (Physical pendulum)	3	1 (+1) = 2	4 (+1) = 5
6	No. 6 (Gravitational acceleration)	4	5	2
7	No. 7 (Equi-potential curves)	4	11	0
8	No. 8 (Polarization)	1 (+3) = 4	2	8 (+1) = 9
9	No. 9 (Rainbow)	2	10	17
10	No. 10 (Diffraction)	8	2	0
11	Not a particular	2	6	2

The category of 'the least liked experimental problem' brought out a clear distinction among the experimental problems. Six students said that they did not dislike any particular problem and therefore preferred to leave the answer blank. The other students, however, had a clear choice, 11 liked Experimental Problem No.7 (determining equipotential surfaces) the least, 10 liked Experimental Problem No.9 (rainbow) the least and 5 liked the Experimental Problem No 6 (determination of gravitational acceleration) the least. The reasons for their choice stated by the students were noteworthy; Experimental Problem No.9 was the most difficult and tedious and hence the least liked for some students. Experimental Problem No.6 involved not much experimental work and its significance was not clear to many students and hence they liked it the least. Experimental Problem No.5 was simple in procedure, but the part of it involving calculation of errors was not appreciated by many students and as a result they liked it the least.

Among 'the most difficult' category, the Experimental Problem No.9, the rainbow, was the most frequently mentioned. As many as 17 students found it the most difficult. The next in order of frequency were Experimental Problem No.8 (Polarization) which was mentioned by 8 students and Experimental Problem No.5 (physical pendulum) and Experimental Problem No.3 (Fourier analysis) which both were mentioned by 4 students each. Experimental Problem No.4 (Magnetic circuit) and Experimental Problem No.6 (Gravitational acceleration) also were mentioned as the most difficult by 3 and 2 students respectively. The reasons given by students for their choice were: not understanding the theory, too many adjustments, too many calculations and tediousness. Two students mentioned two experimental problems each as the most difficult ones; one of them mentioned Experimental Problem No.8 and the other Experimental Problem No.5.

B) To the query how the course helped them, the students gave a variety of instructive answers. The common ones corresponded not only to all the three learning categories, namely, conceptual understanding, procedural understanding and practical skills type, but also the attitudinal and affective aspects. These were:

i) The course taught us use of significant figures, estimation of errors, correct technique of plotting graphs and other laboratory skills;
ii) It introduced us to advanced instruments and their use;
iii) It helped us understand and learn new experimental techniques and methods;
iv) It developed correct ways of analyzing observations;
v) It helped us understand concepts better;
vi) It helped us develop problem-solving and self correction ability;
vii) It stimulated and developed logical thinking and self reliance in this regard;
viii) It made us realize the importance and use of experimental work;
ix) It motivated us and developed a new approach towards experimental work;
x) It boosted our confidence; and
xi) It helped us to evaluate ourselves.

C) When students were asked to give their opinion about the effectiveness of the approach adopted in this course as compared to the traditional approach used in colleges, almost all the students said that the approach for laboratory training, adopted in the course was more fruitful than the traditional one. This confirms that the approach and the course was well received and accepted by the students' community. Students listed the following reasons in support of their opinion 1) "There was no spoon feeding, and the course made us cook our own food"; 2) It forced us to think what we are doing; 3) It offered us an opportunity to prove our ability; 4) Understanding and learning of different aspects were more emphasized in the course than in the traditional approach; 5) It answered many "whys"; 6) It encourages originality, innovativeness and questioning; 7) It gave us new and alternate methods or ideas of doing experiments; 8) It enhanced for us the importance of, value of and interest in experimental work; 9) It is an enjoyable mode of learning physics.

D) To the question whether their expectations were fulfilled, many students honestly mentioned that they had either no or little or 'some indefinite' expectations. They found the course, however, 'beyond expectations'. Some students mentioned that the course was offered by the 'Tata Institute of Fundamental Research', so they expected it to be novel and it was indeed so. By the same token one student expected the course to be 'theoretical', which it was not. Another expected to 'design new experiments', which he could do only to some extent. Some students did expect novelty, skill development, learning physics, doing experiments on one's own and so on, and their expectations were fulfilled. A comment by one student is worth mentioning as representative of the opinion of the whole group. She wrote, "I did not expect a miracle, but the course was a remarkable experience. I would like to attend it again and again!"

