# TEACHING STRATEGIES IN LABORATORY

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**INTRODUCTION**

The goals, aims and objectives we talked about in the last unit assist a lot in determining the aching strategies for laboratory work. In this chapter, we would see how aims and objectives may be translated into the laboratory strategies and tactics which students have to undertake. These teaching strategies will comprised of a general plan which includes structure, desired tended outcome in term of goals of instructor and an outline of planned tactics necessary to implement the strategy.

In this unit, three teaching strategies viz a) Controlled exercises; b) Experimental investigations and c) Research projects are being described for the laboratory. The allied material referred to I is unit gives you an ample opportunity to plan and organize your Laboratory work. The development of laboratory courses occurs in a number of ways. It may be the result of a decision to mount a new course in an existing or a new programme; more commonly, it can occur on an ad hoc basis when particular experiments are modified or new ones introduced. This may be a spouse to some need to upgrade the content of the course in order to produce new methods, techniques or apparatus, or it may be required to address some deficiency which has been identified by an evaluation. The instruction of an entirely new laboratory course, with activities which have not been used elsewhere in some form or another, is a very rare event and a luxury which few departments can afford because of the substantial cost and fort required.

The danger is changing laboratory courses through adhoc revision or rough putting together a collection of activities used previously is that the course will lack coherence and may appear to the students to be a random collection of odds and ends. It is not sufficient that the activities have some face validity in terms of the content of the course: if the course is to do more than simply introduce a number of methods and techniques it must be planned to ensure that it develops the experimental and analytical skills of the students and is founded in the structure of the discipline. Without this the laboratory can generate into a playground of out-to-date gadgets. Nevertheless, we cannot usually start from first principles and are normally obliged to fit in with the existing pattern of teaching activity.

We have seen in unit 1 how considerations of general goals, aims and objectives can assist in planning for laboratory courses. The next step is to see how these can be translated into the laboratory activities that students are to undertake. We should be considering teaching plans: that is, what course planners do to ensure that the hoped for learning experiences take place and the desired outcomes are achieved. Staff has all sorts of things in mind when they are planning any course. There are bits of subject matter they would like to see included, ideas for experiments, enjoyable events, memorable episodes, interesting phenomena they would like to portray, and novel techniques they would like to demonstrate. These can come to mind at any time in the planning process and it is important to record them for later use where appropriate. One way to start is to focus on what Posner and Rudnitsky S2 term central questions and to group the jottings and ideas one has collected around them. In the laboratory context such central questions might include: What are the important techniques to be used? What is the main subject theme to be pursued? What are the key skills to develop? What are the chief attitudes to inculcate? The jottings might themselves suggest central questions otherwise overlooked.

The idea generation stage is necessarily an open-ended one with a strong emphasis on creativity and intuition. But there comes a time when ideas have to be discussed by all those involved in the planning and related to the rational plan which is being formulated. They need to be connected to the general goals, aims and objectives and the teaching plans flowing from them. Acceptance of some of these ideas may make for modification of the goals, aims and objectives and in some cases overturn what were quite systematic, but perhaps pedestrian, intentions. Bright ideas need to natured, but ultimately they need to be subject to a check on their validity and practicability.

Laboratory courses can be organized in many different ways, all broadly classifiable into three main ways depending on their purposes and the degree of detailed control exercised by staff over student’s activities. We have called these ways of organization controlled exercises, personalized system of Instruction, experimental investigations and research projects (after Carter and Lee 1981).

* Controlled exercises are defined as activities which are wholly devised by the staff and can be completed by the students in one or two laboratory periods. The strategies in this category are well suited to the development of fundamental skills and techniques that can be well specified and practiced to give a high degree of competence.
* Experimental investigations defined as longer activities, normally set by the class supervisor and including elements of the choice of procedure and methods of data analysis by the student. This type of practical work may well extend over several laboratory periods. The strategies in this category are well suited to the development of investigational skills, such as using literature, and aspects of experimental design and planning. These activities can give practice in aspects of scientific inquiry.
* Research projects significant pieces of work that may occupy the practical sessions for a term, semester or even one or two years of an undergraduate course. A problem, which is original or novel, is usually defined by a staff member or research group, then selected by a student and thereafter pursued on a consultative basis between the student and research project supervisor. Strategies inquiry skills previously discussed into one coherent activity, and are intended to simulate elements of real-life research and development activities.

**OBJECTIVES**

Enter going through this unit, it is expected that you will be able to:

1. learning about teaching strategies of laboratory such as Controlled exercises, experimental investigations and Research projects;
2. distinguish among these three types of teaching strategies of laboratory;
3. present critiques, on these teaching strategies of laboratory;
4. bring changes and modify your laboratory as science teacher or science educationist.

**6.1 Controlled Exercises**

Controlled exercises are characterized by detailed experimental procedures and a known destination or educational outcome. In the early stages of an undergraduate course, the major emphasis is usually on learning some new manual skill or technique, and using it to carry out an experimental procedure accurately and precisely. The student can measure some effect, or observe an event and then make calculations or draw a conclusion. In some instances, controlled exercises can be used to provide concrete experiences of abstract concepts although well-presented demonstrations might achieve this aim as effectively and without the need to occupy valuable laboratory time. Familiarity with the materials of science, such as laboratory equipment and apparatus, chemicals and living organisms can also be effectively achieved by this approach. In the later stages of the course, the emphasis may be placed upon higher aims such as the interpretation of data or drawing conclusions.

