**SEQUENCING AND ORGANIZATION OF LABORATORY ACTIVITIES**

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**INTRODUCTION**

In laboratory organization, after setting the aims and objectives and identifying the teaching strategies the next step is to give logical sequence to various activities of the laboratory.

In this unit, you will go through a number of principles of sequencing the teaching plan and strategies. These plans will be organized to provide coherent and scientifically sound learning experiences for the students. For this purpose, some of the prominent organizing patterns that can be applied to the laboratory work have been described in this unit. Moreover, some factors affecting the sequencing likewise pro-requisites, motivation and interest have been given in details. In organizing student’s activity, the pre-laboratory and post-laboratory activities have got special focus in this unit.

**OBJECTIVES**

After reading this unit, it is hoped that you will be able to:

1. comprehend the principles for sequencing laboratory works
2. know and apply the strategies for sequencing the laboratory activities
3. familiarize with the factors influencing sequencing laboratory work
4. organize the students activities

**7.1 Sequencing and Organization**

Although some of the methods described in the previous chapter offer a complete design for a whole programme, it is likely that in most situations we will wish to pursue a variety of means. The choice for the course planner is not “What is the best method for many courses”? But what combination of approaches, dealing with which material, will provide the most suitable experience for my students overall? All the methods have their particular strengths or limitations, which have been discussed. The skillful laboratory course designer needs to able to take the desirable elements from each and balance them in a programme which pursues the entire major objectives that have been identified and provides a coherent experience for students.

To achieve the balance is a challenge and can take a long time if full consideration is to be given to all the major educational goals and the essential subject matter. It is such a substantial undertaking that most of us are prepared only to modify sections of the course at any one time, albeit a part of an overall plan for total revision. It takes time to develop ‘new’ exercises, and even the time required to adopt an existing functioning apparatus to a new format can be substantial. Then modifications will be required over the first two or three years of operation in the light of feedback. So, once a course has been designed and is operating smoothly, we would not wish to contemplate any major overhaul in less than five to eight years without additional inputs of funds and staff. The initial development of such a course would require a commitment on the part of the course designers over about three years given normal modifications following feedback. It is interesting to note that the one laboratory course we have discovered that has been subjected to a full cost analysis, including development costs (Fielden and Pearson 1978), was found to require twelve years to break even.

We do not wish to imply that change is not feasible and manageable, however. Although substantial change does not require a substantial input of effort, much time and energy can be saved by a thorough analysis of the demands on the course and how they can be accommodated, and by an investigation of what is available to be borrowed from other courses. Reading the literature is not such a time consuming occupation as developing new experiments. Many staff has found it useful to have later-year students with an interest in education devote project activities to the development of laboratory work for the earlier years of an undergraduate course, either for credit or as part of vacation scholarship scheme.

One of the most important decision to be made once the general goals and aims have been set, and the general course structure and content agreed upon, is how the course should be sequenced. That is, how the teaching plan should be ordered to provide a coherent and educationally sound experience for the students. Following this, decisions have to be made about how the particular units of the course should be structured, what should be included in laboratory manuals, what students need to be before entering the laboratory, and what they should do after each unit.

**7.2 Principles for Sequencing**

Once the broad strategy is accepted, it is necessary to examine the content of the course and its aims and objectives to see the ways in which it can be sequenced to achieve the desired ends, keeping in mind the general goals and values which are being pursued. Traditionally, one or other of the following rule for sequencing has been used (Davies 1981, attributing them to Herbert Spencer):

* Proceed from the known to the unknown
* Proceed from simple to complex
* Proceed from the concrete to the abstract
* Proceed from the particular to the general
* Proceed from observations to reasoning
* Proceed from the whole to the parts and back again to the whole

Each of these different rules possesses a compelling simplicity and they have been cited in teaching methods textbooks for very many years. However, more recent studies enable us to go beyond this formulation and take into account the needs of the discipline, the needs of the learner and the needs of the context for which the student is prepared. Posner and Strike (1976) undertook a detailed analysis of principles for sequencing content and identified the categories which we outline in the following pages. We have used their framework and have illustrated it where possible with examples from basic laboratory courses in various subjects.

**7.2.1 World-related Sequences**

Through world-related sequences content can be made to correspond to the order of events normally encountered in the world. Such sequences will be based upon empirically verifiable relationships between phenomena and might involve:

* Special relationships e.g teaching the elements of electric circuit by consideration of the component parts prior to assembly.
* Relationships in time e.g introducing experiments in historical sequence, such as examining Milliken’s oil drop experiment before that to determine e/m for the electron.
* Physical attributes e.g in astronomy, the observation of bright objects before those of lesser magnitude.