E) When students were asked to give suggestions to improve the learning component in the course, The following emerged as the most common suggestions: 1) The duration of the course should be more than 15 days; 2) There should be a follow-up program after this course; 3) The course should be regularly conducted for students at different levels; 4) There should be theory lectures to develop a good conceptual base for the experimental work; and 5) There should be more experimental problems and demonstrations.

F) Finally, when asked their general opinion about the course, most of the students stated that it was good, interesting, well organized and beneficial to them. The students listed several aspects, which they thought were beneficial, such as 1) The course taught them many new things; 2) It made them realize the importance of different aspects of experimentation; 3) It developed laboratory skills; 4) It developed the ‘right approach’ towards physics; 5) It was an enjoyable academic experience; and 6) In itself, the course is a new, innovative idea meant to develop ‘the experimentalist’ in the students

It is clear from the above analysis that the feedback from the students was consistent with the improvement found through quantitative evaluation, the tests on conceptual and procedural understanding and the experimental test, and also with the results of the analysis of the questionnaire on attitudinal and other affective aspects. The students, according to the feedback, found the course interesting, innovative, different, beneficial, enjoyable and hence acceptable.

6.2.3 Summary of the evaluation results

In the foregoing pages we described the various tests and supporting tools, which were developed and used by us for the evaluation of the course on experimental physics. The course, it may be recalled, was itself designed to evaluate our research project on development of innovative experimental problems, demonstrations and suitable instructional strategy for them. We also presented the analysis of the results of the tests and other tools. We now recapitulate the results. Prior to this a brief recapitulation of our evaluation strategy will be pertinent.

Evaluation strategy briefly recalled

The course on experimental physics consisted of ten experimental problems, which the group of 40 students who took the course had to work on. The format of each experimental session was very different from the conventional practical sessions conducted in colleges. The session began with a demonstration, which was related to the experimental problem explaining either, its theoretical principle or its method or the use of the main instrument employed in the experimental problem. The demonstration was given by an instructor, who was given a definite format for the demonstration. The students were then given a handout and an instruction sheet on the basis of which they solved the experimental problem. The necessary theory, the use of the experimental apparatus and instruments and the guiding procedural instructions of the problem were all there in the handout and the instruction sheets. The procedural instructions were not so detailed as to allow the students to go mechanically through the experimental observations, their recording and analysis including graphical presentation as in the conventional approach, but there was kept a purposeful scope for the students to design their own sub-procedures, observations, analysis and data presentation. The instructors were there to mainly help the students with technical problems of apparatus or instruments if they arose. The students were instructed to report every aspect of what they performed, their method, their observations, analysis, errors and results. The instruction sheet was self-contained in this respect, too. Further, it incorporated questions integrating theory with the experiments and probing the students' reasoning on various fine aspects of the experimental problem; the students had to answer these questions as a part of their report. The students were given enough time (six hours) to solve each experimental problem. The sessions were characterized by an open, 'free' atmosphere encouraging students to make their own judgments and decisions. Further at the end there were discussion sessions with the instructors and fellow students allowing an exchange of information, procedures followed, innovations tried, difficulties that arose, results obtained, errors and mistakes and general experience. The practical sessions were preceded by appropriate lectures on the use of instruments, systematic and random errors and their estimation, plotting graphs and other aspects of procedural understanding.