Controlled exercises typically involve the student in the following steps:

* An introduction to the experiment through some form of pre laboratory activity.
* Carrying out the experiment by following a well-defined written procedure.
* Writing up the experiment and submitting the report for assessment. The major appeal of controlled exercises is that it is easy to find examples in journals and standard texts, and it is very tempting to put the examples with little change into an existing course. However, it is evident that this procedure can then cause teaching problems, for the following reasons:
* The example may be an experimental procedure, with no explicitly stated aims.
* The example may have been used by its author for a different purpose from the one proposed by its adopter. For example, an experiment on the study of the absorption spectra of chromiun chloride solutions could be used as a means of training students in the use of spectrophotometer, or be a demonstration of the Lambert-Beer Law or an illustration that colored solutions have light absorbing properties. It is very unlikely that all three objectives can be met by the one experiment.
* The absence of any objectives makes it difficult for the student, who may read the experiment for the first time immediately prior to commencing the laboratory work, to realize what is going on. Yet because the procedure is so clearly detailed, the student is able to complete the exercise and achieve a result. It is not difficult to understand why, in the absence of clear reason for the activity; students see such exercises as cookbook or recipe work.

There is also the problem that laboratory work is physically separated from the lecture giving the theoretical principles and concepts it illustrates and the connection may not be evident. Nevertheless, controlled exercises can be used with success for a variety of aims and objectives, providing that sufficient time is spent in setting the procedural activities in a format which makes their educational aims explicit to staff and students.

One way to make life easier for student and teacher alike is to design experiments which have a single major objective. The advantage is that students concentrate on one specific aspect at a time, rather than undertake a more complex experiment in which concepts can be obscured by detail or confusing overlap occurs. Another advantage of single concept experiments is that they can probably be conducted in a shorter period of time, and several carried out in a single 3-hour laboratory, or fitted into an out-of-hours’ time slot for remedial or revision purpose. An example of a single concept experiment is provided by CYConnell, Penton and Boud (1977), who designed several for a first-year physics laboratory course taken by students from a variety of disciplines. This one is the use of a cathode ray oscilloscope. The experiment has two sets of written instructions, the first being a description of its purpose and objectives and the second a programmed text describing the operational aspects of the oscilloscope. A similar approach, but using a set of slides with the oscilloscope in a study carrel, has been used by McKittrick and Winch (1972).

Using a Cathode Ray Oscilloscope (aims 2 and 3)

The objectives of this experiment are to make you familiar with the controls of a simple cathode ray oscilloscope (CRO) so that you will be able to:

1. Adjust a CRO to obtain a stable picture of an input waveform.
2. Predict the effect of changing any one of the controls.
3. Make measurements of the voltage and period of an input periodic waveform.

The cathode ray oscilloscope is probably the most used single piece of equipment in any scientific laboratory. Many different types and makes will be met during your course throughout the University. This experiment uses one of the simplest CROs available so that you may become familiar with its controls before passing on to more complicated types.

The programmed script includes an explanation of the function and operating principles of the CRO and takes you through the setting up and use of the instrument stage by stage.

In another approach (Cryer and Rider 1977), a consortium of six British universities produced fifteen do it yourself demonstration experiments. Their purpose was to enable first year students to observe phenomena that they might not had the opportunity to experience at high school, or which they washed to use as background material for their current course. The equipment and apparatus were laid out ready for use in a laboratory supervised by a technician, and students could go in when they wished and sample any demonstration.

Two other quite distinct schemes involving controlled exercises are worth nothing. First, there have been several reports of learning aids laboratories (Pollerans Seeley 1977; Hughes and Robb 1976). Here students are involved in a variety of learning activities by the use audio-visual aids, displays, demonstrations and experiments. Such centers are often operated on a self service basis, and may not be part of the formal scheduled class. They may be used for directed remedial learning, pro-laboratory preparation, and background material and enrichment purposes. A good example is the learning centre of Prigo, Korda and Walker (1975), which was open forty hours a week and filled with commercially and departmentally designed physics demonstrations in mechanics, heat, wave motion, sound, electricity, magnetism, and optics. Students could experience, in an individual and self paced manner, various physical phenomena directly and independently of the mathematical description given in lectures. Similar centers have been described for biology (Ramsay 1973) and chemistry (hughes and Robb 1976).

The second scheme is called the integrated laboratory and seeks to bring separate disciplines or sub-disciplines into one laboratory learning experience. Most reports of the scheme have been about chemistry, and a variety of experiments involving organic, inorganic and physical chemistry have been published. A typical experiment might involve the preparation of an organic substance which is then reacted with a catoin to produce a coordination compound. The compound is then subjected to various analytical techniques and instrumental measurements (see Hanson and Simmons 1972) for an experiment of this nature. The organization of various courses by integrated laboratory has been described by Brown (1972), Cochran et al. (1972), Micheal, Southwick and Wood (1972), Dence (1973), Rose and Seyse (1974) and Aikens et al. (1975). Cartwright (1980) surveyed thirty four institutions in the USA and found that seven used integrated laboratories. He also discussed some of the advantages and disadvantages of the approach.

