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Source Book for Science Teachers

SEPA

Source Book for Science Teachers

Edited by

D. E. B. CHAYTOR, Ph.D.

SCIENCE EDUCATION PROGRAMME FOR AFRICA
SEPA

ACCRA GHANA

September, 1976

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CONTRIBUTORS

1. ALEXANDER (JR.), JACK *West African Mathematics Programme, Freetown, Sierra Leone.*
2. BOTCHWAY, ROBERT O. *Science Unit, Ghana Education Service, Accra, Ghana*
3. CHAYTOR, D. E. B. *Fourah Bay College, Freetown, Sierra Leone.*
4. DYASI, HUBERT *Executive Secretary, SEPA Headquarters, Accra, Ghana.*
5. GODFREDSEN, GENE *Institute of Education, Nairobi, Kenya*
6. KAMARA, ALLIEU *Njala University College, Njala, Sierra Leone*
7. LAING, E. *University of Ghana, Legon*
8. OHUCHE, ROMANUS O. *Alvan Ikoku College of Education, Owerri, Nigeria*
9. SAVAGE, MIGUEL *Institute of Education, Nairobi, Kenya*

PREFACE

The SEPA Sourcebook is addressed to those connected with Science teaching at the primary school level. That includes students, teachers, training college tutors. More particularly, its audience is those working under rather inadequate conditions in various parts of Africa, trying to help young people develop the capability to master and use science in their life activities. Those are conditions somethimes without the laboratories to experiment in; or, where they exist, they are inadequate for the job.

The larger job itself continues to be one of getting science to become an important factor of social and economic development. So this effort is part of a wider participation of SEPA in the development of teacher training materials and procedures, and approaches to the pre-service and in-service training of teachers and tutors.

This Sourcebook is a source of ideas for developing activities for learning and teaching science. The overall aim is to promote in a stimulating way an integrated study of science through activities that the learners perform, discuss, think about and suggest. Right through the text the note is sounded that the teacher is a guide, a counsellor, a catalyst, a motivator, a source of enthusiasm, encouragement, and above all an example to the learners.

We have combined, as usual, the pedagogy with the content - the science information and process - as a reminder to the users that always the two must go together. There is no further argument in favour of allowing the learners to work on their own - with their own ideas, or, even their own materials. That had been done in the Handbook; and it is assumed that those familiar with SEPA approach to Science will already be adopting it. Here we provide additional ideas and suggestions for the instructors to use in guiding students in truly scienctific inquiries.

The aspect of integration has been strengthened by the inclusion of a Chapter on "Mathematics as a tool in Science", but beside that, there have been numerous instances where measurement has been suggested for improving the understanding of a concept or a phenomenon.

Various references to the SEPA Handbook for Teachers (1974) serve only to emphasize the fact that this present volume is intended to be used not as a handbook, but as a companion resource material. The materials that have gone into both volumes developed out of a survey of the needs of a number of education systems in SEPA member countries some five years ago.

We have given recognition to the fact that the teacher or tutor may sometimes be a he or a she and we have used both pronouns liberally in various contexts. This should not appear odd in these days of sex equality.

While it can be claimed that various aspects of primary science education have been left out of consideration, we wish to state that we have had no concern with syllabus, timetable and things like that in this volume. To such matters of organization we feel that a separate effort should be devoted. In addition, we shall address ourselves shortly to further details of primary science classroom work in another supplementary sourcebook.

We acknowledge with gratitude the assistance of all those who in many ways have helped to bring out this volume. Here we think of the USAID who funded the work, Education Development Center, EDC, who managed the funds, the various institutes and Ministries who hosted our workshops and the typists, proof-readers and others who did the difficult chores.

D. E. B. CHAYTOR,
Fourah Bay College,
September '77

1--Introduction

Chapter I—Why the Sourcebook

This is a sourcebook that is different from others aimed at helping with the teaching of science. For this is a sourcebook that combines the pedagogy with the content. It is based on the idea that the best way to teach someone " how to teach " is to do it by example and not by precept.

Teaching is best done by a harmonious marriage of the science with the art of teaching. The moment these two are divorced, teaching begins to lose its effectiveness. Here, between two covers, is an attempt to preserve this harmonious relationship between the art and the science of teaching.

Quite often teachers as well as teacher-trainers would wish to teach in a learning-by-doing way. But in many cases the textbooks do not suggest a sufficient variety of investigations, experiments and activities that would permit the smooth planning and teaching of a string of successive classes.

Ideally, it would be best to have a source of numerous alternative investigations, experiments, activities, methods and procedures which allow the teacher to give the students as much variety as is needed to stimulate them, hold their interest over a long time, and excite them into investigating new lines on their own.

But no such single source is possible other than perhaps the teacher herself. Because she it is who knows her students, their character, preferences and aptitudes. She alone knows what is likely to excite interest among them, or turn them off. She also knows what in her society are acceptable and what taboo among the phenomena she is likely to select for illustrating the various concepts she might wish to teach. If she herself has gone through many of the learning experiences already, she is best suited to decide and choose those initial experiences that are likely to work well in that given environment.

Thus, it would be virtually impossible for anyone to produce a single sourcebook that can answer to the specific needs of every teacher or teacher-trainer. The best that can be done is to train these instructers, the teacher and the teacher-trainer, in the methods of designing, constructing, and adapting suitable materials for teaching in the learning-by-doing way.

But this does not and should not mean that the teacher or tutor should be left with the total responsibility for creating such teaching and learning materials. That would be too much to ask of anyone.

Creative teaching implies that the teacher and learner can both make individual active contributions to the acquiring of experiences and the learning of the useful lessons they contain. Thus they should be given sufficient scope for the exercise of their initiative without, at the same time, being burdened unnecessarily with the responsibility for providing most of their own information and equipment. That is, they should not be made to have to write their own textbooks from scratch nor reinvent the wheel over and over again.

The idea behind this sourcebook is not to " give a hungry man a bowl of rice each day ", but to " teach him how to grow his own rice ", so that he can feed not just for the day but for a life time.

To push the analogy a bit further, we do not grow his rice for him all the time; we allow him to grow his own rice as and when he likes. This means that in situations that do not fit those often prescribed for the standard classes, we do not seek to save the teacher who uses this book from thinking of ways to teach all the topics in the syllabus in a fresh and inspiring manner. But rather, we wish to encourage him to think creatively, without frustration and enjoy it, and grow professionally.

Professional growth and the satisfaction that it brings will come naturally to the teacher as he watches the pile of successful investigations of his students grow under his diligent guidance and inspiration. It will not be only the pile of experiments that grow. Also growing will be the

self-assurance of the class that comes with the habit of students working successfully on their own.

This will be perhaps the biggest source of satisfaction for the teacher. It will augur also a new era in the development of science and science education in our different countries. For it will bring to realization the appearance at last of a new breed of young science workers and science educators who will have the confidence and the will to work in harmony with their environment for the betterment of all. This, in the last analysis, is or should be the prime goal of scientific education.

In the world of science education there are nowadays a great many books, journals, pamphlets and guides as never before. It can be expected therefore that anyone wishing to teach or learn would have very little difficulty gaining access to the relevant literature to suit his purpose. As a result one has to justify putting out a new book to add to the pile. Any new book comes with its own different selection of materials, different slant, different emphasis and special appeal to a different audience.

All this applies to the present sourcebook of science education for teachers and teachers in training.

In addition, times change and people and systems change accordingly. New knowledge is added constantly to the old, new directions are taken and new goals and objectives are adopted by the educational systems. As a result those who dispense the education need to dispense the new variety that meets the altered directions and the changed times.

In our situation, we have found nothing particularly directed to the audience we are addressing in the area in which we are operating. This is meant to be in terms of the stated goals and objectives of the educational systems we have been serving.

It is only in the last ten years that serious attention was first given to what might have been the peculiar characteristics and needs of the region. In that period a great deal was done by the African Education Programme of EDC and later by our own Science Education Programme for Africa to remedy a situation that had remained neglected for several decades. Much of what was produced as a remedial measure has influenced the production of this Sourcebook. In fact this Sourcebook had a fore-runner born in Nairobi in 1971*, but later supereeded by the several developments that later culminated in the present efforts. We can therefore say that in the Sourcebook which follows we have tried to meet the requirements for Science Teacher Education for primary schools as the changed times require.

Chapter 2—The Sourcebook in relation to the Handbook

In working towards a more effective delivery and dissemination of the scientific knowledge and skills necessary for developing our human and natural resources we have come to realize that we must make the difficult tasks of the teachers easier.

Very often, being deeply engrossed in the daily chores of classroom details and responsibilities, a teacher has little time left for scouting around looking for resources to add to, enrich or modernize his teaching. He would welcome a handy resource that provides not only the " how to do " but also the " what to do with " information.

This is the idea that has prompted the production of two volumes in our series—A Handbook, and this Sourcebook. The Handbook expounds the basic ideas underlying the approach to Science Education, while the Sourcebook provides examples of how this approach can be put into practice in everyday teaching. A few illustrations of the differences between the two volumes will make this point clearer:

In the learning of science, we may identify the following important factors:

(*a*) the persons directly involved: the teacher and the pupil

(*b*) the sources of ideas, namely,
— the Sourcebook and the Handbook

* Report of the SEPA Teacher Training Materials Workshop. Nairobi, Kenya Aug.-Sept. 1971.

—other studies than science;

—the environment and the teaching materials;

—the teacher and the pupil (as sources of fresh ideas or ideas resulting from their previous scientific studies).

The teacher assists the pupil. This assistance takes several forms, but remains essentially a guiding, urging, challenging, and motivating endeavour. The pupil, if observed well by the teacher when encouraged, may put forward suggestions for improving the teaching. The suggestions are usually in the form of directions the pupil wants to take in his work, or some ideas he wants to try out or pursue. As teacher and pupil interact, each complements the other in the learning situation. They form a learning team in which the learner understands his role and his task and learning becomes more effective for him. Further, his individual differences from others of the team are recognized in so far as they affect his learning. This means that a good deal of flexibility is embodied in the learning/teaching strategies adopted. The teacher becomes sensitive to the needs of the learner and responds accordingly.

Both the pupil and the teacher can draw ideas from various sources. The teacher " must be humble, and inquisitive. He must by attitude and learning be willing to explore new phenomena with his pupils, seek more knowledge on his own, and be willing to experiment and unafraid of failure ".