The course was the treatment given to the sample group (of 40 students who took the course). The group consisted of students of First and Second Year B. Sc. from various colleges in Mumbai. They all had physics as their major subject. There were 23 male and 17 female students. For the evaluation of the course a three component comprehensive strategy was used. In this strategy we did not use only an experimental test as in the traditional method, but we also used two paper and pencil tests, one on conceptual understanding and one on procedural understanding. All the three component tests were further supported by a questionnaire probing the attitudinal and the other affective aspects of the behavioral change in the sample group of students. The three tests and the questionnaire were given in the pre-course and post-course mode to note the behavioral change. In addition a feedback questionnaire was given to the students at the end of the course. This was to make the evaluation comprehensive. We believe that a sound evaluation strategy of any treatment should use multiple tools and conclusions should be drawn only on the basis of the convergence of the results obtained through such multiple tools. As the analysis of the results presented in the earlier section indicates the tools we used proved to be complementary to each other and showed a great deal of convergence. This convergence makes us confident about the validity of our approach and the results of our evaluation of the course and thereby the conclusions of our entire research project.

Summary of results of the analysis of various evaluation tools

1) In the case of conceptual understanding we found that there was a significant improvement in the students' performance from the pre test to the post test. The difficulty level of the pre and post test was the same. We, therefore, infer that the course on experimental physics and hence the experimental problems, demonstrations and the instructional strategy developed in the research project helped the students improve their conceptual understanding, i.e. the physics pertinent to the course and the project.
2) Similarly, in the case of procedural understanding, the analysis of the pre and post test performance of the students indicated that there was a significant improvement in the students' performance on account of the course. In this case also the difficulty level of the pre and post tests was intentionally kept the same. We therefore infer that the course on experimental physics and hence the developments carried out under this project helped the students build procedural understanding, i.e. the understanding of different concepts of evidence and other abilities like understanding of significant figures, errors and their methods of estimation and interpretation of graphs etc.
3) In case of the experimental test, we observed that there was a highly significant positive change in the students' performance in the post test as compared to the pre test. Here the difficulty level of the post test was purposely kept higher than that of the pre test. We therefore infer that the course on experimental physics helped the students develop various abilities required for solving experimental problems like, practical skills, procedural understanding, conceptual understanding and logical reasoning.
4) There is a certain gender difference in the way the students' performance showed improvement. The female students showed greater improvement in conceptual understanding, whereas the male students showed greater improvement in procedural understanding and overall experimental abilities. (Incidentally, this was reflected in pre and post test frequency difference of the students response to the question 'Who performs experiments better, males or females?' in the questionnaire on affective aspects. In the post test there was increase in the number

of students who replied in favor of ‘males’ and decrease in favor of ‘males and females equally’).

5) The analysis of the students’ responses to the questionnaire on attitudinal and affective aspects, showed that there was a significant and definite, though not a major, change in their behavior, especially with respect to those attitudes and affective traits which are related to the physics laboratory training in particular and physics as a subject in general. Following were our observations in this regard:
   a) The course on experimental physics helped the students realize that both boys and girls equally prefer experimental physics.
   b) It helped the students understand that both the theory and experiments are equally useful.
   c) It helped students to realize that the theory and experiments are integrally related to each other and good experimental work is not possible without theory.
   d) It also helped students understand the objectives of experiments and realize the importance of experiments for learning physics in general.
   e) It helped the students develop interest in experimental physics.
   f) It helped students develop or raise their level of confidence in doing experiments.
   g) It helped students evaluate themselves and understand, in a real sense, what they can do better.

6) The feedback given by the students at the end of the course through answers to an essay type questionnaire essentially confirmed the observations listed above in point number 5. By and large the students felt that although they did not expect a ‘miracle’, the course was a remarkable experience for them. It was interesting, innovative, different, beneficial, enjoyable and hence acceptable to them.

As may be seen the course on experimental physics showed improvement in student performance in all three components of evaluation, namely, conceptual and procedural understanding and overall experimental abilities, especially the last showed highly significant positive change. The results obtained from the supporting questionnaire on attitudinal and affective aspects complemented these results from the quantitative tests. In turn, the results from the questionnaire were confirmed by the feedback from the students. As said earlier, the convergence that emerges from the various complementary tools validates our method of evaluation and allows us to state our main conclusion with a definite measure of confidence:

The developments carried out in the present research project, i.e. the development of experimental problems, demonstrations and suitable instructional strategy for them, if delivered to the students in the form of a course on experimental physics helped the students achieve the better understanding of different aspects and abilities, which are listed as the major objectives of laboratory training in physics.