**7.2.2 Concept-related Sequences**

Concepts-related sequences reflect the relationships between concepts, and make teaching units consistent with the ways in which the ideas of a subject relate to one another. Concept maps are means of portraying such relationships. Concepts can be sequenced in the following different ways, with respect to:

* Class relations, such as their common properties e.g teaching about mammals as a class before teaching about individual species.
* Prepositional relations, such as theory-evidence, rule-examples, or premise conclusion e.g Conducting experiments on the volumes of gases under different conditions of temperature and pressure before introducing Bolyle’s law.
* Sophistication, such as the levels of abstractness of ideas e.g testing PH by litmus paper before using a PH meter or introducing a beam balance before an electronic one.
* Logical prerequisites such as the necessity to understand one idea before another e.g presenting the electrochemical cell before potentiometric titrations.

**7.2.3 Inquiry-related Sequence**

Inquiry-related sequences derive from the nature of the process of generating, discovering, or verifying knowledge. These reflect the nature of one or other of the following two things:

* The logic of inquiry e.g a laboratory course structured around Popper’s ideas of scientific method as a series of conjectures and refutations, or one based on the idea of discovery as a matter of generalizing over numerous instances.
* The methodology of a given area e.g introducing the practice of conducting literature surveys before the design of an experimental activity, or the use of order of magnitude calculations before measurements.

Anderson (1976) analyzed the types of processes involved in science teaching, such as observation, interpretation and prediction and related them to research methodologies employed by scientists. Although he used different terminology from that used in this book, his analysis provides one way of constructing inquiry-related sequences.

Learning-related sequences draw upon knowledge of the psychology of learning as a basis for planning. They are often based upon knowledge of the learner and how the learner perceives the content of teaching. Such learning-related sequences can be determined in the following ways, from:

* Empirical prerequisites that is, the knowledge of how learning one thing facilities the learning of another even though they may not be logically or conceptually related: e.g practice in the use of a pipette (setting the meniscus level) before that of a burette when doing a titration.
* Familiarity using common experiences before resorting to less common ones: e.g the isolation of bacteria in the human body before those from extreme environments or the use of visible region spectrophotometers before infra-red or ultraviolet.
* Difficulty based on which tasks are easier to learn: e.g use of a voltmeter before a millimeter.
* Interest based on which activities are more stimulating to the student: e.g use of yeasts in producing wine before studying metabolic pathways.
* Individual developments in which each experience is introduces at the most propitious time in a person’s development: e.g introduction of concrete experiences in the laboratory before those involving phenomena which are not directly observable.
* Internalization the ease with which students can make ideas their own: eg teaching students principles of laboratory safety before assessing their own aseptic transfer technique.

**7.2.4 Utilization-related Sequences**

Utilization-related sequences involve the organization of units around career, personal or social goals. They would be based upon the ways in which students will use the content after it has learned. Units can be sequenced to reflect one or other of two things:

* Procedures for solving problems or fulfilling responsibilities eg teaching the use of spectrophotometers as analytical tools rather than as means of probing electronic structure.
* The extent to which a particular element of the course will be subsequently used eg teaching how to change a circuit board before teachi9ng how to change a resistor or teaching standard colony culture counting techniques before the use of electronic panicle counters.

As for as possible, the examples we have chosen above have each been included to illustrate one category each. In practice, a number of the principles could be combined; so that one might create a sequence which started with interesting and familiar example’s which were conceptually related and which were representative of the kinds of phenomena which students would encounter in subsequent courses. The kind of sequence selected in any given course will depend on a number of factors including those above, but it will also need to take account of other issues, such as materials and facilities available, time schedules, availability of staff, and teacher’s interest and competencies. Theses have been referred to as Trame factors and they are a very powerful determinant of sequencing (Lundgran 1972). The frame factors are not simply constraints, as they can be regarded positivity or negativity. Materials available locally might have more interest for students, and staff might be encouraged to introduce their ideas of special interest. However, as important as these issues are in practice they should not distract us from consideration of die other principles. It would not be surprising to find that a course which was sequenced entirely on the basis of what equipment was immediately available and what the subject interests were of the staff who designed it was entirely unsuccessful in achieving its objectives, because it had failed to take account of the structure of the discipline and the needs of the students.

**7.3 Strategies for Sequencing**

In order to apply the principles, we have discussed above we need to consider a variety of arrangements for organizing a sequence of laboratory activities or topics. Romiszowski (1981) discusses a number of patterns.