Computers have been used in controlled exercises of many types, mainly to assist students in copying with repetitious calculations. For example, the computer can check that a result calculated from data collected in an experiment is correct, and then process the rest of the data. If incorrect, the computer can check the calculations and locate the error. Various statistical calculations, such as means and standard deviations, can be programmed into the system. This application can be of value to both student and teacher. Many descriptions of such uses of computers appear in the literature ( for example, Dowling 1975; Rinard and Calvert 1973; Bron 1972).

Two other organizational schemes, the Personalized System of Instruction (PSI) or Keller Plan, and the Audio Tutorial method have been widely adopted in undergraduate science teaching in the last decade. They are both well suited as vehicles for controlled exercises, since they both pay special attention to the use of specific objectives. In addition, the PSI scheme uses a concept important in the area of fundamental skills and techniques called mastery learning. A level of mastery is often set in terms of the level of skill or knowledge required in subsequent parts of the course, or in future courses, of which the present course is a prerequisite. Proponents of mastery learning argue:

* That there is an identifiable set of skills or knowledge that is necessary to instill in all students taking the course, i.e a kind of core material.
* That it is possible to specify a level of performance that is accepted as indicative of mastery of the skills or knowledge.
* That there are techniques available to assess whether mastery has been achieved by the student.
* That student, given enough time, can reach the set level of mastery. Putting behavioral objectives together with mastery learning is an excellent combination in the teaching of basic skills, and is one of the underpinning features of PSI.

These are activities which are wholly designed by the teacher and are often thought of as verification exercises. They can be completed by a student within a short timespan, typically one or two laboratory periods. There is a known outcome and if students follow the instructions, they should arrive at that outcome (more or less).

**Advantages of Controlled Exercises**

They can provide introductory experience with the materials and processes of a discipline, equipment, apparatus, organisms, and chemicals, as appropriate. In many disciplines, the whole procedure has become very well honed. Teachers who wish to use controlled exercises with their students can often locate suitable experiments in laboratory manuals from their own student days, in commercial texts, or in discipline-specific education journals. For faculty, a major appeal of using controlled exercises is the ease of finding them and the charm of their predictability. They can be used from year to year with minimum fuss.

**Disadvantages of Controlled Exercises**

A major disadvantage is that students often do not like controlled exercises very much, finding them dull and tedious. Students may not be very sympathetic towards the elegance of exercises nor regard their lab work as a microcosm of experimentation. They can find the pre-lab work a meaningless ritual, the introductory talks and the controlled exercises as lacking personal satisfaction or connection to their world. Results and reports from students in previous years are often readily available and there is the temptation for the task of writing up to become one of 'faking good' the results.

**Examples of Controlled Exercises**

An example of a controlled exercise which students found boring and alienating is the following from a materials science lab where students are expected to learn about the properties of polymers; specifically how polymers behave under different conditions. The students are asked to conduct a series of tests to explore the properties of polymers. They are given samples of a specific size established by standards and asked to test them in tension using a tensile testing machine. Usually they would not do the tests themselves, but watch whilst a technician conducts the tests. After the samples of a range of polymers have broken, the students are required to calculate the basic properties of each material. An assignment is to write the experiment up, with the emphasis being on presentation and producing results of the right order of magnitude. In all, there is little or no opportunity for the students to engage with the techniques or to relate the exercise to their world.

By contrast, the following is an example of a controlled exercise which students found more engaging. It is on the same topic, how polymers behave under different conditions.

Students are asked to test the bouncing power of squash balls at different temperatures, including first dropping them into liquid nitrogen. One student described it as an experiment which he found useful and which captured his imagination. He said the students had fun and got a physical feel for the glass transition temperature and its relation to mechanical properties. Here the squash balls are something that most students recognise. Both the balls and the use of liquid nitrogen have about them an element of drama. Students are asked to do the tests themselves rather than watching someone else and are required to show their results to their demonstrator.

## 6.2 Experimental Investigations

This term is used to cover a wide variety of teaching methods which foster deep approaches to study by encouraging students to take personal initiative in the performance of the exercise. This might range from experimental design, choice of variables for investigation, choice of materials or methods, choice of methods of data analysis, through to choice of the problem for investigation. The investigation would usually be limited in time and scope and would not qualify as a project. Thus, it might be an extension of a controlled exercise which appealed to the student, or a variation of a well-known theme or method. Experimental investigations can be more or less structured - and often this means shorter or longer.

Structured investigations retain teacher control of materials or methods whilst giving students an opportunity for enquiry. Unstructured investigations retain teacher control of the aim but allow students to plan the materials and methods. In practice, experienced teachers can do much to anticipate students' needs in the laboratory and avoid situations where unforeseen or unreasonable demands are placed on the technical support system.

### Advantages of Investigations

The first is the opportunity to allow students to practice skills of scientific enquiry, such as planning part or all of an experiment, whilst the second is the provision of a good motivational context. The two are linked: planning requires students to invest some personal initiative, and a sense of ownership and initiative is likely to be motivating. In the laboratory setting, it would seem that independent learning, project work, and experimental investigations share the qualities of independence and student motivation, but with decreasing freedom for independent learning.

