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) <u>Identification of the required tools, devices, instruments and the experimental arrangement</u>

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) <u>Design and fabrication of the apparatus and the experimental setup</u>

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) <u>Assembling the complete experimental setup</u>

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) <u>Checking for the correctness of the experimental problem and obtaining the solution of the problem with required data and results</u>

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) <u>Identifying the objective of the demonstrations</u>

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) <u>Checking the correctness of the demonstration and recording the relevant data</u>

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) <u>Developing and preparing the instructors' handout for each demonstration</u>

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.