Here then is basis enough for the Sourcebook as a companion to the Handbook. Both give ready suggestions.

The teacher and the pupil can themselves generate fresh ideas or render suggestions from their previous scientific studies to expand current work or lead off in new directions.

Ideas may also stem from other areas of study, other activities, and from the environment itself.

The suggestions from the Handbook and the Sourcebook are thus starters only, and are to be supplemented with the teacher's own ideas and ideas from other sources. Furthermore, it is advisable for both teacher and pupil not to limit their sources of ideas and suggestions, but to move freely from any one of these sources to any others. It is usually the case that useful ideas may come from any of these sources or combinations of them.

The Sourcebook and the Handbook are complementary. While the Handbook, in general terms, gives an approach to the teaching and learning of science, the Sourcebook gives details of how to carry out activities, where to obtain materials and ideas, how to prepare teaching materials, how to make full use of various teaching and learning aids. In other words, the Handbook is general in providing a background, putting one in a certain frame of mind or convincing one of an approach and illustrating the approach with a few examples. But the Sourcebook is specific. It provides details that are useful in carrying out individual lessons or investigations effectively. It is a sort of " further evidence " that it can be done even with limited or scant physical resources.

The two books therefore are to be used together for these complementary purposes. The one for constant reminders and discussions on broad approaches, the other for details to be exploited in specific lessons, experiments, activities or situations. Direct cross-references from one book to the other are clearly provided.

Note, however, that the Sourcebook can be used independently of the Handbook. The table of contents and the index aid in finding the information relevant to one's immediate needs and interests. It will be clear that we have catered for a really broad range of such needs and interests.

Chapter 3—How to use the Sourcebook

As stated in Section I Chapter 2, this Sourcebook is best used as a companion to the *Handbook for Teachers*; but, it can also be used independently, purely as a resource facility for teaching and learning science.

Ibid. 1. FAFUNWA, B., Keynote Address, SEPA, Nairobi, Kenya, 1971.

It has been designed partly to give further help to the teacher in studying, understanding and working with learners; partly to introduce a refreshing way of looking at the task of teaching science in a way that involves presenting the subject vividly, dynamically, enthusiastically—as that one is infected with the urge to search more, and find out more than just what is introduced. Also, it has been designed to provide ready sources of techniques that can be employed simply, even in areas without ready access to laboratory and complex equipment.

The Sourcebook gives a variety of such techniques, recommends various methods to adopt, sources of information to tap, and materials that may be needed in different circumstances. The emphasis on improvisation should be welcomed by those who will wish to work in circumstances where sometimes the barest minimum of " standard " facilities may be unavailable.

Then there is the important chapter on how to use mathematics to help you study and understand your science problems. In the case of physical science this is often readily apparent. But in the case of the biological and social sciences it is sometimes difficult to identify some of the important parameters needed to throw light on the subject.

For instance, the example given in Section IV Chapter 16 on " Extensions of Growth " shows how useful the quantitative approach to science is. Indeed, someone has said " if you can measure a thing you can understand it better. " This Sourcebook encourages one to measure as often as possible, the factors, phenomena, charateristics, etc., of the natural world that form the basis of the study of science.

To be truly integrative, the study cannot be unbalanced, one-sided or discriminative. The physical, chemical, biological, social and other aspects must be taken into account even if not all are fully pursued at the same time. The most useful tool for such an integrative study is mathematics.

While this Sourcebook has not dealt with the use of Mathematics exhaustively here further assistance can be obtained from following up the topics in the chapter on " Mathematics as a tool in Science. "

Among the many ways of using the Sourcebook is the straightforward one of trying to write a module or unit from a syllabus topic. The procedure in the Handbook simply says; " write down preliminary ideas which you can test "; it does not give actual steps that can be adopted in putting down those preliminary ideas. Section IV, Chapter 16, gives several examples of putting down not only related concepts, but also related phenomena dealing with the topic. This is applicable to all topics. The important point to bear in mind is that the topic is introduced not merely by definition of the topic. Out of this examination an initial understanding of some related concepts and of the topic itself is expected to arise. In the process, several practical situations that will facilitate this understanding will have suggested themselves. These will be the *activities* that the learners will perform—simple but illuminating, graded in difficulty and ultimately challenging.

Here we reiterate that the teacher or instructor need not always turn to this for every lesson. Once the process starts it snowballs. That is, the momentum carries things along as new activities arise from students interests and investigations.

Section V Chapter 19 is what the student will turn to in choosing methods of investigation for particular studies; or for selecting alternative procedures in order to improve an investigation.

Section VI aids in identifying sources of information which are usually not obtainable from standard textbooks or journals. It also helps with sources of materials that are useful for improvisation of apparatus and equipment, as well as for making recipes or substances from recipes.

The aim has not been to present what is called a cook-book. The user is given illustrations from which he is expected to carry on on his own, developing his own ideas along with either tutor, or fellow students or young learners in his charge. No matter what the initial subject matter, the model developed here shows how it can lead to a truly integrated study of the human environment as man stands in relation to it. Thus every study should be outlined, if not fully developed, in this way if the potential richness of the design is to be realized.

When a design like this puts a particular topic or concept in its broader perspective in, this,way, it permits a learner to see readily the major justification for working hard at learning and mastering it. This has proved a powerful method of inducing motivation in a learner.

As regards the activities suggested here, they should not be taken as part of a curriculum being suggested or proposed. They are not meant to cover even half of the usual ground. Lots of other activities will be thought of by teachers, students, tutors; even other readers. The usual scheme of making a flow chart will always help the growth of ideas related to the topic at hand. When the ideas stop flowing, reference can be made to Sections V, VI and even IV Chapter 17 for further techniques, methods, and suggestions relating to similar ideas or topics.

This Sourcebook should serve as an example of a compilation one should make for oneself.

Add to it from your own reading, your own investigations, suggestions from experienced friends, and from your discoveries in libraries. Give it an organic life—let it grow.

You may find other useful resources in the form of reference books, or persons—immediately note these in your book.

You will thus be developing into a resource person yourself, armed with your expanded Sourcebook.

In particular, there may be useful references to the local environment: local flora check-lists of animals, maps of soils, rocks, etc., that the original compilers of this Sourcebook could not be aware of. These must appear among your additions. Your sourcebook then becomes a real companion as you contribute to it while drawing ideas and information from it. This is what is meant by giving it an organic life and letting it grow. It is the best way to use a Sourcebook.

Chapter 4—The Handbook as a Resource—Outline

4.1 Rationale for an Approach
- Traditional approaches
- Activity based approach
- The Handbook is a statement of the desired approach

4.2 The Learner as a Resource
- The progressive school of thought
- Studying examples of student work
  - (*a*) At the College level
  - (*b*) At the School level

4.3 The Teacher as a Resource
- The teacher in a new role (no longer just a giver of information)

4.4 The learning Materials as Resource
- Local and easily acquired materials
- Effectiveness in learning

4.5 Interaction of learner, Teacher and Materials
- Components must work together as one
- Handbook is a source for ideas, not a textbook.

4.1 Rationale for an Approach

Traditional practices of science education at the classroom level are based on an approach. Sometimes the approach is subject-matter oriented, sometimes the approach is that of rote-learning or that of problem-solving. At any one time, the teacher and his class demonstrate a favoured approach in the classroom. It is, in fact, relatively easy to describe and act out a number of teaching/learning approaches. On the contrary, it is particularly difficult for a teacher to state and play quite clearly the classroom roles of an activity-based approach to science education.

The entire handbook is a carefully prepared statement of the approach– the descriptive aspect (Section I), the illustrative aspect (Sections II, III, IV) the inferential or explanatory aspect (Section V), and the technical aspect (Section VI). Each of these aspects is a resource in its own way, and together they represent the following items as distinct resources: the learner, the teacher, the learning material and the inter-action among the learner, the teacher and the materials.

4.2 The Learner as a Resource

Educators who subscribe to the progressive school of thought put great stock in observing learners to ascertain the objectives of education in general. In the teaching of science we can gain a great deal of insight into what might be most useful and effective by not only studying the learner, but studying examples of their work at various ages and levels.

From studying examples of work done by students at the College level we can learn about relationships of learning materials with society. At this stage students have developed interest and methods for dealing with problematic situations. We can, by observing, take note of those things that are worthy of investigation concerning the materials.

The teacher will then be in a position to design more significant learning activities, he will be more cognisant of problems associated with students efforts and will develop a sense of strengths and weaknesses of certain aspects of materials.

The Handbook also describes children's activities from which one could gather source material on children. The observant teacher will be able to note young children's ways of looking at phenomena and how they interpret them. We can further get an idea of the children's knowledge of certain materials and which aspects of the materials are of interest to them. There will be certain facts that will be intrinsically interesting to the children.

We can take note of how children keep records and when necessary, help them develop methods and schemes that are more accurate. In general, we will be able to see what resources children use for themselves and observe their relationships with their environment.

4.3 The Teacher as a Resource

The activity approach in the learning of science makes certain demands on the teacher. The teacher becomes one of several resources in the classroom and not always in the form of a giver-of-information. The Handbook illustrates the resource function of the teacher in several ways.

In the first place the teacher attempts to identify children's needs by allowing them to learn things that interest them. In connection with this, the teacher helps the student to identify and use necessary tools for whatever work they wish to do. In doing so the children's work is facilitated. Clearly the teacher must get completely immersed in the children's interest.

In the teacher's advisory role, he must be a good observer of the children's actions so that their capabilities can be drawn out. Given that the teacher has done all of these things he will be in a position to help students formulate good inquiries and suggest extensions and expansions to what the children have already done.

As is traditionally done, the teacher should also suggest questions and activities from his own interest. It is quite likely that the children will also find these things interesting, particularly if they have some connection with experiments and activities they have already been involved in.

At all times the teacher should be professionally honest. If he does not know something this should be indicated clearly to the class. It could then be a project for both teacher and students to explore. There is nothing wrong with the teacher asking the class for information. There are always ideas and facts that children can supply the teacher with. An atmosphere in the classroom of teacher-helping-student and student-helping-teacher creates a kind of congeniality that promotes learning for both teacher and the students. If everyone in the class (teacher as well as students) is having an interesting and enjoyable time, the chances of learning more science are definitely enhanced.

