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 19^{th} 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 19^{th} 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 19^{th} 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 20^{th} 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.

[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 10^{th} 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) <u>Development of innovative experiments and demonstrations</u>

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.