CHAPTER VII

Conclusions and Recommendations

We are now ready to present the conclusions about and from our research project. The design of the project was presented in chapter IV. The description of innovative experimental problems and demonstrations was presented in chapter V. The format used for the presentation of the experimental problems was based on the conceptual framework of the project described in chapter III. The package of the experimental problems and demonstrations developed was put into the form of a course on experimental physics, which we conducted for a group of 40 undergraduate students in physics. This course allowed us to evaluate the whole project. The course and its subsequent evaluation was described in chapter VI. The conclusions of the evaluation of the course were presented at the end of chapter VI. These form the basis of the overall conclusions, presented in this chapter (chapter VII), about and of the whole project. The present chapter also gives our recommendations, which emerge from our work, regarding improvement in physics laboratory training in Indian colleges and universities. A research project of this kind obviously has limitations in its scope and implementation. These are discussed also in the present chapter. The chapter ends with suggestions for further research work.

7.1 Conclusions

Conclusions about the research work

1) In the present research work, we undertook the development of innovative experimental problems and demonstrations with suitable instructional strategy for their delivery to students. The principal objectives of the project, stated in chapter IV, were as follows:

  i) To develop a set of ten innovative experimental problems and related demonstrations in physics, suitable for the laboratory training of +2 (i.e. higher secondary) level and undergraduate students of Indian colleges and universities.
  ii) To develop a suitable instructional strategy for the delivery of these experimental problems and demonstrations to the students, which can be used for laboratory training in physics.

It would be proper to recapitulate what the project has achieved with respect to these objectives.

i) A set of ten innovative experimental problems and related demonstrations in physics, suitable for the laboratory training of +2 level (i.e. higher secondary) and undergraduate students of Indian colleges and universities was developed in the project.

This development is one of the three major contributions of this research work and we feel that our present system of physics laboratory training in India needs such innovative experimental problems and demonstrations. The experimental problems and demonstrations developed are innovative with respect to their content, format of presentation, the experimental set-ups, instruments and experimental techniques used and the experimental situations. These experimental problems and demonstrations are based on the core areas of physics, which should be essentially taught at the +2 and the undergraduate levels. They involve various types of practical work, such as inquiry, illustration, skill, observation, investigation and exploration.

ii) Equally importantly, a suitable instructional strategy for the delivery of these experimental problems and demonstrations to the students was developed in the project. The strategy may be used for laboratory training in physics for +2 and undergraduate level at various colleges and universities.

We first formulated the conceptual framework for the developmental work. For this, we modified and extended the work on practical science carried out by Gott and Duggan for school level science teaching, to suit our purpose and applied it to the +2 and undergraduate level. We believe that, even at the higher level, the model, the taxonomies and the approach taken by these authors remain pertinent and applicable. Through this work we could identify some aspects and abilities that should be emphasized and are usually overlooked during physics laboratory training. These abilities correspond to what Gott and Duggan have called and have repeatedly been referred to in this thesis as ‘procedural understanding’. Procedural understanding is the understanding of concepts of evidence, which mediate between conceptual understanding and skills.

We also developed a new format of presentation of experimental problems and demonstrations based on the above conceptual framework and the approach followed in the experimental examination of International Physics

Olympiad (IPhO). Our instructional strategy used a 'guided problem solving' approach for the delivery of experimental problems to the students. In this strategy, the demonstrations are presented in an interactive mode and as an orienting introduction to the experimental problems.