4.4 The Learning Materials as Resource

By far the most realistic resource for learning is the materials used by the learners. The Handbook gives (Chapter 2 Section III) several concrete illustrations. Here we find several suggestions for questions based on the learning materials. Further, the kinds of materials suggested are available in abundance (metal, string, cloth, wood, etc.).

We need to be selective to the extent that we utilize materials that are easy to handle and at the same time are not injurious to the learners. These materials should lead to enjoyable activities and relate directly to children's lives. Making furniture, constructing animal cages or building bridges are relevant examples.

4.5 Interaction of Learner, Teacher and Materials

A careful reading of Section III will give many ideas on how the learner, teacher and materials can all be effectively combined to stimulate effective learning of science. Ideas and materials are wedded so that movement from one discovery leads naturally into other activities. The children are not pushed in any direction, but, by the teacher suggesting new questions, directions of enquiry are taken up by the student.

In Section V there are many helpful ideas having to do with the recognition of individual differences, intellectual development and motivation. Again, realizing to some extent how children view the External World the teacher is in a position to suggest and select appropriate materials. What we need to strive for is a complete interaction of Learner, Teacher and Materials. Only when we have all three components working as one will the learning be exciting and useful.

It is not suggested that the specific examples of children's work or even the materials suggested in the Handbook ought to be repeated. The ideas in the Handbook are there to give suggestions and ideas. What actually goes on in the Teacher's classroom should be determined by the learners, their conditions, the material available, as well as the teacher's ideas. In short, the Handbook is not a textbook, but a guide and should be used as such.

2--The Process of Scientific Inquiry

Chapter 5--The Nature of Science

There is sometimes a mystique surrounding the notion of science held by many persons. But this is usually due to the fact that they have only a stereotype in mind when they think of science or scientists. Yet if we look closely at the question of what is science we are bound to come up with more sobering answers.

Take for instance the man who studies insects and the problems they cause for the farmer*. He has studied the problems for long. Direct methods of attack have failed. Indirect methods are suggested. He asks himself the question " What leads these insects to their mates? Is it some perfume or other odour? Can we extract the substance and learn to produce it artificially so that we can use it to trap harmful insects and destroy them?" He then goes on to crush some of the female insects, to extract some of the products with suitable liquids, and to separate their components on a special paper by a process called chromatography. Lastly he dissolves out the components individually and examines them to determine their nature. He then goes on to test their effects on the insects individually: and finds that two of them do produce the effect on the mates, but to a less dramatic extent. He then concludes that perhaps these two components need to be combined either with one another or with some other agent in order to produce the full effects. And so he proceeds to try this out.

Such a man we call a scientist: and what he has been doing we call science.

But let us look at a student in college, also studying insects. This time we find the student interested in the cockroach that causes so much problem in the kitchens and pantries and even in the house. " How can we keep the cockroach population down? " he asks himself. He then goes on to read everything he can lay his hands on about the cockroach and begins to observe some of them at close quarters. In the process, he comes to find that someone had reported that some particular powder (Boracic acid) could be used against the insect successfully. He then tries this and finds that contact with the powder kills at least half of the number of cockroaches in one day. He then goes on to find out how this is achieved. He suggests that it may be the powder blocks the breathing holes of the cockroach or gets into its mouth and poisons it. But which, if any, of these two possibilities is correct? So he decides to test the ideas one after the other. He carries out experiments and makes careful observations of the behaviour of the cockroach in contact with the powder as well as without the powder. He then concludes that the powder makes the insect lose too much water and dry up. A further question then arises--how does the powder do this? But that would be another study altogether. For the moment the student has concluded one study or project.

Similarly, we can look at students at a still lower level of education. A teacher takes a class out into the field to explore the natural environment and a few minutes later some are interested in the webs of the garden spiders; others in the insects walking on the surface of the water; and still others in the grasshoppers, and so on. The students return to class with samples of their interests and try to see what more there is to them. Observations continue as the insects are made to walk on water in the class. Questions arise. How is it possible for insects to walk on the water (surface)? Can other insects do so? Can all insects do so? And so the trials begin first with one kind of insect, then with another and so forth. It soon becomes clear that not all insects can walk on water as the records begin to show. And so the inevitable " why? " question crops up. Why is it that some insects can walk on water while others cannot? Suggestions begin to come up " Because they are heavy. Because the water is not strong enough. Because their feet are too big. . . . . ", and so forth. And so to further activities. Try heavy and light materials- pins, match sticks, tooth-picks, straws, small stones, match-box; to test the heavy-light idea. Try pulling on the water surface to test the surface strength idea; try making different sizes of artificial insects out of pith and straw to test the heavy or big feet ideas. It goes

An entomologist, or an agricultural entomologist.

on like this for several weeks until the students arrive at answers that explain the phenomenon—surface tension, light weight, spread over wide area of water surface.

If we examine these examples closely we find so much common to them. They all start from observations of the environment, relate the observations to current knowledge, find that some gaps exist in the explanations and raise questions about these. The questions provoke guesses at possible explanations and in order to decide on which guesses are more correct, certain activities are carried out to provide further observations. These are explained in relation to the guesses made earlier and to the observations of others. Then suitable conclusions are arrived at and new questions arise. The whole thing becomes a sort of circular spiral in which new knowledge is added to the old by following a particular procedure and adopting special mechanisms, even without giving names to these procedures and mechanisms.

This knowledge then, the old and the newly added, together with the methodology employed in its acquisition and the mechanisms used in arriving at them, constitute science. All these people we have been considering have been *doing science*. They have been operating with scientific knowledge, scientific methodology and scientific mechanisms both physical and theoretical. The nature of science then emerges as a composite of a *corpus* of knowledge, a particular methodology and a variety of consistent mechanisms appropriate for use in adding to or modifying the body of knowledge. In the examples we have been considering, the participants have been carrying out similar exercises with different degrees of sophistication or refinement. But the essential similarity is there right through. They have been doing science, using the same methods and similar mechanisms, namely, physical (experimental) manipulation of their environment, physical models; theoretical mechanisms such as hypothesis (guesses), theories, laws (rules about how things in the environment behave), and models.

Thus doing science has come to mean gaining knowledge by observing and asking questions about the world around us; observing this world closely again, developing hypotheses about the possible answers; experimenting; and explaining the results or further observations; drawing conclusions and relating the total experience to known (previous) knowledge. In the process new knowledge is acquired, be it new only to the learner or to the rest of the scientific world or to the rest of mankind. Constant practice at this leads to the development of a particular way of looking at the world. This has come to be called the scientific attitude. It is basically a search for cause and effect relationships and patterns in the natural world, on the premise that every event has a cause which can be identified through proper search, using the methodology and mechanisms outlined above.

Chapter 6—The Process of Scientific Inquiry

The Scientific Method: The methods adopted by the students and the scientist have come to be called the scientific method. It is a method of solving problems that has developed over more than two thousand years. Let us look at its characteristics a little more closely.

We can recognize six clear steps in the process, namely—

(i) Observation

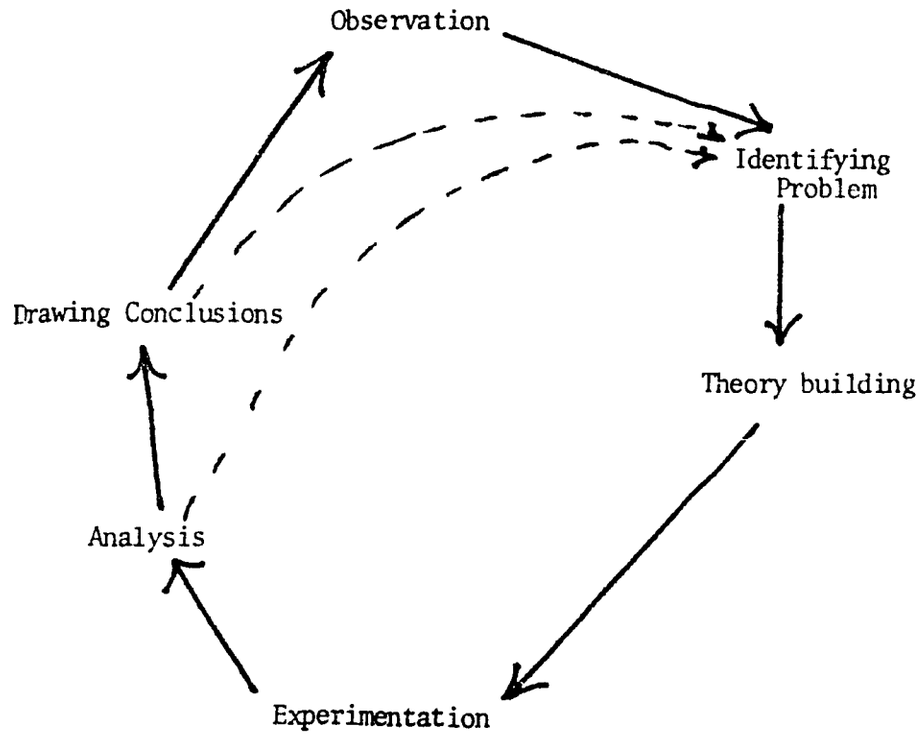
(ii) Problem identification

(iii) Theory building, prediction

(iv) Experimentation and further observation

(v) Analysis, comparison of theory with observation and results of experimentation

(vi) Drawing conclusions and generalizations



In each of the foregoing examples quoted above, these six stages can be readily identified Stage (*i*) includes a pre-requisite element to careful observation; that is, curiosity or inquisitiveness. This gives more than a casual character to the observation. Following this one moves on to stage (*ii*) in which questions arise. This is an active process. The questions are asked in such a way that they can be answered by going through the other steps in the process. Stage (*iii*) is then carried out, usually on the basis of information derived from past experience, including also that of stage (*i*): for here the information derived from stage (*i*) is related to all similar information accessible to the observer. Stage (*iii*) then leads to active investigation, usually taking the form of manipulating the system being observed in particular ways to obtain predictable outcomes. This active investigation is stage (*iv*). It is in fact this stage that, above all, characterises the scientific method and distinguishes it from others, especially that of philosophy. Stage (*iv*) is determined by a number of factors such as the goals set out at the predictive stage, the instruments, both physical and intellectual, that are available for the task; and the subsequent analysis and generalizations that are likely to follow from its outcomes. Careful observation and neuromuscular skills come into play here. Stage (*v*) is the point at which the outcomes of stage (*iv*) are reviewed and classified within the scheme of previous information. It depends heavily on the intellectual tool invented for this purpose by Aristotle some 2,000 years ago, namely, logic. For upon this analysis will ultimately depend to a great extent the validity of the conclusions and generalizations of stage (*vi*). If sufficient care and attention has been given to stage (*iv*) then the analysis in stage (*v*) may lead us back to stage (*ii*) where new problems are identified and another cycle is started. Step (*vi*) might be seen as the terminal stage of the whole procedure. But it may also be a lead back to stage (*i*) or even to stage (*ii*). Even conclusions that yield results which are of practical use in everyday life are often tentative in the sense that further improvements may come at a later date. These then are the principal stages of the scientific method.