**7.3.1 The Linear Approach**

The simplest way of arranging topics or laboratory activities is in a serial fashion time.

Topic1

Topic 3

Topic 2

Topic 5

Topic 4

**Figure 7.1 The Linear Approach**

The order of the units can be chosen on the basis of any of the principles discussed above. Either all students will study the same sequence in the same order or they may follow essentially similar parallel paths. One of the great advantages of all students following the same path in lock-step is that the laboratory course can be linked directly to parallel lecture and tutorial sessions, thus allowing a coherent programme of theory and practice to be pursued. However, the great limitations of this approach is that multiple versions of the same equipment and materials are needed, which can be a very inefficient use of resources.

**7.3.2 The Spiral Approach**

A variation on the linear approach is the spiral, whereby students follow a linear sequence but deal with the same or similar topics at progressively greater levels of sophistication.

Topic 2A

Topic 3A

Topic 1A

Topic 4A

Topic 1B

Topic 2B

Topic 3B

Topic 4B

Topic 3C

Topic 2C

Topic 1C

**Fig 7.2 The spiral Approach**

The spiral approach provides students with the security of dealing with topics at a simple level before proceeding to the more complex. It is possible to use elements of the spiral approach without using it in it’s entirely. For example, a laboratory sequence could start with some basic experiments which introduced a number of concepts and techniques in a straightforward manner before proceeding with the application of theses to more complex phenomena.

**7.3.3 The Core Approach**

The core approach has some similarities to the simple version of the spiral we have just outlined. All students commence with a set of core activities dealing with the basic aspects of the course and then proceed with other activities arranged as a circus. That is, different students or groups of students work simultaneously on dissimilar topics using different apparatus. The core need not all be completed at the beginning of the course; it may be introduced when students proceed from one major segment of the course to another.



**Figure 7.3 The Core Approach**

**7.3.4 The Pyramidal Approach**

The pyramidal configuration is a way of describing a sequence in which topics are progressively built up from a common base to reach higher levels of sophistication. In this it has some similarities with the spiral approach. Thus a course might commence with activities which developed basic skills and methods, then apply these to common problems in the subject area, use them as the basic for experimental investigations, and end with the completion if research projects. A variation on the pyramid is the wedge. This follows essentially the same pattern, but experimental investigations and research projects are phased in progressively.



**Figure 7.4**

**7.3.5 The Inverted Pyramid**

It is not always necessary or appropriate for all the basics to be completed before higher levels of experimental activity are explored. In some circumstances the pyramid can be inverted and basic skills and knowledge and experimental investigations organized around an overriding research investigation or project. The inverted pyramid is particularly appropriate to the problem-centered strategy described earlier in the chapter. The focus is on the problem, and all other activities are centered on the need to solve it.



**Figure 7.5**

**7.3.6 The Student Choice Approach**

In most of the approaches cited above the learning sequence has been chosen in advance by the course organizer. An alternative is to allow students to determine their own sequence with or without the guidance of staff. They thus decide for themselves, within the overall resources constraints of the course, which areas they will pursue and in which order. Such an approach can be often found in the kinds of advanced courses in which students might be concerned to explore those paths which are most directly related to their vocational plans. It can, however, be applied at any level. Its main rationale is that the logical sequence or the sequence which teachers regard as the most appropriate on the basis of their appreciation of the subject may not be the most suitable for every given student.

**7.4 Some Factors Influencing Sequencing**

Described above are some of the major organizing patterns that can be applied to laboratory work. Any course can be structured around any one of these approaches, or any sensible combination of them, and the principles for sequencing content that have discussed earlier should govern the detailed arrangement within the overall pattern. In the laboratory context some of these principles will feature more prominently in decision making than others. Let us examine in greater detail some of what we regard as the more important principles and their application. Each of these can be linked to Posner and Strike’s (1976) sequencing principles. Prerequisites and motivation and interest are learning related and the nature of the learning tasks is utilization related.

**7.4.1 Prerequisites**

In any conceptually complex subject detailed attention needs to be given to whether some knowledge and skills need to be taught before others. In the laboratory, prerequisites in knowledge and skills are the three main types: logical prerequisites deriving from the conceptual structure of the discipline (for example, velocity needs to be taught before acceleration); the prerequisites of inquiry (for example, in setting up an investigation the hypotheses to be tested need to be established before the instrumentation designed); and practical prerequisites (for example’s, the requirements of future courses or employment).

At the entry level to course simple teats of prerequisites knowledge and skills might be administrated and students allocated to specific activities designed to bring them to the desired entry level. The use of single purpose packages offers an example of this (Long 1975; Price and Brandt 1974).