Interviews with students show that they are very aware of the freedom for independence and of its effects on their motivation: the key to running successful investigations with junior students is not to throw them in from the deep end but to help them proceed from an adequate base of knowledge and skills. The idea of learning cycles is well described in the literature (e.g., Atkin and Karplus, 1963) and is further discussed in Boud et al. (1989).

### Disadvantages of Investigations

Why are controlled exercises retained as traditional fare? When do the disadvantages of investigations outweigh the advantages? Costenson and Lawson (1986) interviewed teachers and proffered a list of the top 10 teacher perceptions which have prevented the introduction of enquiry-oriented curricula into junior courses, or have resulted in this type of curriculum being discarded. Any faculty member introducing an investigative approach in undergraduate laboratory work might take note of which of these views they have heard expressed by colleagues.

1. Requires too much time and energy
2. Too slow
3. Required reading is too difficult
4. Risk is too high
5. Tracking - only the best students can cope
6. Student immaturity
7. Teaching habits are too ingrained
8. Sequential material is a management problem
9. Teacher discomfort with perceived loss of control
10. Too expensive

The issues at the heart of this worry list need to be seriously addressed although sometimes such views are based more on perceived threat, prejudice or conservatism rather than rationality and evidence. Two important factors in improving the successful running and institutionalisation of a program of investigations are teamwork and staff development.

### Example of an Investigation

As an example of an experimental investigation, this one allows for more investigation than the controlled exercises discussed above, but is still on the same topic - how do polymers behave under different conditions? In this investigation, the students are given a series of different polymers, a few different testing apparatus and temperature controlling devices. The students are then asked to design an experiment which will explore the viscoelastic properties of polymers. There are many different possibilities including producing a stress/strain plot at different strain rates or temperatures, or by exploring stress relaxation, and these possibilities use the same basic equipment as before. Each student then produces a different piece of work, there can be no copying, and each feels as if they have done something useful. There is no right answer but a feeling of having discovered what the concept of viscoelasticity is all about. It can be related to a real life issue such as investigating the properties of a polymer for use in skis, which need to be used at different strain rates and temperatures.

Done as a structured investigation, the students are given ready-made test pieces from which they select the polymer and decide on the test conditions. As an unstructured investigation, students decide what test pieces are required and either make them themselves or ask the workshop staff to prepare them. They decide on the test conditions and plan accordingly.

**6.3 Personalized System of Instruction (PSI)**

The Personalized System of Instruction (PSI) or Keller Plan is one of the most publicized, non-traditional approaches in teaching in higher education, and is one of the few teaching innovations which have been carefully evaluated and clearly demonstrated to be more effective in given circumstances than traditional teaching methods (Kulik, Kulik and Cohen 1979a). The major distinction between PSI and traditional courses is that the students works through a number of written units each consisting of an introduction, a list of objectives usually written in behavioral terms, student activities and a series of study exercises. A one semester course might consist of twelve such units. There is no regular formal lecture series and Roller (1968) summarized the distinguishing features of the scheme in the following way:

* **Self-pacing**: The student progresses through the units of study at a self-determined.
* **Mastery learning**: Students are expected to demonstrate, through testing procedures, a high level of mastery of the specified course work. The students decide the appropriate time to take the unit test, and then can reset the test at a later date if the prescribed master level is not achieved.
* **Motivational Lectures**: Lectures are used occasionally as a means of supplying motivational material. Most applications of the PSI scheme have concerned theoretical material, i.e the material traditionally supplied in a lecture course, but there are examples applied to courses involving both theory and laboratory work. Self-pacing can be achieved in the laboratory context by opening the laboratory for several sessions per week and allowing students to book a period convenient to them. Even so, there may be limitations on providing the whole menu of experiments at any one time, which can be an inefficient use of staff time and laboratory equipment. It is more common for an exercise to be available for one week, with the student required to complete the exercise within that period. This can provide the pressure to keep to a regular schedule and avoid procrastination, which has been identified as one of the problems of PSI courses.

Detailed objectives are usually written for each laboratory exercises, and this is beneficial since they provide a clear specification of what the student is expected to achieve on completion of the work. One problem with published behavioral objectives/mastery learning combination for uniquely laboratory based activities, such as manual skills, are often omitted. Hence it is difficult to judge to what extent these ideas are carried through a laboratory teaching. A lot of time is required to achieve mastery, and if this aspect of PSI is to be retrained then only a few of all the techniques encountered in, say, a typical first-year course can be dealt with at this level of competence. However, it is possible to provide the practice in a variety of contexts, so that although each exercise may have a different purpose, the correct use of a technique may be a common requirement.

One characteristic of laboratory courses using PSI which has become evident is that there may be a minimum core of practical’s to be carried out with additional optional exercises. Students who satisfactorily carry out the basic requirements are awarded the minimum passing grade, so that completing the optional exercises becomes the method for awarding higher grades (Valeriote 1976; Cassen and Forrester 1973; Patterson and Prescott 1980).