There are certain aspects that we can single out as being of particular importance. Firstly, we have the idea of *cause and effect*. Any successful application of the scientific method must be based on the recognition that each effect which is observed can be attributed to one or more causes. These causes may be very complex and therefore not easy to detect. They may even apparently be impossible to detect in a given set of circumstances. Yet the application of this method rests on the assumption that nothing "just happens", and that everything that happens has a cause.

Secondly, comes the important aspect of *reproducibility*. In adopting the scientific method the assumption is made that given the same conditions, we expect to obtain the same results every time. This allows other people, using the same procedures, to reproduce and check the results of our work. In this way we say that our observations, analyses and generalizations are objective. They do not depend purely on the person making them. Others in similar situations can also make them. This idea of *objectivity* is very important. It means that we can build our understanding of the world in which we live, and of ourselves, on the work of others in the past. This element of objectivity coupled with the factor of reproducibility of results upon which it often depends, has been largely responsible for the enormous accumulation of knowledge that has taken place in the last few hundred years.

Thirdly, we have the element of *predictability*. It follows from the ideas of reproducibility and objectivity that the application of the scientific method should often allow us to predict certain events even before they take place. Such predictions are made possible by looking at what has happened in similar circumstances and then by assuming that the principle of reproducibility will apply to bring about the predicted results. If the results predicted do not take place, this will cause us to search for effects in the situation of which we were not previously aware. Such failures of predictions have led to some important discoveries in modern science.

The process of scientific inquiry has become more than just a vocational procedure. It has led to a situation in which science has influenced in important ways every aspect of human life in the modern world. It would be interesting to trace its origins in the ancient world and follow its development over the years up to the present time.

Chapter 7—Historical Development

This grand design, this elegant procedure that has come to be the standard method for looking at the world and understanding the underlying laws of nature and how they apply to ourselves, did not develop overnight. It took mankind a long time to arrive at it by a series of trials and errors. Even up to the beginning of the last century not all the scientific world had settled down to adopting just this procedure. But today no scientific work is accorded validity that does not adhere strictly to the scientific method of acquiring knowledge.

This history of science, with its vast body of knowledge, its characteristic methodology and its analytical mechanisms, is a long and interesting story; and one cannot do justice to it in a few pages here. However, there are a few highlights that can be given out to outline the critical paths in the development of science.

The roots of science lie buried in the remote, unwritten past of human social evolution. They all go back to the days of systematic tool-making and weaponry, when trial and error gradually gave way to reliance on past experience not only of individuals, but also of whole families and even of larger communities. In terms of numerical time-scale this takes us back to some 400,000 years when symmetrical forms of tools and weapons were probably first being made.

Considerably much later, mankind learned to leave behind deliberately the ideas going through his mind. In those times, some 30,000 years ago, he began to leave behind portraits of his game animals in positions of movement. Such achievements indicate careful and precise observations and recording of what was happening around him in the natural environment.

Observations and recordings naturally led to recognition and use of cyclical phenomena with their regular periodicities. Thus we find that about 13,000 years ago, man was doing his food gathering and hunting using the lunar calendar.

Later on when the practice of agriculture led to settled communities, perhaps a few centuries later, the problems of soil fertility took on importance as a limiting factor of the size and stability of many of the neolithic communities. However, in river valleys and deltas, where annual flooding and siltation regularly restored the soil fertility, the communities grew in size and complexity from villages to towns; and from towns to cities. A priestly class arose and

developed an administrative system to organize the complex activities of urban communities. This was probably the situation around 3,000 B.C. in the Indus, Tigris-Euphrates, Nile and Yang-tse valleys.

By then permanent records of agricultural produce and those of the technical arts were kept by the priests, using numerical systems and pictographic scripts which, with modifications, later led to the development of a literature dealing with astronomy and cosmogony, mathematics, mythology, history and medicine: and religion.

Two traditions thus developed, which were to give rise jointly to modern science. These were the technical tradition, in which practical experiences and skills were handed down and developed from one generation to another: and the spiritual tradition for a similar succession of ideas and aspirations.

For the most part these two traditions developed separately through craftsmen's guilds and priestly corporations. Not until more recent times did they come together to give rise eventually to modern science. And they were to come together first in the civilization of Greece, largely through the work of one man, Aristotle, who was born in 385 B.C. Indeed, the very word science comes from the Greek word meaning " knowledge. "

Aristotle was the first man in recorded history to attempt to devise a method for arriving at secure and reliable knowledge based on the results of observation. His writings were subsequently put together under the title the " Organon ", meaning " instrument " (i.e. of gaining true knowledge). His major contributions to the development of science were—

(*a*) the invention of logic

(*b*) an outline of the method for acquiring knowledge of natural things.

To Aristotle the ultimate object of science was " to know what something is ". He has been called the Father of Logic because he invented it himself. Other contemporary civilizations, in Egypt, India, and China, did not develop logic and without logic there can be no true science. For logic, as a separate discipline among the Greeks, led to the setting up of a *standard of rationality*. Logic makes possible a coherent and consistent argument and allows us to follow an argument step by step: and to check whether it is true or not. This, as we have seen earlier, is an indispensable component of the scientific method and thus of science.

Aristotle altered Greek science when he emphasized and undertook extensively empirical enquiries, setting a trend which was followed widely by his successors. His zoological works contained a great deal of observation. The school he set up was later taken over by his pupil Theophrastus (372–287 B.C.). This latter not only continued the descriptions and classification of plants and animals, but formulated the objectives of science in terms that suited later developments and that remain valid today. Thus Theophrastus suggested that the scientist should explain natural phenomena in terms of the processes observed in the mechanical arts, proceeding generally " by making reference to the crafts, and drawing analogies between natural and artificial processes ".*

Strato of Lampsacus succeeded Theophrastus as head of the Lyceum (Aristotle's School) and he went beyond observation and hypothesis to experimentation.

Thus, in what is commonly called the Bronze Age, scientific knowledge was mainly mathematics and astronomy which were used for keeping records of accounts and surveying, as well as for making maps and calendars. The knowledge of the craftsman did not constitute a science. As a body it remained as an art in each case.

By the time of the Greeks science was making appreciable advances. The most important step forward was taken when the Greeks generalised the discovery that facts derived from experience (empirically) could be shown theoretically to hold for all similar cases. This was done for the laws of levers as well as in the case of Pythagoras's theorem.

Furthermore, the Greeks used geometry to interpret theoretically what they observed and recorded in astronomy. This was another major step forward since it marked the first step in the use of empirical data to build a quantitative structure out of the current theory of the universe.

Quoted in MASON, S. F. 1956, 1962 *A History of the Sciences*. Collier Books, New York P. 46.

But little experimentation was done. Accordingly, the experimental method as is known to-day did not develop and did not exist. Science, as we know it as a body of knowledge which can be applied to new fields of human activity, was at an infant stage where it was applied only to military engineering and map making.

Later in the period of Roman supremacy the growth of science was retarded. Science literally marked time. The Romans made no major advance over the achievements of the Greeks. Similarly, no major advances came from India or China.

When the Muslim civilization succeeded, some advances were made in experimentation in alchemy. But again, these were in a minor key. This situation persisted until the recent periods in Europe called the Medieval Period. Then, a misunderstanding of the nature, thinking and practice of science led to an institutional suppression of science.

It was only in more recent times, some four to five hundred years ago that science was able to escape gradually from suppression and scientists could practice science openly, free from fear of accusation and persecution. Consequently, it was then that science was able to start its vigorous growth and blossomed into present day system of knowledge, of thought and of outlook.

This growth and blossoming has been due to the fact that the applications of science to daily life have increased in scope and complexity. The effects have been great historical changes. These changes have affected not only the natural sciences, but also the social sciences and even what traditionally have been regarded as the arts. All these have been made more precise by the experimental enquiry and the processes of scientific thinking.

As people in all works of life came to develop confidence in these approaches to the problems of their disciplines, science became more and more important in their thinking. This influenced their outlook on life and their view of the world. In other words, the human mind was itself progressively secularized.

As applications of science spread from the original accounting, surveying, calendar-making, and map-making, to navigation at sea, thence to industry, agriculture, and medicine, changes took place in man's thinking and behaviour to the extent that modern civilization is stamped with the indelible impression of science. In the process of spreading modern civilization, man has had to discard many of his old ways of doing things—his old ways of life and beliefs and to abandon or change many ancient traditions. This process is still going on today and it is particularly evident in fast-changing situations in present-day Africa.

Over the past few decades these processes of scientific thinking and enquiry have been spreading into even remote villages in every developing African country. They have come not only through schools, but also through radio, extension work in agriculture, public health, and hygiene, social welfare and maternal and child care. Old ways of living and doing things are gradually, some say rapidly, giving way to new ones as the need to " develop " becomes at once a social and an economic imperative. The question is no longer one of choice; but of inevitability. The scientific attitude is spreading into more and more communities and leading people towards a rational viewpoint. It is to be expected that as the scientific method spreads so its effects on human behaviour will become more manifest in our several communities. Human relationships will come increasingly under its dynamic and inventive quality. This will move men to adopt a system of forward-looking values, accept change more readily, and discard systems and institutions that resist the tendency to change.

Chapter 8—The Scientific Attitude—(Individual and Collective)

The development of a scientific attitude has become so fashionable that educators in all other disciplines strive to make their disciplines scientific—hence we hear of the social scientist, the environmental scientist, and the behavioural scientist.