O’Connell, Penton and Boud 1977, students who need, say to master the setting up of a cathode-ray oscilloscope is given a self-contained instructional package designed to teach the basic steps involved in preparing the instrument to display signals. The package includes a self-test, and when students are able to demonstrate mastery of the skill, they proceed to the main laboratory activity. On larger scale an introductory course might be devoted to teaching basic techniques which are to be used in subsequent courses.

Another sort of prerequisite is the need for certain knowledge and skills to be learned prior to engaging in experimental investigations. Several examples have been reported of schemes which start from prescribed activities before proceeding to more inquiry-oriented activities. Venkatache-lam and Rudolph (1974), for example, discussed a scheme which is based on two phases, a learning phase and a challenge phase.

The learning phase consisted of five activities; a reading assignment, a discussion session, a controlled exercise, a write up, and feedback to the student. This phase provided the background information and skills necessary to undertake the challenge phase, which commenced with an open-ended question and was followed by experimental design, data collection a write up and an evaluation of results. A typical sequence might consist of learning about acid-base titration and then taking up a challenge question such as “How do you apply acid-base titrations to the determination of aspirin in aspirin tablets”? The problem is thus presented by the teacher, but the methodology for solving the problem is in the hands of the students. In practice, this might only involve finding the correct text in the library and then selecting an appropriate method, but that still emulates the process that a scientist in industry might follow to achieve the same end. Patterson and Precott (1980) have used the learning challenge phase idea in a physics programme, and a similar scheme in physics is the divergent laboratory (Commission on College Physics 1972; Lerch 1973). Several other examples have also been reported of courses where students spend the first portion of the year on controlled exercises, and then complete the course either with individual experimental investigations (Wehry 1970; Adelberger, Mischke and Strovnik 1972; Finegold 1972; James and Kennard 1976) or a group project (Buono and Fasching 1973; Johnson and Wham 1979).

The building of basic skills and knowledge needs to take account of a number of factors other than the perquisites of a given content area. In all sciences there are a number of general skills and strategies which can escape attention if too great an emphasis is given to specific content areas. Examples are estimating quantities, determining errors, scaling, and translation of abstract ideas into practical form (Blacl, Griffith and Powell 1974; Boud and Gray 1978; Ogborn 1977). Reifand StJohn (1979) and Stjohn (1980) described a laboratory course which aimed to promote some general scientific skills; it included being able to comprehend an experiment and talk about it in a manner understandable to others, to remember the central ideas of an experiment, and to adopt an experiment to suit slightly different circumstances. Their laboratory programme was organized into blocks.

The first activity is a series of mini-labs which consist of short experiments designed to teach a few basic skills. When these have been completed students can take a self-test to check their understanding. They can then request a block interview with the laboratory instructor, who examines them on the mini-labs and self-tests and asks them to describe orally selected parts of the work. The next stage is the group lab, which involves four students in a co-operative laboratory activity. Preparation for the group lab starts several weeks before the actual laboratory activity. Each group has a pre-lab interview with the instructor, who asks a structured set of questions requiring individual students to describe the proposed experiment in various levels of detail. The students complete the experimental work and present themselves for a check-out interview. Finally each student takes a block test.

**7.4.2 Motivation and Interest**

A course in which students performed adequately but were deterred from pursuing the subject further would not be a very successful one. The importance of stimulating student’s interest in the content of laboratory cannot be underestimated. We have seen above how student involvement in the choice of topics and projects can contribute to their motivation. Student interest can also be generated by the laboratory designer’s selection of topics and the ways in which they are presented. An example of the importance of the latter is a course in which one of the authors was involved as an evaluator (O’Connell, Penton and Bond 1977). After students had completed each experiment in the course, they were asked in a questionnaire to rate the level of difficulty and interests and the relevance of the experiment. One experiment, titled the “The Flame Photometer”, which involved identifying various impurities in different samples of water, received low rating in all scales, but particularly for relevance. Something had to be done about it, but it was not obvious what should be modified. In desperation, the course designer decided to change its title to “Population Monitoring” and add an introductory sentence setting the measurement in the context of the need to monitor water supplies to check on chemical contamination. With this apparently trivial modification the rating improved not only on relevance, but on the other scales as well.