2) After the developmental project was carried out, we designed a deliverable package, through which, we plan to deliver what we have developed as a pilot research project to the present system. This was a course on experimental physics, essentially incorporating the experimental problems and demonstrations developed and the instructional strategy for them. This course was modular in the sense that each of the ten experimental problems included in it could be delivered separately as a module and each may be modified and even substituted or omitted as per need, and new experiments may also be added to the package. The course was an intensive 15 day course with a six hour session everyday. Since such a mode of delivery may not be easily replicated in a college, we believe that the course may best be tried as a remedial or supplementary course to support regular physics laboratory training at colleges and universities. It may be given with the same or the modified 'content', but essentially with the same format and mode of presentation. We found that such a course is indeed well received by the students' community.

3) We investigated the effectiveness of the developments carried out under this project, through the evaluation of the course on experimental physics referred to above. For this evaluation a pre and post test design with a single group was used. (Use of a control group design was neither feasible nor essential). The null hypotheses used were with respect to no improvement in scores in separate tests on conceptual understanding, procedural understanding and experimental or practical skills and abilities. They corresponded to no behavioral change in the sample group of students on treatment, i.e., on account of the course. The course was given to forty students in two batches with a batch of twenty each.

The null hypotheses were rejected on the basis of the analysis of the students' performance, in various pre and post tests. It may therefore be concluded that the developments carried out in the research project, i.e., the experimental problems, demonstrations and the suitable instructional strategy, if delivered to the students in the form of a course on experimental physics fosters among the students the following aspects and abilities:

i) Conceptual understanding, i.e., the understanding of substantive or declarative concepts.
ii) Procedural understanding, i.e., the understanding of concepts of evidence.
iii) Experimental or practical skills and experimental problem solving ability.

The fostering of these abilities is essentially the most important objective of laboratory training.

Further, a positive change in various attitudinal and affective aspects related to physics laboratory training, reinforcing the above conclusion, was noted among the students as seen through a questionnaire given to the students both before and after the treatment and feedback given by them at the end of the treatment.

The instructional strategy developed in the project and used in the format of presentation of the experimental problems and in the conduction of the course on experimental physics was the second major achievement of the project. The third major achievement of the project was the formulation of the course itself, which is a deliverable and ready package as a supplementary remedial measure for laboratory training at the undergraduate level.

Conclusions from the research work

In addition to the three achievements listed above, namely, development of innovative experimental problems and demonstrations, development of a suitable instructional strategy and a course on experimental physics, our research work has brought out the importance of following three aspects of laboratory training:

1) Procedural understanding

As said above procedural understanding mediates between skills required to carry out an experiment and the conceptual understanding. Skills refer to activities such as the use of measuring instruments and construction of tables and graphs etc. We may repeat here what was given in chapter III (p. 24). “Procedural understanding is the understanding of a set of ideas, which may be termed as ‘concepts of evidence’, related to the ‘knowing how’ of science and needed to put science into practice. It is distinct from, yet complimentary to conceptual understanding. It is the thinking behind the doing, or the decisions that have to be made for doing practical work. That is, if a student is asked to study the motion of a freely falling body, with respect to its changing velocity, then all such knowledge as planning of the experiment and decisions to be taken as to what is to be measured, what the appropriate range of readings will be, with what accuracy and at what intervals the measurement will be carried out and how one may derive meaningful outcome from the measured data constitutes procedural understanding."

In our project the importance of procedural understanding is explicitly recognized. What Gott and Duggan have used at the school level, we have tried to extend at the +2 and undergraduate levels. The instructional strategy developed by us stresses development and testing of procedural understanding as an essential part of laboratory training. Procedural understanding is usually overlooked in the traditional laboratory training. Our research project underscores the need to treat development of procedural understanding as an important objective of physics laboratory training.

2) Innovative format of presentation of experiments

The second aspect which present work has brought into focus is the format of presentation of experiments. Our format is very different from the traditional format. It is based on the 'guided problem solving' approach, which combines the Gott and Duggan approach with the approach followed in the experimental component of the International Physics Olympiad Examinations. This was discussed in chapter III (p. 34) and chapter IV (p. 38).