One is therefore tempted to ask: what is the scientific attitude? The scientific attitude consists of a cluster of behaviours—ways of looking at events that lead to the solution of problems. These behaviours include: criticism of self and others, the ability to split a problem into its component parts, questioning, evaluation, reporting one's findings to others honestly, gathering data, and a host of other behaviours.

Criticism

The ability to give and receive criticism is a very important attitude in scientific work. Scientists spend a lot of time examining each other's data to see whether they are consistent with the established theory. In this search, there are often disagreements. However, when a scientist succeeds in making a point against stiff opposition he feels he has accomplished something more than if there was no opposition encountered. The reason for this is that with scientists, the reasons "why" are much more important than who says so. Occasionally, an unknown scientist with good reasons for criticising a famous scientist'. work may become very famous. Evaluation of one's own ideas in contrast to others in terms of how the data fit an explanation is also a useful scientific attitude.

Splitting up a problem into components

Learning how to split up a problem into its component parts and learning how to investigate each aspect of the problem is another important scientific attitude. For example, a student working on motion constructed several nice tops and started spinning them. But it was not until he had devised a systematic way of measuring the length of time for each spin and the other factors involved that he started learning about the motion of a top. Having learned the skill of splitting up a problem into its component parts, he was ther able to use that skill to find out how the following factors affect the motion of a top:

(1) the position of the centre of mass

(2) the diameter of the shaft of the top

(3) the length of the shaft

(4) on what surfaces tops spin best.

Trying to find out what important variables are involved in a given scientific phenomenon preoccupies a lot of the scientist's time.

Communicating ideas to others

Sometimes scientists get together at a symposium to communicate ideas to each other. At a symposium, scientists give lectures to explain to others what they have found out and receive feedback from others. They also write and publish their findings in important scientific journals so that others may know what is going on in different fields.

Gathering data

Scientists take the attitude of not accepting things at their face value. For this reason they make apparatus to extend their senses: like microscopes, telescopes, micro-balances, and sensitive indicator papers—litmus paper. These instruments are then used to collect data by observation, measurement, comparison, and a lot of other activities are done. All these activities then lead to the making of inferences and deductions, the interpretation of data gathered, and the making of conclusions based on data. So you know what was meant at the beginning when it was said that the scientific attitude is a cluster of behaviours. It is these behavioural patterns that characterize the scientific attitude. For details of techniques in data gathering, see Section V Chapter 20 (ii).

Chapter 9—Science and Development—Technological, Economic, Social
Outline

9.1 Basic peculiarities of Science and Technology

(*a*) Two viewpoints
  (*i*) understanding (Science)
  (*ii*) control and use (technology)

9.2 Science, Technology and Society

(*a*) Considerations for making discoveries useful to the public
  (*i*) environmental concerns
  (*ii*) public safety
(*b*) Need for clarity from scientist and technologist
(*c*) Need for scientifically educated populace
(*d*) Need for scientifically educated policy-makers

9.3 The need for Interdisciplinary Approaches

(*a*) An example
(*b*) Aims and Purposes
(*c*) Attitudes, codes of conduct, laws
(*d*) Bright hopes for the future.

9.1 Basic peculiarities of Science and Technology

Just as basic viewpoints can be adopted and/or combined, there are two viewpoint about what we mean by science as opposed to technology.

Serious scientific study aims at understanding which embraces knowledge of the phenomenon in all its manifestations, as well as an appreciation of the internal processes or component reactions of the phenomenon, its causal aspects or how objects displaying the phenomenon react or respond to various factors. In a word, we are talking about the description of the phenomenon and an understanding of its causal basis.

Technology includes the scientific study of a phenomenon, but goes on, in particular, to its exploitation or use for specific purposes.

Thus, an understanding of the physiological processes underlying food storage in a crop plant—wheat, potato or cassava for example, constitutes a scientific study. The full exploitation of this knowledge, together with an understanding of suitable varieties for a particular region, times of planting, irrigation, machine for harvesting, suitable storage systems, etc., constitute the technology of agriculture.

These two viewpoints of understanding (science) on the one hand, and control and use (technology) on the other, are two faces of the same coin of human curiosity and exploitation. One feeds the other. Problems arising in technology lead to new scientific investigations which in turn may lead to improvements or innovations in technology.

9.2 Science, Technology and Society

The usefulness of a discovery cannot always be predicted (not even by the discoverers themselves). Famous examples are Faraday's discovery of electricity and Einstein's discovery of relativity. Other discoveries may be needed in conjunction with a specific one in order to make it useful.

Often a discovery may have both positive and negative applications or impacts (consider the use of explosives—they may be used for cruel purposes or for building roads and dams). A dam may support irrigated agriculture and provide electricity, but may lead to the spread of water-borne diseases.

There is usually a time lag between a discovery and its application. Between a discovery and its general use by the society there may come:—

(1) A spread of knowledge pertaining to the discovery
(2) Attempts at putting it to use (technological research)
(3) Creation of prototype instruments or methods (developmental research)
(4) A study of its economic feasibility for general use or a study of the safety in its use (e.g. consumption of a new drug)
(5) Legislation to protect the public and to ensure high standards of production
(6) Production: and last
(7) General adoption by the public

However, in modern times there are ways to reduce this lag.

In this day and age we must be concerned about exploitation of modern science and technology, without destroying our environment (problems of the conservation of the natural resources and protection of the environment.) as well as without jeopardizing our own lives or those of future generations.

Then, too, developmental research necessarily requires financial backing, either from well-established private companies or from government. Without it a number of scientific discoveries may remain unexploited.

Lastly, decisions on the control of ambivalent uses of technology may require evidence from scientists and technologists. These people have some responsibility towards society and must explain as clearly as possible the implications of their findings to society. Their decisions may also require debate by the public (society). This means that the modern citizen must learn enough about science and technology to enable him to contribute to or follow the debate intelligently.

It is also likely that policy-makers will have to give the final approval (or disapproval) on the aforementioned uses of technology. This, of course, requires that policy-makers themselves be more aware of, or understand more, science, technology and their social implications. Furthermore, policy-makers may be recruited from, but not restricted to scientists and technologists.

9.3 The Need for Interdisciplinary Approaches

In a number of instances we need to understand our environment as a totality—a system of interacting components-- and to learn to manage the system as a whole rather than simply interfere with single components of it. E.g., in attempting to eradicate an insect-borne disease, we now consider together the biology of the insect, use of insecticides, use of sex attractant to lure the males to their death, release of sterilised males to cause a reduction in the size of the population, understanding natural friends and enemies (including diseases) of the insect, the natural behaviour of the insect, human social practices that may favour the insect, build-up of genetic resistance in the insect population against our insecticides and so on.

This is a many-pronged attack that requires the co-operation of many specialists from many subject areas (some scientific and technological, some sociological).

The above considerations support the trend towards interdisciplinary studies, i.e., a problem is attacked by a team of experts drawn from various subject areas, a team that functions as one mind as far as possible.

The question of aim or purpose, and even that of values, is inevitable when we consider uses of the fruits of science and technology. It becomes, therefore, important for our scientists to decide for themselve their own aims, purposes, emphases and priorities in the improvement of the lives and the life-conditions of the people. In so doing, we notice the complexity of the network of influences tying together many aspects of society: health education, agriculture, communication, law, etc. No one area can be ignored with impunity.

From their nature, science and technology may throw up novelties. These may force us to reconsider attitudes, codes of conduct and laws we have found satisfactory until now. Such are some of the problems raised by control of fertilization and transplantation of organs.

Society hopes for a bright future in which the fruits of science and technology are fully enjoyed with full respect for the dignity of man.

3--Thinking and Learning

Chapter 10--Manifestations of Thought

In 1972 three-year old Ike was the last born and only male child in a family of five children and there was a six years' gap between him and his immediate older sister. One morning Ike's mother served the usual family breakfast of fried plantains with stew which he had grown to cherish. He took a look at the plantains, kept quiet for a moment and then said ' plenty fire. ' His parents and sisters got the message. Some of the plantains were partly burnt and he proceeded to avoid eating those.

On another day in 1973 when Ike's three oldest sisters had returned to their respective boarding schools his ten-year old sister Nene sat between him and their mother at the breakfast table. Toward the end of breakfast Ike looked up and said ' Nene is bigger than Mama. ' Nene said, ' no, Ike, that cant be true. ' Ike retorted ' it is true, Nene is in the middle; see my fingers.' At this point their father who had begun to take some interest in the conversation smiled. He said to Ike, ' if you mean that Nene is taller than Mama then you should watch them when they stand up after breakfast. ' Then he told them a small story about an event several years ago involving Nene. One evening when she was two she tried unsuccessfully to feed a beautiful singer who appeared on television.

There is no doubt that adults have serious problems comprehending children's reactions to situations. Usually what we get is the end result to a thought process which usually gives no clue to the path traced by the thinker. That is, unless as was clearly indicated in the *Handbook for Teachers*, one observes the thinker at work. Both for those who prepare teachers and for teachers there can be no substitute for direct observation of children at work.

Knowledge may be classified into logical, physical and social knowledge. Physical knowledge is the result of feedback from actions on objects, social knowledge arises from feedback from people and logical knowledge is due to the internal consistency of any system that one is working with, while both social and physical knowledge are based on ideas absorbed from the external world, logical knowledge depends on the consistency of views held by the individual.

Both social and physical knowledge should be clear. Perhaps logical knowledge needs further explanation. Suppose I claim that all mammals have four legs; logical knowledge forces men to accept that a human being has four legs since a human being is a mammal. The truth or falsity of the statement " all mammals have four legs " does not matter in this context; what does matter is the internal consistency or agreement of a set of statements. In contrast the truth or falsity of " all mammals have four legs " would matter for physical knowledge. That veracity or lack of it is determined by the external world.

Logical knowledge may be further differentiated into logico-mathematical relations and spatio-temporal relations. In the case of the latter, spatial and temporal arrangements are important. If we say that a cow is a bigger animal than a goat which is bigger than a fowl, we have established some relationships which make it necessary for us to conclude that a cow is bigger than a fowl. Temporal relationships involve internals and temporal order such as first, second, to the left and after, and spatial ones deal with such topological concepts as in, out, and in-front-of.