Not all experiments can be so simply reinstated, but some effort can be made to find topics of intrinsic interest of the students. Burns (1976) provided a slogan for this approach in the title of his paper “Science can be fun and tasty”. It is quite clear that, for example many students take an interest in activities in which impinge on their own everyday life. Even a simple idea, such as a student obtaining a water sample for analysis from a local stream or reservoir instead of being supplied with it as a prepared laboratory sample can improve interest. Many example of this kind can be found in the subject-specific teaching journals, together with other ideas to stimulate the design of specific activities.

Some typical example of experiments of this kind in analytical chemistry are the determination of bicarbonate in Alka Seltzer (Peck, Irgolic and O’Connor 1980), of sodium ethylenediamine-tetraacetic acid in bathroom cleaners (kump, Palocsay and Gallaher 1978) can phosphoric acid in Cola beverages (Murphy 1983). Such experiments can be carried out on different materials to stimulate a consumer survey. In microbiology, Leslie and McKinstry (1972) describes how students could monitor water samples from woodland streams, relating bacterial pollution to the effluent from septic tanks and sewage treatment plant; Durand et al. (1973) and Wilson, Weisburd and Mizer (1974) discussed the use of the normal flora of the human body and of clinical specimens; and Whatt (1975) described an entire course at the University of Bradford based on the Clotheir Report, investigating the death of several hospital patients due to bacterial contamination of glucose drip bottles. In physics, Kay, O’Connell and Cryer (1981) based a first-year experimental investigation on anti-skating devices in the arms of record players.

The purpose of these kinds of experiment is not just to make students life more interesting. White (1979) argues that striking episodes are important in learning science and that it is necessary to engage students fully and relate science to their own experience if they are to develop an understanding of the subject. He draws attention to two types of experiment which should be added to physics courses.

One type is the unusual experiment which engages the emotions through being odd, dramatic, beautiful or puzzling. A few of these experiments in a year’s course should be used as powerful aids to the recall of the most important topics. Another type is intended to establish generalized episodes involving materials and events of common experience, with the purposes of linking….. subject matter and daily life and of providing experiences which will be called into play in making subsequent information comprehensible.

Although White was talking in the context of secondary science, similar considerations would apply at introductory tertiary levels. It is important to recognize though that notions of interesting, puzzling, dramatic and relevant depend on individual perceptions. Experiments which the designer believes exhibit these characteristics may not serve the intended purpose for every student.

**7.4.3 The Demands of the Task**

An important factor influencing the sequence of activities within a given unit of a laboratory course is the nature of the practical tasks which students are expected to perform; it is a utilization-related issues. A method known as task analysis (Davies 1971) is used extensively in training contexts for planning the teaching of particular tasks. In industrial and training settings a common approach to task analysis is as follows (Rowntree 1981):

Observe someone who is carrying out the task (procedure) competently.

Note down exactly what they do, how they do it and what results they produce.

Then analyze their activity very carefully, breaking it down into a set of fairly minute sub steps which need to be followed in order to ensure success.

This analysis enables the laboratory designer to decide on a suitable sequence of instruction and practice.

Rowntree (1981) quotes a framework devised by Clive Lawless of the Open University for analyzing and designing a task-based component in a course:

1. What is the task?
2. What should the task be carried out?
3. What tools, equipment, and materials are needed?
4. What are the objects on which the task is carried out?
5. How is the task carried out? What order is followed? How long does each step take?
6. What safety precautions have to be observed? What are the most likely errors?
7. What are the criteria of successful performance? (How can the performer tell when he or she has carried out the task successfully?)
8. What is the use or application of the task?
9. How much practice must be built into the training?

**7.5 Organizing Students Activity**

Making the decisions about course aims and objectives, and then arranging various experiences into a sequence that provides the right balance of concept development, skills development, and motivational aspects is certainly a major part of course design.

It is also important to consider how the various experiences can be presented to the students. When they come to a course, they are unaware of all the efforts that have been made to mount it, and what they receive is a very sparse account of all its planning and organization: Consequently, some mechanisms need to be developed to inform the students about the reasons for the inclusion of certain activities in the laboratory course, and what each activity is designed to achieve. The student may need to be aware of certain theoretical knowledge in order to carry out the laboratory work in a meaningful way. Many such needs can be catered for by pro-laboratory activities, involving a variety of techniques such as written assignments, electronic media and computers. There is also a need to consider what debriefing activities students should undertake upon completion of the laboratory work.