An example of the PSI scheme applied to first year general chemistry students is reported by Valeriote (1976). From a total enrolment of 400 students, two groups of twenty four were allocated to the self-paced format. Students were informed that the laboratory would be open for the scheduled sessions and additionally in the launching periods. Each term students were required to do a certain number of set experiments. Optional exercises were also available. Each experiment consisted of a pro-laboratory assignment, experimental work, calculations and write-up. All experiments were graded by the demonstrator in the presence of the student, and assigned a grade of fail, pass or good. No experiment could be commenced until the previous one had been graded. A written laboratory examination on the set experiments was given at the end of each term. The self-paced groups scored a final mean laboratory grade of 72 compared with 65 for the regular group. In the self-paced group 67% and 76% of the students completed extra experiments in the first and second term respectively. The author stated that personal contact with the students definitely increased, and students slowly but definitely accepted responsibility for their own progress through the course.

Patterson and Prescott (1980) described a first year physics laboratory which had some aspects of PSI. The students worked in pairs at their own pace until they decided that the experiment was complete. Their notebooks were checked and their records discussed with the instructor. In some cases the instructor had the opportunity to ask further questions if necessary, test understanding. If the work was deficient in any of the set aims, then the student was sent back to redo part or all of the experiment. The experiment ended and the next one commenced only when students and instructor agreed that the work was substantially complete. The final grade was determined by the score achieved for all the completed experiments. Thus the able students, who could proceed at a greater rate, achieved high score, whilst the weaker students tended to proceed at a slower rate and thus achieve lower scores. In this study, assessment in the laboratory did appear to be measuring kills that were different from those measured by examinations on lecture material. Another example, of the application of PSI in a physics course is given by Brown et al (1977).

A survey of research findings (Kulik, Kulik and Cohen 1979a) clearly indicates that PSI courses enhance student achievement, and that students rate PSI classes as more enjoyable, more demanding and higher in overall quality and contribution to student learning than conventional classes. These authors also found that completion rates are similar in PSI and conventional classes, and that there is no significantly increased demand on student time between PSI and conventional courses. These findings are, however based on overall success, and the laboratory component has not been examined in isolation. It is a pity that more attention has not been given to this aspect, since a PSI laboratory course based on self-pacing, objectives, mastery tests and the use of instant feedback via proctors would appear to be an excellent vehicle for training students in essential basic skills and techniques.

**The system consists of three basic components:**

* **Independent study sessions** usually carried out in a specially designed learning centre. The centre is equipped with study booths or carrels which contain a tape recorder, some audio-visual equipment such as a slide projector, and any other appropriate learning materials. Ideally the centre is open continuously, so that the student can choose the most suitable time for the study work to be undertaken. The students book a place, and receive a list of behavioral objectives for the weeks work, a taped study programme and a study guide. The tape via the recorded voice of one of the staff, guides the student through a variety of learning experiences, which might include performing an experiment, collecting data from a demonstration, reading, viewing some slides, or filling in diagrams or charts. If the experiment requires the use of bulky equipment, then the practical work may be carried out in another area of the learning centre. When the segment of work is complete, the student leaves the centre.
* **General assembly sessions**: Large group activities held towards the end of a week’s work, which might be used for viewing long films, listening to a guest lecture, or doing a major examination.
* **Small assembly sessions**: Small group activities, in which students meet with a tutor to discuss the previous weeks work. Typically eight students are involved in a 45 minute session. One or more students are randomly selected to give a short account of a particular section of the work, and the presentation is graded by the tutor, although feedback can also be provided by the other students. One of the major features of the A-T method is the close association between lecture material and practical work. It is common during the independent study period, for the student to carry out a piece of practical work in conjunction with some theoretical material presented through the tape recording and/or study guide. A discussion of cell structure, for example might be presented in such a way that the student examines some cells under a microscope while listening to the recording. The student may also be instructed to leave the carrel in order to carry out a more extended experiment, or to view a display or make some observations. Consequently the A-T method is excellent in meeting those aims associated with integrating theory and practice, such as using experimentation to illustrate theoretical principles. Indeed, a basic principle of the A-T method is that there is no artificial boundary between theory and practice, and that the two aspects flow naturally into one another. It is also an excellent way of teaching laboratory techniques, since the media presentation of the steps of the techniques gives individual students a much better opportunity of seeing and understanding them than when a large group of students are all viewing one demonstration. Mastery learning was shown to increase the test scores achieved by students relative to a control group not using the mastery learning approach. However, student proctors were found to be less effective in promoting learning than full-time academic staff.

Class sizes vary, but many of the reported schemes involve large groups. For example, Carre (1969) described an A-T programme which involves 1200students, and Dowdeswell (1973) discussed an American course at Ohio State University catering for 3600. Such large groups are often the ones that motivate the use of A-T methods, as a means of individualizing learning and/or using existing facilities more efficiently.

One of the best documented A-T methods is that of Brewer (1985), not only for a description of the process but also for her evaluation studies. She called her courses SIMIG self instruction by modules and interactive groups. In her model, the self-instructional modules, designed for self-paced individual study, were the course of the necessary information defined by the course syllabus. Each module had objectives and means for self-testing. The purpose of the interactive group was to stimulate skills such as problem-solving and oral communication. Audio-visual media were widely used in both components of the scheme. An evaluation by the scheme (Brewer 1985) indicated that students achieved higher gradesby the SIMIG method on three categories of question; recall, comprehension and problem-solving. The students were heavily in favor of the SIMIG approach of learning, and also rated highly the integration of theory and practical work in the self-instructional modules. Fisher and MacWhinney (1976) also reported enhanced learning by A-T methods relative to conventional ones, as well as favorable student attitudes. Kulik, Kulik and Cohen’s meta-analysis (1979b), however, found only small increases in learning by the A-t method compared to traditional methods. These authors conclude that, in general, the A-T method was at least as effective as conventional teaching.