Logico-mathematical relations have been recognized by Piaget and others to involve classification, seriation and cardination and ordination of number. Classification is the ability to group objects in terms of their similarities and differences. It includes the important concept of class inclusion. We shall elaborate. Suppose we have five 'star' and seven 'club' bottle tops. When asked whether there are more bottle tops than 'club' bottle tops a child who has not achieved class inclusion will be confused.

Unlike classification, seriation has to do with arranging objects in terms of a dimension along which they differ. Given ten pieces of stick the child who has not achieved seriation may

not be able to arrange them in order in terms of increasing or decreasing lengths. It is not necessary for the purpose of the development here to go into further discussion of cardination and ordination.

With each of these three sub-classes of knowledge is associated 'representation' which is necessary but not of sufficient condition for the acquisition of knowledge. When a child perceives an event he needs to construct it so that he can recognize it later. Thus the representation of objects and events observed directly requires construction on the part of the child. When the object is not observed directly then more active internal construction is necessary if the child is to recall it. Imitation provides the vehicle for representation. The child would move from external imitation such as pretending to drink from a cup to imitating events and objects through imagining actions associated with them. He forms a mental image which is the result of internal reconstruction of the object or event. It is the mental image which makes it possible for the child to use such external forms of representation as indices, symbols and language. The important point is that it is activity which will ensure that the child evokes clear and detailed mental images. Used in this sense activity is actually of three types. First there is physical activity which involves the direct manipulation of objects. Then as the child reasons about what he is doing and abstracts concepts from this physical activity he is involved in the second which is mental activity. Working and discussing with other children is the third type of activity which is called social activity. This helps him to develop a critical attitude and to learn to appreciate points of view different from his.

In the years before school it is essential that the prerequisites to reasoning be taught to the child and only through activity can we be fairly certain that the necessary concepts will develop. Verbalization does not in any way indicate a child's attainment of a concept since language is not a source of knowledge and does not indicate capacity to reason. Yet verbalization following attainment of a concept should be encouraged because language serves as a tool for comparisons and for storage and retrieval of information.

Emphasis on activity should continue through the early years of primary school. Through classifying, seriating and other activities on objects the lower elementary school child gradually but surely arrives at the stage of concrete operations. He achieves conservation of discrete and continuous quantity and acquires some flexibility in his thinking.

Consider for example the manner in which the child develops the concept of substance. During the sensorimotor and pre-operational stages a child learns to differentiate his body from other objects in his immediate environment. He learns to see the world as made up of many objects which have separate and individual existence and which generally maintain their shape and size. But what he does not understand is that the amount of matter in any substance will remain the same in spite of such external transformations as changes of position and shape. In Piaget's language he has not attained conservation of substance.

Several experiments were used by Piaget to differentiate between children who have attained and those who have not attained conservation of substance. He also discovered that there was a transition stage. These experiments have been replicated in different forms by many other people in many parts of the world. Most of them have arrived at the same kinds of results that he arrived at.

One version of the experiments that has been replicated in many parts of Africa is the coloured liquid experiment. Two identical tumblers A and B are filled to the levels indicated in Diagram One with the same amounts of liquid. The child indicates that the amounts are the same.

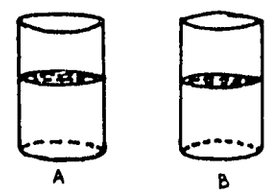


Diagram 1

Then in the presence of the child all the liquid in tumbler A is poured into tumbler C which has a narrower diameter. The experimental situation is now as indicated in Diagram Two.

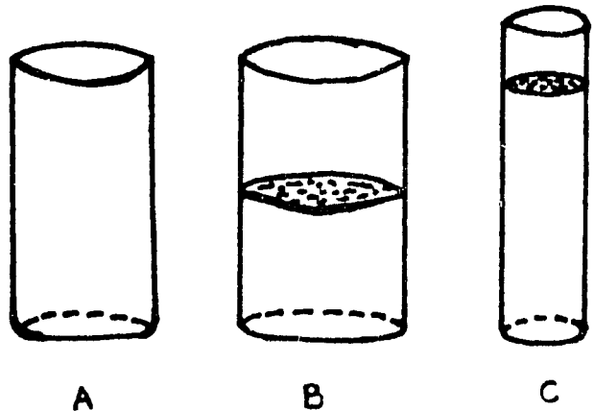


Diagram 2

If now required to compare the amounts of liquid in tumblers B and C, children at different stages of development react differently. The non-conserver would invariably respond that there is more liquid in C because the level is higher and the conserver would maintain that since the amounts of liquid were the same before the situation has not changed. The non-conserver is unable to grapple with more than one variable at a time. He concentrates his attention on one dimension; in this case level of the liquid and loses sight of the diameters of the tumblers. The conserver can manipulate more than one variable at a given time.

But there are those children in transition. This type of child may accept that the amounts are the same in Diagram Two and yet claim different amounts if a tumbler narrower than C is used or if some other experimental variable which keeps the volumes the same is introduced.

In fact evidence seems to indicate that, with respect to substance, children who are conservers in one situation may be non-conservers in another situation. For instance, a child who conserves the equality of the amounts of liquid in Diagram Two may fail to conserve if the liquid in C is poured into several smaller tumblers and he is requested to compare the total amount of liquid in these tumblers to the amount in tumblers. Alternatively, a child may conserve all through the liquid experiments and fail when asked to use a variety of tasks associated with a particular concept if we wish to assess whether or not a child has conserved that concept. But for each child there arrives a time when the abilities associated with concrete operational thought are established.

More activity is now needed to encourage the slow movement to formal operations which takes several years for many children and there is reason to believe that most children in upper primary school and lower forms in secondary have not attained formal operations. The person at the formal operational stage, you will recall from Section V of *Handbook for Teachers* (SEPA, 1974) is no longer dominated by his immediate experience. He is able to operate on hypotheses and to comprehend and handle in a systematic way the interaction of several variables. He can reason in purely abstract terms. Displacement volume, quantification of probability, proportion, curves of movement and combination of colourless liquids experiments* have all been reported as methods which the teacher could use in various combinations to tell which of his students have not attained formal operational thinking.

Also the concept of energy has been used* to differentiate between concrete and formal operational stages. Energy is the capacity to do work. Many children operating at the concrete operational stage grasp quite intuitively the concept of work because they lift things or see others lift things or have similar experiences. Such pupils grasp intuitively that muscle, fuel, wind and electricity are sources of energy. They are also able to cope with the fact that water from a waterfall is a source of energy or that in general somethings can provide energy either through movement or because of their position.

*LAVELL—Nairobi Report.

Yet this intuitive comprehension is different from that of the person who has attained formal status. His approach will be analytical and he will relate all the concepts that built up to the concept of energy. Force, mass, acceleration will not be thought of in the intuitive sense but in terms of the relationship that exists among them. The product of mass and acceleration is not an intuitive concept. Then 'work done' is viewed as the product of a force and the distance through which that force moves. Energy will then fall in place as the capacity to do work and distinctions can be made between potential and kinetic energy.

Teacher educators and teachers should therefore be aware that thinking is 'something' that develops gradually. Thus, there are qualitative differences in the responses of children at different stages of development. We should not be deceived by mere ability to verbalize. Perhaps, the surest way to ascertain whether a verbal response by a given child represents the attainment of an associated concept is to probe the response in the manner indicated in Section V of the *Handbook for Teachers.*

Chapter 11—Thinking and learning

All through this Sourcebook you have been consistently told that the general objective of science teaching is to develop " appropriate thinking processes, " and attitudes and skills. By implication, you have also been told that activities are necessary for the construction of knowledge, and that knowledge is what each person constructs about his environment. By now, you might begin to wonder about what thinking processes are considered appropriate? And how does a teacher get a child to cultivate appropriate thinking processes? The answers to these questions lie in the teacher's perception of what science is, and the reasons he believes underlie the teaching and learning of science.

A teacher may view science as the body of knowledge that has accumulated through the centuries and thus perceive his task as one of transmitting that existing or known body of information to his students. Such a teacher would emphasize the acquisition of already established concepts of science. Another teacher may view science as a way of thinking about one's environment. Such a teacher would tend to emphasize the processes that characterize science rather than the products of science.

How does a teacher arrive at a rational decision on which approach to employ? A decision can be made by considering who the learners are, the resources that are available for teaching and learning, and the teachers perception of science. In this Sourcebook the emphasis has been on the second approach. This approach has been selected because our knowledge of how children learn favours activity science; secondly, most African schools are critically short of supplies and materials, but the African environment provides a rich source of materials that can be used by the teachers; and thirdly scientific knowledge is constantly changing and therefore it is impossible to master but a fraction of what has already been discovered.

In inquiry science, appropriate thinking processes are the activities that are normally engaged in by a scientist in the process of conducting an investigation. In Section II Chapter 6, we identified six steps used in the process of scientific inquiry. Below we give a more detailed list of the processes characterizing scientific investigations:

(1) Observation
(2) Classification
(3) Communication
(4) Counting
(5) Measurement
(6) Questioning
(7) Predicting
(8) Experimenting
(9) Formulating Hypotheses

(10) Interence

(11) Making Operational Definitions

(12) Controlling and Manipulating Variables

(13) Interpreting Data

Relationship between activity and thinking

Different topics provide different kinds of thinking processes. One topic may demand more observation and classification and another may demand another set of thinking processes. One of the roles of the teacher is to be able to screen various topics in order to determine the possible thinking processes that can be learned by performing each activity. To illustrate the point that this discussion makes, an example of an activity done by a group of college students is cited below.

Investigating Termite Colonies

A group of students noticed a termite hill near their classroom and became interested in finding out more about the colony. But how was the investigation to be started? The group decided to first observe the outside of the hill without disturbing any parts of it. They observed the various features such as colour of the earth, the shape of the hill, the height, the texture of the earth that formed the hill and so on. While this activity was in progress a member of the group made a small hole (window) on the top of the hill in order to expose several nests within the hill. The nests exposed were covered with a piece of glass to allow observation of the activities of the termites. The termites seemed to avoid the area under the glass from which the top layer of dirt had been removed. More windows were made on the hill with transparent coloured cellophane to see the effect of restoring darkness on the activities of the termites. The investigators found it necessary to keep a record of their activities and observations by recording these in a notebook.

Many questions arose out of the activity such as:

(1) Why do the nests differ in shape?