**Pre-laboratory Activities**

Expecting students to engage in laboratory activities without same form of prior consideration or tuition may leave them feeling insecure, and result in a rather poor understanding of what is happening. It is therefore, usual to engage them in some form of pro-laboratory activity highlighting the essential ideas of the work, introducing new principles and concepts, and pointing out pitfalls. Pro-laboratory activity may be conducted in the first portion of the laboratory time, or carried out prior to the scheduled laboratory period. The former method has immediacy as a major advantage, since the main activity follows on directly. There is, however, little opportunity for students to reflect on what has happened, and to check up on any aspects of information that they are unsure about. For these reasons, we advocate that pro-laboratory activities should be carried out before students enter the laboratory, unless these are unavoidable constraints.

One of the simplest ways of getting students involved in the practical is to require questions of the activity to be answered by them in a written assignment before they enter the laboratory. This approach has been used for many years in one of the author’s courses on analytical chemistry. Contained in the laboratory manual is a section labeled pre-laboratory work. This usually consists especially for the exercises carried out early in the semester, of a large number of precise questions concerned with the analytical method used. The purposes of the questions are:

* To ensure that the students know, in general terms, what will happen in the next laboratory session?
* To assist students to understand the steps involved in the analytical procedure by focusing attention on the chemical processes involved.
* To direct students’ attention to key aspects of the procedure.

Some of the answers to the questions can be derived from information provided in the manual, but the use of text books is also required. Students are expected to arrive at the laboratory session with written answers, which are inspected and checked by staff. Those who arrive with no pro-laboratory write-up are not allowed to carry out the activity. Students respond very well to the idea of preparedness for laboratory work, and once the system has been established for a week or two it runs very smoothly. The number of questions asked decreases as the semester progresses, so that students are then expected so find the key ideas themselves and to write about them ultimately students are expected to be able to discuss and account for every step in an analytical procedure, and the importance of being able to do this is further emphasized by the inclusion of a major question on this process in the end of semester examination.

Another method for the exposure of students to laboratory activities both prior to and during the laboratory session is through the use of media such as videotapes and tape-slide programmes. These are popular because the products are cheap to prepare compared with films, and they can be easily changed or edited to suit any particular teacher or class. The use of media has several advantages:

* Materials can be placed in libraries or other readily accessible places.
* All students receive the same information.
* The material can also be placed in the laboratory during the session for re-view by students who need reinforcement.
* Techniques and skill can be presented in an encapsulated form which permits students to gain overviews of the procedures.
* Specific procedures or techniques can be displayed in a manner not readily available in other formats, i.e. close-ups of small-scale techniques which may be different to demonstrate to large groups of students in the laboratory, the use of diagrams or even animation. The ability of TV or slides to focus on specific parts of apparatus and exclude other extraneous sections is very useful.

The most common use of media for both pro and in laboratory instruction is in the training of students in manipulative skills. Pantaleo (1975) used videotapes to each students basic skills of weighing and titration. In the week before a particular laboratory session, students were assigned to view an appropriate tape in the library, and then expected to answer a fifteen minute quiz before the commencement of laboratory work. In the classes ninety per cent of the students using the tapes met the acceptable operational criteria compared with 75% not using them. It was also found that the average grade in quizzes for students using tapes was 86% while grades before the use of tapes averaged 73%. Gagen (1978) has described the use of videotapes for teaching infrared spectroscopy, and Fine et al. (1977) the use of lap-dissolve projection systems for chemistry techniques.

Computer assisted learning (CAL) is increasingly used in a pro-laboratory role, as a means of guiding the student through the theory associated with an experiment, and examining the experimental design. This includes what experimental techniques are possible, why ^ particular one is chosen, what ranges or readings can be made, and what precautions need to be taken. In some cases, simple manipulative skills have been programmed, such as assembling apparatus correctly as a practice ‘dry run’ prior to carrying out the experiment in the laboratory. All of these different experiences can give the student mental or physical practice (Beasley 1979) for the coming experiment, and maximize the efficient use of laboratory time.

A good example of the use of CAL in the pro-laboratory mode has been provided by Wilson (1980), whose physics laboratory students complete a CAL activity prior to the actual experiment. The program provided a general description of the experiment; the student then selected the independent variables and assigned values to them. The simulation provided data on the dependent variables just as would be provided in the laboratory. Simulated oscilloscope traces, diffraction patterns, multi-channel analyzer displays and light patterns were presented as results of experiments. Many programs included a date analysis section in which the student may be asked to decide what type of graph would be most appropriate for the data, lo select appropriate units and scales for axes, ad to draw conclusions from the resulting graph. An important aspect was that the student needed to prepare for each CAL activity, since the computer logged incorrect answers to specific questions and could bar the student from completing the program. The programs were thus intended to discourage students from guessing their way through the various simulations without understanding-them.