It is simply not practicable in terms of the available time to permit students to do every experiment themselves, and advantage can be taken here of using other peoples data interpretation rather than collecting one’s own. Many examples of the use of computers in this role have been published, mostly concerned with various forms of data and assumption: fitting data to various models or being able to vary experimental parameters and examinants the effects. The use of the computer enables students to test hypotheses, and look for trends in the relationships between sets of data.

Tawaney (1977) has discussed the use of computers in checking the match between experimental results and various models. In one exercise, students were requested to write programmes which measured the field strength near a magnet, the first based on the exact classical formula and the second on a well known approximation of it. They were then asked to compare data from the two in biology are often reported. In one course (Norberg 1975) students made genetic crosses of Drosophila and analyzed data from F1 and F2 generations to establish dominance and excessiveness, linkage pattern, and percentage crossing over. Prior to making the crosses, students ran computer simulations illustrating evolution and population genetics and simple Mendelian genetics. The author pointed out that these kinds simulation greatly shortened the time required to carry out an experiment, and allowed the student the option of experimenting with a number of solution to the problem, a luxury not always available within the usual time limitations of practical laboratory work.

Pencil and paper exercises can also be used to stimulate inquiry skills, and an interesting one has been reported by Finegold and Hartley (1972), who gave senior physics students an opportunity to design a big experiment which might cost large sums of money. The students had to justify their design in the form of a written proposal. Information for the experiment was obtained from the literature, including manufacturer’s catalogues. Generally examples of this mode of learning are rare, especially compared with the availability of CAL programmes, and more attention might be given to this neglected area.

One well defined laboratory programme designed to encourage inquiry skills was called the investigate laboratory (Thornton 1972). It has the following characteristics:

Students are made aware that the purpose of the course is to engage them in an investigation of their own choice. The laboratory course begins with a series of activities, which may involve the development of both manual and cognitive skills, designed to prepare the student for investigative activities.

In consultation with the teacher, each student formulates a problem and plans a procedure for solving it. Proposals may be oral or written. The student carries out the work, and then submits a written and/or oral account of the work.

This scheme is intended to take the students through the entire range of investigation work, and is unusual in that there is a strong emphasis on involvement in problem formulation, and aim which is frequently omitted from other inquiry approaches. However, the identification and statement of a problem is a very difficult task, especially for first year student, particularly if it is to be solved within the constraints of time and equipment available. Reports from academic institutions (for example, Thornton 1972, p. 51) which have allowed problem formulation on an unguided basis have usually found that students are either completely lost or suggest problems that are unrealistic. This is not an unexpected outcome; in science, it is necessary to have a reasonably deep understanding of a topic before problems areas can be identified. It is also true that students generally seek problems that are just too big to cope with in the available time. Hence in this section what is referred to as a problem is a relatively small and quite simple in activity in which for example, an experiment might be performed with the variables extended to other limits, or an apparatus modified to meet an alternative measuring need, or the behavior of the microbe in different nutrient media examined. Thus, realistically, problems, especially at the early stage in an undergraduate career, must involve the simple extension of known material into a region that is unknown to the student, and for which help and assistance is not available in direct form in the laboratory manual. Having identified the problem, it is necessary to define it for students in such a manner that it directs the wave to proceed with the investigation. It is also help if the problem can be expressed in quantitative terms. For example, the statement that this analytical method produces incorrect results is a beginning, but if this is refined to this analytical method produces low results then some interference could be sought which gives low results. To end up with a problem definition such as “The depressant effect of small quantities of element X on the spectrophotometer determination of Y” has in fact suggested a working hypothesis (element X is the reason for the analytical values being low) and an experimental programme for testing the hypothesis (make up solutions of Y laboratory investigation). The discussion periods were used to plan experiments and to specify materials and apparatus needed for the laboratory work. Over the vacation period, each student wrote a report on personal experimental activities and a short account of the topic under study, and prepared a short talk based on a published paper concerned with the topic. In the next stage, each sub-group studied a different field of application, their work being presented in the final week as an oral report to the whole group. Each student produced a file for assessment purposes, containing answers to set problems, essays and reports. There was no written final examination. Students were generally enthusiastic about this approach compared with coverage of other topics in conventional lecture-laboratory courses, but some reservation was expressed about the 20% greater time commitment required by the group studies.

A group approach was also used by Buono and Fasching (1973) with about 100 students in n analytical chemistry course. Students were placed in groups by the laboratory instructor, and one was designated group leader. The group first selected a problem from a list, or generated its own problem, then spent time in the library searching for different methods of analysis. Examples of problems included the determination of lead in gasoline, and of zinc, calcium and iron in blood. The group then consulted with the laboratory supervisor on the suitability of their methods, the availability of equipment and chemicals, and the likely time required to complete the investigation. A ten or twelve page report was submitted to the supervisor, and in some cases student evaluation of other’s work was required. The written report was graded by instructors on four categories: the degree of difficulty of the problem (30 points); originality and ingenuity (40 points); Presentation of report (40 points); extent of scientific approach, i.e evidence of planning (40 points). Each student was also assessed on a 150 points scale for individual performance, and the comments of the student group leader and other students were taken into account. The two sets of marks were combined to give a grade.