In the new perspective of practical science described by Gott and Duggan, problem solving is seen as an important aspect in the teaching and learning of science. They emphasized the role of investigatory practicals in teaching of science at school level. We in our project extended the perspective and applied it with necessary modifications to the +2 and undergraduate level physics laboratory training. We present the experiments as experimental problems to be attempted by the students. Taking into account the requirement of training, we feel that it may not be advisable to present an experimental problem as a single, monolithic unit, but instead may be presented as a collection of interrelated, successive subsections, each subsection being a small problem, through which the students are stepwise guided to the complete solution.

This is the 'guided problem solving' approach referred to earlier. Following this approach we carefully designed self-sufficient handouts and instruction sheets for each experimental problem to be given to the students. The handouts were self sufficient also from the point of view of theoretical explanation. One of the important elements in our instructional strategy was the purposeful integration of theory with the experiments. Further, questions to be answered by the students in their reports were incorporated within the handouts. These served to focus on issues of conceptual and procedural understanding.

Another aspect of the format of presentation was that the self-sufficient handouts and instruction sheets allow minimal intervention by instructors. The instructors provided minimal guidance to the students working on the experimental problems. This format was essentially directed towards inculcating self-reliance and independent thinking on the part of the students. The laboratory atmosphere was essentially conducive to this. It was open in the sense that the students were expected and allowed to take their own decisions about procedures and measurements based on their understanding of various concepts of evidence and other experimental aspects.

What is traditionally referred to as explanation of an experiment was substituted in the above format by a related demonstration. A demonstration accompanied every experimental problem and was given as an introductory prelude to it, serving to introduce to the students that concept, instrument, technique or method which was central to the experimental problem.

An non-trivial and concrete outcome of this project is that a course on experimental physics incorporating not only innovative experimental problems and demonstrations but also a novel format of presentation based on the detailed instructional strategy described earlier has been now become available.

3) Evaluation method

In the traditional method of evaluation of various aspects and abilities related to experimental physics, only the experimental test is used and there is no separate evaluation of students' level of procedural and conceptual understanding.

In this project, we have used a comprehensive method of evaluation consisting of three separate tests. Two of them are paper and pencil type tests, one each on conceptual and procedural understanding. The third one, an experimental test, measures students' experimental skills and abilities required to effectively solve a given experimental problem together with the cognitive (i.e. conceptual and procedural) understanding. We used objective type questions for testing students' conceptual understanding. For testing procedural understanding we used descriptive essay type questions based on various experimental situations and related concepts of evidence. We used, as in the case of the experimental component of the International Physics Olympiad Examinations, an identical experimental test to be given to all the students. This ensures that all the students are tested on the 'same ground', unlike in the case of the traditional laboratory evaluation method in which different students are given different experiments, which may have very different difficulty levels.

Another important aspect of our method of evaluation of an experimental test, which, too, we have borrowed from the method used in the experimental component of the International Physics Olympiad Examinations, considerably reduces the subjectivity of assessment present in the traditional method. We ask the students to report practically every observation they take, every procedural step they follow etc. The students are graded entirely through their comprehensive reports, totally avoiding subjective judgments based on the 'observations' and 'interrogations' by the examiner.

We believe that an important outcome of our project is the novel method of evaluation described above. The method is more comprehensive (tests different aspects of laboratory training), more objective, more valid and reliable as an achievement test, than the traditional method of evaluation of laboratory work.

7.2 Recommendations

We give below, recommendations and suggestions for improving the quality of physics laboratory training in India, at +2 and undergraduate levels. These recommendations are based on the research and development carried out under the present project and the findings of the evaluation of the effectiveness of the development.

1) We believe that our project has given a concrete outcome in the form of a well-tested course on experimental physics of direct use at the undergraduate level in Indian colleges and universities. We recommend that a course on experimental physics of the kind, developed in the present research work, should be conducted at different institutions, colleges and universities to supplement regular physics laboratory training. This kind of course may be conducted for students at different levels, starting from higher secondary up to the postgraduate stage, with appropriate modifications as per the need of the levels. The modifications may be with respect to contents, duration, difficulty level of the

problems and guidance provided to the students. The instructional strategy may, however, be essentially kept the same.