An example of a CAL activity involving diffraction and Youngs double slit experiment was described in some detail. Similar CAL experiences in chemistry (Moor, Smith and Avner 1980) involved a simulator of the determination of the percentage of oxygen in a sample of KC 10 by thermal decomposition in the presence of MnO. Here the student must demonstrate the ability to set up the experiment by touching the line diagrams of the various pieces of equipment displayed on the graphical display unit and moving them to the correct place in order to give the correctly assembled apparatus. To complete the simulation the student must weigh the sample, heat to constant weight, cool, weigh the residue and do the calculations. These authors also described a program for training students in the correct use of an analytical balance. The balance and its controls were displayed on the screen, and by touching the appropriate location the student could perform the necessary sequence of events to make a weighing. Incorrect actions were indicated by the computer. According to an evaluation of this program, students in the non-CAL group were about twice as likely to make an error in weighting as students in the CAL group, and this finding was again evident in a replication study carried out in the next semester.

Wiegers and Smith (1980) reported ten pro-laboratory lessons using the PLATO system for an organic laboratory course, and claimed that in nine of them the use of the programs resulted in a reduction in time for completion of laboratory work compared with the time taken by a control group with no CAL exposure. In four of the experiments the time reduction was between 20-26 minutes out of a scheduled four-hour laboratory session. In a simulation of an absorption spectrophotometer (Gilbert, Mounts and Frost 1982) students were able to optimize instrumental parameters to yield accurate absorption spectra by investigating the effects of special band width, wavelength scan speed and pen period on the spectra. The students then carried out laboratory work involving these functions on a real spectrophotometer

One of the criticisms of laboratory work is that the emphasis is usually on the methodological aspects of the exercise. Thus even if the exercise is well designed, and the student produces a set of results or observations, these are not readily related back in a meaningful way to the conceptual framework that underpins the experimental work. The experimental results are isolated from theory, and the experiment can appear to be trivial and out of a scientific context. An instructional device to link concepts and methods 10 help overcome this problem is called V mapping (Nevark 1979, 1981; Novak and Gowin 1984; Novak, Gowin and Johansen 1983).

The essential features of the map are displayed in Figure 3:10. At the base of the V are the events, or results, that occur as an outcome of some experimental activity. On the left hand side are the theoretical aspects of the work, increasing in generality from the bottom of the V, where specific concepts are sited, to general theoretical schemes at the top. The right hand side is concerned with the methods used to generate knowledge, again arranged in hierarchical order from records taken of the events to generalized knowledge claims.

The major purpose of the V is to help students understand the function of laboratory work in science; it is particularly useful if constructed as a pro-laboratory activity. The teacher might, for example, construct a V map in a tutorial session, building up the connections between theory and method by starting with a discussion of the event being observed. This lead to a discussion of what records might be taken and what concepts are used to guide observation of these particular events, or take those particular records. An alternative approach is to provide some aspects of the V and then expect students to complete the map as an individual exercise. V maps can also be included in laboratory manuals.

By way of an illustration of the manner in which a V map might be constructed, and to define the elements of the V given in Figure 3.10, we will consider an experiment in which students are making some measurements using a spectrophotometer.

* The focus question involves an examination of the current conceptual knowledge of the student, and prompts an experimental activity which the lead to new knowledge claims that enhances or refines students’ existing concepts and theories. The knowledge claim may involve various degrees of conceptual development, from a simple differentiation (e. g what is the difference in the visible spectra between two different chemical compounds) to explanations that require significant conceptual understanding of theoretical frameworks (e.g. way is there a difference in the visible spectra obtained from two different chemical compounds).
* Objects are the materials, procedures, equipment that allow the event to occur. In the above example, the visible spectrophotometer is the main object, and sample cells are minor objects.
* An event is the result of using the objects, e.g. the recorded visible spectrum.
* Concepts are regularities in events or objects, e.g. ‘spectrophotometer’ is a generic concept used to denote electromagnetic radiation measuring devices, although there are many different kinds of spectrophotometer depending osn the wavelength being measured and the principles of operation.
* Principles are conceptual or methodological rules that guide the experimental process. For visible spectrophotometer, the Lambert-Beer Law is the principle involved. Conceptual systems are frameworks that show how individual concepts are interlinked.
* Theories are statements which attempt 10 explain the relationship among concepts, events and knowledge claims. The theory of electromagnetic radiation and how electromagnetic radiation interacts with matter is the theory that makes various predictions about spectrophotometric measurements.
* Records are permanent chronicles of events and objects, e.g. traces of spectra.
* Transformations are manipulations of records, e.g. converting spectra into a tabulation of wavelength maxima.
* Knowledge claims are the answers to the focus question, and these may also suggest new investigational lines.
* Value claims are judgments made about the usefulness, relevance or merit of the particular exercise.