Finegold (1972) gave his students a choice of experimental activities which, among other things, required them to:

* Choose one, two or three experiments from those already set up in the laboratory.
* Develop a new experiment for the laboratory.
* Suggest and develop their own experiment.
* Combine any of the above three activities. Each experiment was scheduled to last for four, six or twelve weeks. One week was spent in the preparation of a one or two page plan or flow chart of the students approach and predicted time schedule.

The final model, which has been called project orientation (Cornwall, Schmithals and Jaques 1977; Cornwall 1978), is based on the educational premise that the subject matter studied in a course should be determined only by the practical and theoretical needs of real problems. In these circumstances projects tend to be of an interdisciplinary nature, and oriented to real world social and political problems. Proponents of the system claim that project orientation forms the central and dominant component of the curriculum and conventional didactic teaching is only provided to supplement the requirements of the project topics (Morgan 1983, p.68). Consequently, the student is involved in project work as a central theme for the entire undergraduate course.

Morgan (1983) has suggested that there are four major educational themes apparent in project work:

Relevance to the student and student participation in learning: Many students claim that the project work is the most satisfactory and enjoyable part of their undergraduate science course. Bliss and Ogborn (1977) cite many cases to support this notion.

The removal of external threats: The argument here is that the pressure of assessment and the need to obtain good grades should be de-emphasized in project work, so that learning for its own sake is encouraged.

Learning by doing: Real understanding of scientific work only comes through experiential learning, that is by the student personally carrying out the task, rather than by reading about it or attending lectures.

Learning concerned with personal involvement: This is related to the learners personal interests and motivation. Thus one student may wish to contribute to scientific knowledge, while another may wish to demonstrate the ability to act in a professional manner.

Apart from the obvious point that the research project is the closest experience to real-life problem-solving that the student is likely to encounter in an undergraduate career, a number of other factors are often quoted in support of research as a teaching strategy.

* Students are encouraged to accept responsibility for and from a commitment to the problem. This is founded in the reality of the problem: the work is important as a scientific activity.
* Students are able to experience the satisfaction of working at an involved task over an extended time period.
* Opportunities are provided for students to develop and practice oral and written communication skills. The project work involves frequent oral consultation between research supervisor or members of a group, and a final written report is required.
* Various general and specific aims are integrated into one activity. The student is expected to meet the challenge of a new problem and use imagination and other personal attributes to reach a solution.
* The learning is individualized, because the problem and the way in which it is tackled are a unique experience.

For any project schemes to be successful, considerable attention needs to be paid by the supervisor or team leader to the management of the research. Doiwdeswell and Harris (1979) have discussed the issue, and the UK Science and Engineering Council has published a pamphlet (1982) intended for post graduate research work. Some of the more important points and recommendations from these two publications are as follows:

* The objective of the work should be clearly stated and presented to the student.
* A research schedule should be prepared by the student which covers the whole research period and is submitted to the supervisor for discussion.
* Regular meetings should be held between student and supervisor to check progress. These could also be occasions for the supervisor to check the students laboratory book to ensure that good records are being kept of work carried out.
* The role of the supervisor should be to guide student progress, not totally direct it, and the student should fulfill a complementary role in contributions to the directions of the work.
* The supervisor should scrutinize and critically discuss with the student the production of interim and final reports as well as any seminars that the student is required to give.

The Science and Engineering Research Council pamphlet also suggests that some considerations should be given to the production of a departmental documents on supervisory practice; and that efforts should be made to see that student and supervisor are matched in characteristics and temperament.

 **6.4 Project Exercises**

In the form of project work called a project exercise, students normally take, on a research project in the last term or semester of the final undergraduate year, which is often the only practical work carried out in chart term. The project is seen as the exposure of students to a real problem-solving activity prior to emerging.

* The project is limited, in that problem formulation and hypothesis generation is usually given by the project supervisor. It does not therefore exercise all aspects of the processes of scientific inquiry, but only the experimental work, interpretation and discussion of results, and report writing.
* There is too much emphasis on grading, and not enough on maximizing learning. Gabb (1981) has reported that some students use strategies, such as attending their research supervisor’s seminars, in an attempt to influence their grade. These students are indulging in enterprises that are not relevant to the intentions of the project work.
* Objectives are not precisely defined.
* Students often have difficulty with project work because they lack similar previous experiences.
* In real life, scientists are more likely to be working as part of a team rather than on their own.

Some of these faults have been partially rectified, so that experience in small scale project like activities (which have been called mini-projects) and group projects has become more evident in undergraduate courses. Some examples are given in the previous section, and in Chapter 3. Much attention has certainly been focused on the assignment of projects (see Chapter 4 for details) and this in turn has directed attention to the objectives of such work. Whilst it is apparent that project work is now an integral part of many tertiary level science courses, surprisingly little formal evaluation of educational outcomes has appeared in the literature. There appears to be room for improvement in this area of activity.