We believe that such supplementary courses on experimental physics, if conducted regularly, will serve to improve the quality of physics laboratory training in India.

2) We describe below the changes or modifications, which we feel if incorporated in the present practice of physics laboratory training in India at +2 and undergraduate level will go a long way in improving the effectiveness of our physics laboratory training.

a) Some of the experimental problems designed and developed in the research project may be introduced in the regular physics laboratory training at different appropriate levels. The experimental problems may be introduced as they have been developed or with some modifications to suit the need and conditions of the laboratory training. If an experimental problem is found to take longer hours than what the systemic time constraint permits, it could be divided into subsections.

b) Even in case of existing experiments in the present laboratory courses, a novel reformulation of the content, experimental technique or method, the instruments used or method of data analysis similar to what has been done in the project, will improve the quality of laboratory training.

What is important is not novelty per se, but the fact that a non-routine, novel experimental situation engenders interest among the students. This has been one of the significant experiences of the present project.

c) During the regular laboratory training, an important aspect of experimental science, i.e., the development of procedural understanding is often neglected. We feel that procedural understanding should be explicitly recognized as an important objective of the physics laboratory training and emphasized during the training.

d) We believe that there should be some qualitative change in the approach used in the present laboratory training in Indian colleges and universities. This strategy is more or less based on a ‘prescriptive’ or ‘programmed’ learning method. We feel, that a ‘guided problem solving’ method with certain openness and a provision of students’ self designed experimental work, as has been the case with the course on experimental physics designed by us, may be introduced. We believe that the experiments in the present laboratories are delivered in such a novel format, they will, even if their content is unchanged, improve the quality of laboratory training.

3) The course on experimental physics as was designed and conducted for students by us may be conducted for in-service teachers as a refresher or orientation course in experimental physics. Through such courses, important aspects that should be emphasized during laboratory training may be introduced to the teachers with necessary content and examples. We may also introduce new experiments, demonstrations and the new approach through such courses, which teachers may transfer to regular laboratory training.

4) It has been observed that, the evaluation method which is being followed in India for experimental physics is basically a check of "How the student has performed the set of allotted experiments throughout the year" and not "To what extent the student has developed experimental skills, conceptual understanding, procedural understanding and other related abilities". We feel that the evaluation method designed by us and used in the course on experimental physics is more fair, more comprehensive and more reliable and hence more satisfactory than the traditional method. It is comprehensive as it supplements a purely experimental test with written tests on conceptual and procedural understanding. It is fair in the sense that the same test is given to every student. Also, it is more reliable as it removes the subjectivity of judgment through personal observation as is practised in the existing system and replaces it with the grading based on a comprehensive report by the student.

We believe that the method of evaluation designed and used by us for the evaluation of the project, if used in full or in part, will prove useful in improving laboratory practical evaluation in Indian colleges and universities.

7.3 Limitations of the research work

We describe below, the limitations of the research work presented in this thesis. These limitations are based on a critical analysis of the research work.

1) The ten innovative experimental problems and demonstrations developed in the project represent the areas of mechanics, optics, electricity and magnetism. While there are certainly important core areas of physics, areas such as heat and

thermodynamics, electronics and modern physics have not been covered. In a more comprehensive course on experimental physics than the one developed by us these areas should also be included.

2) The experiments that we have developed being novel used set-ups specially fabricated by us. This could prove to be a limitation, especially, cost wise, if individual institutions wish to replicate the work. On the other hand large scale production of the apparatus may reduce the cost involved.

3) The demonstrations, which are part of our instructional format of presentation of experimental problems, require a large teacher to student ratio. Further, the format requires more time to be given to students for each experimental problem. From the point of view of direct introduction of the experimental problems developed here into the present laboratory training, this is a limitation. If the course incorporating these experimental problems is given as a separate, special, remedial course, say, during vacations by colleges or institutions the limitation may be overcome.

4) The category of students with whom the course on experimental physics we developed, was tried could be classified as ‘somewhat above average’. We believe this not to be a strong and essential limitation of the project, although it may be worth repeating the course for more ‘average’ and ‘below average’ students.