**The experiment has been converted to a V map in Figure 3.11**

The major value of the V map is that it can be developed by students as an active consideration of all the facets of experimental science, and not just the methodological features. The V encourages students to think as scientists before they enter the laboratory rather than behave as recipe followers, just doing as instructed. However, it is also evident that it could be used for more ambitious enterprises, such as experimental investigations, where the focus question becomes the research question.

**Post-laboratory Activities**

Post-laboratory work is usually interpreted at the undergraduate science level as the preparation and submission of written report. This is handed in and marked by someone associated with the laboratory, and then returned to the student with a grade and some written comment. A report has the advantage of being permanent and portable, ad able to be taken away from the laboratory for assessment; it gives the student an opportunity to demonstrate various skills of calculation and communication. However, the report may not always be representative of a student’s practical ability or of fundamental understanding of the work carried out, as it may have been copied, for example, from another student, or the results made up. The use of reports as the only form of post-lab activity may restrict not only the information to be obtained by the laboratory demonstrator about the student, but also the learning to be obtained from the experience by the student. The demonstrator may have a limited understanding of the student’s strengths and weaknesses, and hence not know what remedial action to take. Other forms of post-laboratory activity, particularly interviews and discussions, can enhance student learning. Tamir (1977), reporting on a survey of one university in Israel, found dial no post-laboratory discussions occurred between staff and students, which fact promoted the following statement:

The complete neglect of post-lab discussion is especially disturbing sine this phase may serve as one of the best occasions for developing and practicing intellectual skills as well as for conceptualization and deeper understanding. The post-lab is essential for problem solving investigative labs.

Tamir’s perception of the importance of pose laboratory discussions appears to be supported by evidence from laboratory courses in physics where students are Bristol University were interviewed by the laboratory demonstrator at the end of the experiment (Harrap 1977, pp.94, 106). The interviews lasted an hour or more. The major thrust was to prove students’ understanding of the experiment, and of the procedure and theory, and to establish any areas of weakness. As one student said:

…. a quite penetrating discussion. The demonstrator usually manages to find something you aren’t clear on and quiz you about it… so that by the end of the interrogation, if you like, you do end up getting a little bit more understanding about it Similar comments were made in the same study by students at Manchester University about student- demonstrator interviews on laboratory work.

Interviews can be very helpful in giving students experience in expressing ideas and explaining procedures orally to other people, as well as in defending themselves against criticism, and justifying their actions. Interviews and discussions have a very high validity in science courses, since it is an activity in which most scientists engage. It is also a valuable feedback device, as well as a means of developing students’ oral communication skills. Although interviews are valuable in these respects they’re also expensive to conduct in terms of staff time. For this reason opportunities for post-laboratory interviews should be carefully selected and the interviews well planned.

There is some evidence that computers are being used for post-laboratory activities. For example, after collecting experimental data, students in a course reported on by Davis, Coffey and Macero (1973) where able to use a programme to check calculated value, draw graphs, investigate other ranges of variables, check error analysis, and do various statistical checks to determine the acceptability of results. They could also investigate what conditions were likely to produce statistically or experimentally more acceptable results.

The V map described earlier has been used ai the high school level (Novak, Gowin and Johansen 1983) as a post-laboratory technique, using a similar procedure 10 that described in the preparation of a map in a pre-laboratory classroom discussion.

**Other Issues**

There are many other organizational issues which need to be considered; how teaching plans can be communicated to those who will be involved in their day to day implementation, how to train demonstrators and laboratory assistants, how to prepare laboratory manuals, how to deal with matters of safety and training for safe practice. Space limitations prevent us from exploring these issues in any detail. However, useful material on the training of demonstrators and teaching assistants can be found in Alien (1976), dark and McLean (1979) and Manteuffel and Von Blum (1979). Many laboratory manuals are commercially available and provide useful sources of experimental procedures and activities (see, for example, Primrose and Wardlaw 1982). However, it is necessary for manuals to be designed specifically for most courses. The design of instructional materials, of which laboratory manuals are an example, has been comprehensively treated by Hartly (1978). On matters of safety and training for safe practice, Young (1982) considers the evaluation of the hazards of experiments, while valuable material can be found in the Royal Institute of Chemistry’s Hazards in the Chemical Laboratory (Bretherick 1981) and Sax’s Dangerous Properties of Industrial Materials (Sax 1984).