**Participation in Research**

An alternative discipline-based scheme involves the student working as part of a research group or team rather than pursuing individual work. The research group is usually an established one and may be working within the institutional at which the student is taking degree studies, or be part of some external research organization.

One of the best known approaches in the UK, called degree by thesis, was introduced at Sussex University (Eaborn 1970), and subsequently evaluated by Mathias (1976) after five years of operation. In this scheme students carry out formal studies for the first two terms of the degree course, and then can choose either to continue or to select a research project, which then becomes their main commitment? The projects, which were devised by staff members and derived from work carried out by their own postgraduate research group, were designed to cover a broad area of chemistry, to utilize a wide range of techniques, and to off a high possibility of success which a reasonable amount of efforts from the student.

In addition to research work, students were expected to demonstrate familiarity with chemical knowledge typical of a traditional course by passing term tests based on material presented in the lecture course. The tests were graded on a pass/fail basis, and did not affect the student’s Final degree classification. A minimum of a 70% pass rate was required. The final grade of the student was based on the quality of the research work carried out, as evidenced by theses, literature surveys and research reports. Two members of a review board also evaluated progress through discussions with the student and with the student’s postgraduate supervisor. The latter was responsible for the student’s day to day activities, and offered advice and assistance in conducting the project. The evaluation (Mathias 1976) of the degree by thesis was generally supportive of the scheme and made some general points:

* Students tended not to be over specialized in one subject areas, but could demonstrate a broad, knowledge and understanding of a large proportion of the traditional course.
* Students could successfully carry out original research at an early stage in a degree level course providing adequate support and planning was available.
* Students progressively took control of the direction of the research as they progressed through the course, and became much less dependent on their postgraduate supervisor.
* The degree by thesis approach required a greater time commitment than the traditional course.
* All students enrolled in the degree by thesis course enjoyed their studies, but only about half of the students enrolled in the traditional course did. It was pointed out that some students transferred back to the traditional course because they were uncomfortable with the degree by thesis approach.

Students at the Massachusetts Institute of Technology can gain credit by enrolment in the Undergraduate Research Opportunities Programme (UROP) (Cohen and Mc Vicar 1976), which is described as an institute-wide programme that actively encourages intellectual collaboration between faculty members and undergraduates. Twice each year an MIT URQJL Directory is published which lists participating staff and descriptions of their research interests, and is circulated to students. The student then approaches a suitable staff member, and selects a project. In 1971 it was accepted the students should be encouraged to spend 15% of their time in such activities. Since then, students have also been able to carry out their work in off-campus organizations such as medical research centres and hospitals, industrial laboratories, various government agencies and even foreign organizations. Similar “internship “schemes have been reported by Kloss (1969) and Hoener (1980).

**Project- Orientation**

Probably the most complete adoption of research projects as a teaching and learning strategy occurs in project-orientation. Several examples of project-orientation courses detailing their development and organizational structure were described by Cornwall, Schmithals and Jaques (1977), as have been several other examples of more limited project work. Kleijer (1977), for example, described development in the Netherlands, and listed the characteristics of project orientation as:

* The principle of emancipation, meaning that studies should be aimed at social and political change.
* The principle of democratization, meaning that the group participants (both staff and students) should have equality.
* Pedagogical principles, such as learning by experience, problem orientation, and relating theory and practice.
* Structural principles such as interdisciplinary, study in small groups, seminars and courses, co-operation.
* Non-traditional assessment systems.

A course that contained some of these elements was discussed by Kleijer and by Cleij and Covers (1977). Theirs was eventually called a Chemical Research Shop. Eleven projects had been undertaken which lasted between three and twelve months and were carried out in conjunction with organizations of working people and action groups. Four of the projects were concerned with industrial hygiene, six were in co-operation with urban action groups on the subject of environmental hygiene, and one was at the request of a government medical committee.

**Conclusion**

This section has described strategies which may provide opportunities for the pursuit of various educational aims in laboratory teaching. Controlled exercises can be used effectively to train students in basic skills and techniques, and the Personalized System of Instruction, which combines behavioral objectives with mastery learning, is a particularly powerful strategy for meeting the same aims. The curriculum needs to be balanced, however, by the inclusion of appropriate experimental investigations and research projects that will provide graduates with the requisite skills needed to meet the range of professional demands.

It must be emphasized that the mere adoption of these strategies does not guarantee a successful outcome. For example, PSI schemes could be used to develop concepts at the expense of the hands on experience necessary for the development of basic practical skills and techniques. The potential of research projects to install various high level skills may not be realized if the student is involved only in the detailed aspects of the work, and not made aware of the broader issues.

The laboratory provides many opportunities for students to talks and writes about science. With a little though and planning, and not too much extra effort on the part of students, its activities can be the basis for building communication skills, a matter which is discussed in Dunn, Boud and Hegarty (in preparation).

**Self Assessment Questions**

Q.1: What do you know about controlled exercises? Support your answer with the help of examples?

Q.2: Why experimental investigation strategy is used in laboratory teaching?

Q.3: What is the role of research projects in laboratory teaching?

Q.4: Distinguish among these three types of teaching strategies of laboratory;

Q.5: Give critical review for these teaching strategies of laboratory?

Q.6: How will you bring change and modify your laboratory as science teacher or science Teacher or science educationist?