5) There are two important aspects of the research carried out in this project. One is the development of innovative experimental problems and demonstrations and other is the development of suitable instructional strategy for them. Both are evaluated together through the course on experimental physics designed and tried out by us. The effectiveness of the two aspects therefore cannot be separated. This could be achieved through the use of successive control groups. Also, if an exact comparison is to be made between the traditional instructional strategy and the strategy developed here, the control group technique is necessary.

6) For the evaluation of the project, we conducted the course on experimental physics on a sample group of 40 students. For drawing more concrete conclusions from this kind of a project the sample size may be increased.

7) We have carried out the work mainly in the context of undergraduate physics. Although we believe that the conclusions of the project are applicable to the post-graduate level as well as to higher secondary level, this needs to be probed and established.

8) The project broadly aimed at improvement in laboratory training practices in India at the + 2 and undergraduate level. We did not carry out a systematic and extensive survey in this regard for assessing the need for improvement and its exact nature.

Work needs to be done to remove or minimize the effect of these limitations, especially when the experimental problems, demonstrations and the instructional strategy developed here are applied with a view to improve the state of physics laboratory training in the country.

7.4 Suggestions for further research work

We give below suggestions for further research work, which may be taken up at different levels for research and development in physics education. Some of these suggestions emerged from the limitations discussed above.

1) As described earlier, the experimental problems and demonstrations that we have developed are based on concepts from some core areas of physics, but some important areas in physics, which should be taught at the undergraduate level, are not covered. We feel that, there is a need to take up a similar developmental project in which many more innovative experimental problems and demonstration based either on some other concepts from areas covered here or on some other areas like heat and thermodynamics, electronics and modern physics may be developed.

2) We have tried the course on experimental physics developed in this project, on undergraduate students from various colleges in Mumbai. We have checked the applicability and suitability of such a course on these students. We feel that, the course may be tried with suitable modifications on the +2 level and post-graduate students for checking its suitability and applicability as a remedial supplementary course on experimental physics.

3) We have tried out the course on experimental physics through which we evaluated the entire research project, on a sample group of 40 undergraduate students, who may be said to belong to ‘above average’ category of undergraduate students. We feel that it may be worth to try the same course and thus investigate the effectiveness of the project, on undergraduate students belonging to ‘average’ and ‘below average’ category.

4) As said earlier, we tried out the course on experimental physics to evaluate the effectiveness of the developments carried out in this project on a group of 40 students. We feel that further work may be taken up for establishing the effectiveness of the developments with larger sample size.

5) For the evaluation of the project we have used a single group methodology to study the effectiveness of the development carried out in this project. We studied the combined effectiveness of the innovative experimental problems (and demonstrations) and the novel instructional strategy developed for them. We feel that, a comparative study may be taken up in which the individual effectiveness of these two developments may separately be carried out with respect to their traditional counterparts, i.e. traditional experiments and traditional instructional strategy. This study may be carried out using a control group methodology.

6) A developmental project may be taken up in which a course, of the kind developed in this project, may be designed with essentially our format of presentation and the instructional strategy but with traditional or regular laboratory experiments being used in laboratory training at various colleges. We believe that, even such a course will also prove effective as a remedial supplementary course for students.

7) We feel that, it is important to try out the course on experimental physics developed by us with physics teachers. This may be taken up to study the suitability of such a course for teacher training and acceptability by teacher’s community as a refresher or orientation course. This may be tried on +2 and undergraduate physics teachers of various colleges and universities.

8) We have used a new perspective of practical science and defined a novel conceptual framework of this project. We feel that, this new perspective and the framework may be applied to the laboratory training in other branches of science

and thus an attempt may be made to improve the quality of laboratory training in other branches of science.

9) We feel that, further research work may be taken up to establish more concretely the effectiveness of the method of evaluation developed by us in this project. It may be worth to develop and try out a suitable evaluation strategy based on this work for other branches of science and for various levels of laboratory training.

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