(2) How do the termites build their houses?

(3) Does each worker go down into the ground to bring dirt to attach to the house?

(4) Do they like a certain shape of house and so would try to fix it back to that shape when it has been broken?

(5) Why do the termites flee from the opening?

(6) Do they avoid air or the light?

Questions like these and many others kept the group busily engaged in finding answers to these questions. Soon some answers began to come out.

The termites were blocking the windows in the similar domed shape that was destroyed. The winged castes have a strong aversion to being exposed to the open air—this is probably a negative reaction to light. Sealing off damaged tunnels left open took priority over sealing off areas covered by glass.

The method of building new layers on the hill seemed to be for several termites to approach an open space at the surface and lift up pieces of black soil over their heads which stuck together perhaps by some sticky stuff added to the dirt.

The investigation continued over a period of several days and more answers were found along with more new questions that arose out of the activity.

Commentary

Several elements of thinking were employed by the investigators during the activity:

(*a*) The investigators had to think about how to extend their powers of observations by inventing what may be called in this case a " termite scope " (the glass window). This can be likened to instruments like microscope and telescopes that aid the naked eye.

(*b*) Thinking is greatly enhanced by asking questions and questions help to guide inquiry, for example, do they avoid the air or the light?

(*c*) It is not enough to simply observe but in addition it is necessary to keep records of observations for the future, as well as to enable the same observer to compare his thinking as it becomes confirmed or changes from time to time.

(*d*) Activities need to be classified—in this case sealing damaged parts was classified as an activity different from building new layers.

(*e*) Generating hypotheses is a key element in scientific thinking. The investigators might have hypothesized that sealing off a damaged area is more important to the termites than building new tunnel. Can this hypothesis be tested? If it can then it is a good hypothesis.

(*f*) Drawing conclusions from data is not a simple process, it requires thinking of all the variables that are pertinent to the data before a conclusion can be reached. For example in the above investigation it was concluded that " winged castes have a strong aversion to the open air. " What variables do you think that the investigators must have considered in order to reach this conclusion?

The preceding discussion raised some salient points about thinking and learning, and the appropriate processes involved in scientific inquiries. Thinking involves the planning of activities. The execution of activities generates more thinking, and more thinking employs the thought processes that enable one to classify or categorize various phenomena. The categorization of events results from the searching and reflecting of activities of the mind which allow it to accommodate new concepts. Learning then may be seen as the processes whereby the mind classifies and categorizes events to enable it to accommodate new ideas into the individual's existing intellectual structures.

Chapter 12—The Cultural Context of Learning

Children are born into societies with prescribed beliefs and ways of doing things that are common to that culture or society. Some of these beliefs often conflict with already established or known scientific concepts. It is a known fact that the beliefs held by a learner may interfere with that learner's ability to assimilate new scientific concepts when these concepts conflict with an existing belief. The teacher needs to be sensitive to these conflicts and to provide evidence that will demonstrate to the learner that certain beliefs are not scientific. If the evidence provided is not sufficiently convincing a learner will merely accept the concept but will not incorporate it into his thinking pattern. Examples of these kinds of problems that have been encountered by other teachers will help to clarify how one's cultural background sometimes interferes with one's ability to assimilate a new concept.

Two college students were on holidays and had gone to their parent's farm to help them. Sellu and Abu were returning to their village from the farm when this incident happened.

The sky was getting darker. Through the trees they saw distant flashes in the sky. All of a sudden there was a crash above their heads and for an instant all round was lit up in a flash of light. Abu covered his eyes and ran under a tree very frightened. Sellu came over to join him and then the following conversation started.

Sellu: Why are you so frightened?

Abu: The thunder is so loud. It will come upon me.

Sellu: What is it that frightens you?

Abu: It might strike me to death.

Sellu: How do you know?

Abu: Once the people brought one thunder medicine man to our village to swear my brother.

Sellu: What happened to your brother?

Abu: The thunder medicine man told my brother that in the time of thunder and lightning, he would be struck to death. People sent him out of the village. They were afraid that they would be struck too—since another man had been struck to death in our village.

Sellu: But this swearing is on your brother not on you.

Abu: I am afraid that he has extended it to the whole family.

Both students returned to their training college after the holidays. That term they had to study electricity and Abu had a hard time grasping the concept. In one of their lectures, the tutor said that thunder is caused by electricity in the clouds. Abu, preoccupied with the belief that the thunder medicine man also has the ability to cause thunder raised his hand. The tutor recognized him and the following conversation took place:

Abu: I think that thunder can also be caused by the thunder medicine man.

Tutor: I know that story, and know also that lightning is very dangerous and can harm people, houses, trees and other things. But nobody can control thunder. It happens in a natural way.

Abu: Sometime ago the thunder medicine man swore at our village and subsequently one man was struck dead by thunder.

Class: Following Abu's statement, many other members contributed instances in which thunder had caused damage to people and property in their villages. (The discussion and argument that ensued convinced the tutor that this belief was pervasive among his students and that there was need to do some experiments that will demonstrate to the class that thunder was a natural event and not man-made).

Tutor: Would you like to find out how thunder happened?

Class: How?

Tutor: I think we can do that by way of experiments.

The whole class then did a series of experiments that explain:

(*a*) How thunder is formed, and

(*b*) What makes the lightning and thunder.

The discussions that followed the experiments illustrated to the tutor the need to be sensitive to the students cultural background and how a lack of this sensitivity might hamper students learning of new scientific concepts. Another example of this kind of thinking might help to buttress the fact that beliefs like these are commonly held by students.

A Student's idea about Falling Objects

At a science workshop for teacher training college tutors and students a group was working on " Energy ". One of the student participants had designed a machine that could measure impulses of objects dropped from different heights. Discussions on this machine were going on when another student called Sano presented a problem. He said that he had been told that *if a man falls from a high tree he will not hurt himself as much as if he fell from a low one.* His weight gets less as he gets further down: the further he falls, the more weight he loses.

In exploring what he had in mind with this idea, the question arose concerning people's weight decreasing as they get further from the earth. Sano raised the fact that he knew that the further people got from the earth the less their weight became until far away they became weightless. However this was not his problem.

He was asked to explain his problem again and perhaps describe an experiment which would test it. Using a lump of plasticine as an example, he explained that if the plasticine were weighed and then taken up in an aeroplane and dropped back to the earth and then weighed

again, the second weight would be less than the first. Sano took the plasticine and dropped it first from a height of one metre, then two metres, measuring the compression of the spring each time. He observed that the second compression was about double that of the first.

He paused, looked at the plasticine . . . .

" But this is like a metal "

" In what way?"

" Well it is airtight. I must find something that lets air through it. "

He looks around the workshop to find suitable material to repeat the test. In the meantime, the plasticine has holes bored through it, and is presented to Sano as an example of something that is not airtight. This was rejected by him. Instead he chose a piece of wood. When asked how this was not airtight, he replied that there were small holes in it which let air through.

He then repeated the dropping experiment with the wood. First, he dropped it from a height of one metre, then two metres. The second measurement he repeated three times. In each case the compression of the spring was greater than that at one metre height. Sano nodded his head quietly. " Yes, I am satisfied that my question is answered. "

Here again we see how the ideas a person brings to class can be firmly held, and it takes sensitivity and devotion on the part of the teacher to get a learner to substitute a previously held belief with a scientifically established concept.

For learning to occur, it is simply not enough for a teacher to expose a student to a new idea and expect that that idea will automatically be incorporated into the student's thinking. In cases where the new idea conflicts with a previously held belief, the teacher has to probe the student in order to determine the source, or sources of the belief(s) and design activities that will help the learner to verify the truth or falsity of the belief.

Using the Learners Cultural Background

It would be misleading to go with the impression that all beliefs brought to the classroom by the learner hamper learning. On the other hand a teacher needs to build on the previous experiences of the learners to enrich their thinking. Here is an example of an incident in which the teacher utilized a learner's cultural background to extend a belief into an investigation that became scientific.

A teacher had given a variety of leaves to his class to classify. The children made several different groups by using different visible criteria. However, one of the children classified all his leaves according to uses. The classification was quite elaborate: edible, non-edible, medicinal, non-medicinal, edible-medicinal, non-edible-non-medicinal, etc.

The teacher looked at this child's classification and was intrigued by it. He probed the child and learned from him that his father was a herbalist. This discussion drew the other children's attention to this classification and soon the whole class was engaged in activities on medicinal uses of leaves. Activities done by children included methods of extracting medicine by boiling, and pounding, and the determination of appropriate dossages.

4--Looking at the Environment

Chapter 13—Introduction

The environment is the starting point of learning as well as the most fruitful in terms of topics and ideas. Starting with the environment, one can go in any direction, cutting across and uniting several established disciplines to give a truly integrated science study. It is the way best suited to young children and it is the way best suited for applying science to the problem of natural resource utilization.

This section seeks to present a fresh view of how we can use the environment in teaching or training others to teach through involvement of both teachers and learners in interesting science activities.

It starts with a model that permits the choice of a strategy from a vast array of possibilities. But as these possibilities are examined it becomes apparent that they are all linked together in one conceptual network.

From this vast welter of possible alternatives it is possible to select one, treat it intensively in a manner appropriate for the level of study (in terms of background, understanding, and interest and ability), and to get a small sample of material forming the learning experiences. Chapter 16 of this section illustrates this procedure.

Chapter 17 then gives further examples and annotations on topics that can be used similarly. It should be noted that in an attempt to encourage learners to adopt this approach we should make provision for a good deal of exercise of the learner's initiative, creativity and interest.

It should always be borne in mind that this chapter is to be used not just to choose materials to be taught; but only to develop materials into (learning) experiences for the learners

Chapter 14

ALTERNATIVE APPROACHES: POLLINATION

In discussions of approaches to be adopted in the presentation of science, or in the creation of a teaching or learning situation in science education, a number of possible alternative approaches are often stated.

The thought arises as to how far these approaches are mutually exclusive. Do they perhaps represent differences not in kind, but in relative emphasis? Are they perhaps mutually compatible in the hands of a good teacher?

With this in mind, we can consider the phenomenon of pollination from the various points of view offered below:

Any approach to a topic will center around a phenomenon, theme, or concept. From the study of the phenomenon of pollination various other themes may arise for investigation, such as:

Self-pollination, reproduction, animal behaviour, animal communication, (dancing bees, vision in bees, etc.), plant breeding, fruits as human food, economic botany, plant-animal interdependence, the ecological web, and many others.

During the investigation various concepts may be formulated;

continuity, discontinuity, reproduction, heredity; evolution, growth patterns, similarity, correspondence, variability; biotic interdependence, adaptation (i.e. mutual adaptation, sex, meiosis, reproductive potential, hybridization, antigen-antibody reaction), etc.

A variety of processes must be employed as the investigation gets underway. For instance:

—hypothesis formation from time of flower opening: size and colour(s) of flower; structure of flower,

—presence of odor or scent

—verification by patient observation or experiment (controlled or not controlled);

—recording phenomenon in diverse ways: notes, simple sketches, photography, models, etc.;

—measurement of biological affinity: hybridization, chromatography, refractometry, cell culture, etc.

Bearing this in mind, consider the phenomenon of pollination from the various points of view listed below, and what each encompasses:

1. Environmental

1.1 Human dependence on pollination for fruiting, food and other economic products such as: vanilla, sweetening substitute, drugs, ornaments (e.g. perfume), etc. Disease or fatalities arising from pollen (e.g. hay-fever and other allergies)—abrin, ricin. Plant seed and fruit dispersal. The flora and dependent fauna. Ecological niche. Decrease in population of pollinators due to insecticide pollution, thus a loss of crop. Children's games with flowers.

1.2 Economy/Development: Pollination as a technique in plant breeding for better crops (for food or drugs). Perfume industry. Honey production.

1.3 Molecular with physiological study: Specificity of pollination and fertilization, physical and chemical basis of incompatibility. The chemistry of nectar and flower scents (essential oils). Mechanism of vision olfaction and flight in insects and other animal pollinators. Mechanisms of endogenous rhythms in flowers and pollinators (e.g. in nectar secretion and timing of anthesis).

1.4 Man-made systems (engineering): plant breeding; new crops; agriculture; conservation; cell fusion; patenting of new crop-plant varieties; genetic engineering. Population and food: dangers of monoculture; plant substitutes for milk, etc.

2. Operational

2.1 Descriptive: Pollination mechanisms, process of fertilization; flora and fauna; species and speciation; classification and phylogeny of plants; plant geography; plant introduction; economic botany; the terminology of pollination (etymology of terms).

2.2 Experimental/discovery: finding out the pollination mechanism of selected flowering plant species; hand-pollination; intra and inter plant breeding, in experimental study of evolution; cell fusion as tool in molecular biology (gene regulation; nucleor-cytoplasmic interactions).

2.3 Library Search: Pollination; fertilization; reproduction; History of study of reproduction, pollination, fertilization, speciation. pollination in plant-breeding and economic botany; on-going research in local institutions involving pollination (e.g. local plant-breeding stations for raising maize, beans, rice, cocoa, oil-palm, etc.)

2.4 Group project: group research (observational, experimental, library) on pollination of selected plant-species.

2.5 Oral tradition (use of): survey of observations made by children, farmers, others (e.g. as starting point in investigation of pollinations when they are most active or efficient).

2.6 Child centred/Teacher centred.

3. Material

3.1 Earth Science (Paleontology) Fossil flowers; evolution of flowers and seeds, polynology (pollen studies) and geological dating—climatic changes.
Physics and molecular architecture of pollen wall, membranes; mechanism of allergy; olfactory and visual mechanisms of pollinators; study of nectar. . . .

3.2 Life sciences; evolution and adaptation of flowers and animal pollinators (biology of pollination; applied biology of pollination) pollen allergy in medicine, pollination in a crop improvement, pollination in theoretical biology; speciation, evolution, phylogeny).

3.3 Engineering (Man-made systems) substitutes for pollination (e.g. horn pollination) in induction of fruiting. Pollination in crop-improvement. Radiation-induced mutants by irradiation of pollen. Vibrator for pollinating tomato in glass-house.

Furthermore, we list some concepts, and an illustration of each, which may arise during the investigation.

4. Minimal Basic Concepts

Concept	*Illustration*
Order	Antigen-antibody reactions
Pattern	(allergy, incompatibility)
Measurement	Genetic relationship (phylogeny)
Functional relations	Size of pollen; number of pollen grains, anthers
Estimation	Reproductive potential of a Flower
Operational relations	or plant. Flower-pollinator system as efficient design
Systems	Goal design in adaptation of pollination; mechanism and pollinator flexibility
Probability	Chanciness of pollination; reproductive potential;
Variation	Colour pattern; variation in pollination mechanisms
Conservation of energy	Nectar an energy source for bees, moths, ants.
Existence of basic forces	*See* systems
Feedback	Olfaction and vision in pollinators
Communication Models	Correspondence of flower and pollinator (one-many pollination and seed dispersal in spread of gene in population). Biotic interdependence of flowering plant.
Ecology	Species and pollinator;
Conservation	Pollen storage; conservation of germ plant
Evolution	Evolution of flower
Heredity	Flowers as mechanism of outbreeding; genetics of crop-plants
Controlled experiment	Problems of establishing pollinator
Engineering (Control of the environment)	Pollination as tool in plant breeding

After reviewing the aforementioned approaches, concepts and examples, perhaps you may ask: " Why not use a simpler selection, more fundamental examples? " " How do you decide what is the most appropriate approach? " " Could you treat other topics in this manner?

Our illustration has shown that any scientific idea, problem, or situation admits the simultaneous application of a number of the supposedly different approaches. However, the most appropriate combination of approaches for a particular topic or situation requires the exercise of judgement on the part of the teacher and the relationship of pupils and environment. As stated earlier, this illustration and alternative approaches are not given as a basis for lectures, but rather as stimuli for thought. . . .generators of ideas. This is definitely an advantage as it makes for flexibility and adaptability in teaching and learning situations.

Chapter 15—A Model for Looking at the Environment in Terms of

(*i*) Viewpoint: Static & Dynamic

(*ii*) Concepts

(*iii*) Phenomena

We are about to present a simpler way of examining a scientific problem or of generating activities. It is only a means of suggesting activities; and only one of several possible ways in which activities or questions could be stimulated.

We cannot always tell what will start a scientific activity; whether an observation, a claim by someone, a question, a dress, a problem that has arisen in the garden, kitchen, or factory. But whatever the initiating stimulus, the scientific activity may take the form of an interaction between the investigator and the world around him. In some ways science is like conversation. We cannot always tell what topics will turn up for discussion (even where the initial topic is pre-arranged) or what conclusions will result. And the conclusions may only be tentative ones, possibly in the form of an interim hypothesis, or a series of fresh questions to be answered by further observations or investigations.

(*i*) *Viewpoints*—Mankind has long observed things and phenomena in nature and has noted changes in them. In trying to explain the occurrences and changes of things and phenomena in nature he has developed concepts as tools for thinking.

In his handling of both the concepts and the phenomena there have been two viewpoints in which they have been examined or developed. These are a static and a dynamic viewpoint. The static viewpoint deals with descriptions of things and phenomena in nature as they are and forms the basis of later correlations and explanations. The dynamic viewpoint is that in which the changing patterns in nature form the starting point; and it seeks correlations, explanations and the creation of analogies and models in order to understand those changing patterns.

In order to be able to understand these viewpoints and decide whether one is using the static viewpoint, we can take a topic out of any syllabus or outline and treat it as a separate learning point for the student. Thus, if we choose a topic like insects, we would be adopting the static viewpoint if we try to write out lesson notes on what is an insect; common types of insects; insect life cycles; and so on. And then teach this to a class by " Providing activities that the students can do " with an insect like the cockroach or the grasshopper. Such an approach would be treating the subject from a static point of view. It will lack spontaneity and is likely to generate little enthusiasm or lasting interest: especially if the lessons last for only a few periods of class meetings over a short period of time.

However, we can view the same topic from a dynamic viewpoint if we allow the students to search for, observe and collect insects in their natural habitats, making careful notes of where, when and how they collected their specimens. Attention may be paid to what the insects were doing at the time of collection. The dynamic viewpoint includes the plants or animals with which the insects were associated, the form in which they occurred, the various sizes and shapes they come in, and the general external features of their bodies. Classwork will continue these observations and record-keeping as the students move on to explorations of the behaviour of the insects they have collected. Soon the question of how to keep them alive overnight or for a couple of days or even for an extended period, will crop up. This will be discussed and suggestions will be made as to what to tempt the insects with as food substances. The Dynamic viewpoint requires that they be allowed to try their own suggestions, and keep accurate records of their results. For it recognizes that there will be no failure of any trials. If the insects feed on the substances provided, then the student knows that he has found at least one correct food for the particular insects. If they do not, then the chance is that the food offered to them is probably the wrong one. Even if the insect in a particular study dies in captivity the student would have learnt at least one condition under which the specimen could be killed inadvertently.

There would naturally be several different species of insects in such a study. Comparisons can then be made of the kinds represented to lead on to the concepts of classification and if appropriate, dimorphism. But the pattern is clear now, the study will evolve out of the need to learn certain things about the insects; things that have fascinated the students. Such things usually relate the insects to their environment and also concern their relation to man. Thus questions like " Does it bite? " " Is it harmful? " will quickly arise to form the starting point of personal interest and motivation. The study will then roll on from there. All the other topics like life cycles, culture of eggs and larvae, making cages, food plants, etc. will fit into a smooth pattern. This then will be viewing insects in a dynamic way. It will be a viewpoint that sees the insects as a part of the environment. These relationships will emerge from a familiarization process with the insects and not as a topic of lecture by the teacher.

An example of this at the teacher training level is found in SEPA Handbook for teachers, entitled " Investigations with the Ant Lion ", pp 15-25, 1974. At the primary school level there are two examples. One, for the lower primary level is "The Sensitive Plant" and the second, for upper Primary level is " Juba Beach " both in the *Handbook for Teachers*, Section IV. " Unawajua (Do you know them?) " is of course the actual example chosen to illustrate the viewpoint. See Handbook, pp 189-208.

Any point of view that we find convenient to adopt is a viewpoint worth considering. By way of further illustration, let us consider for example the study of leaves or a particular leaf.

In our example of the leaf, one simple viewpoint is that which asks:

What is the shape of the leaf?
What is its colour?
What texture is it?
What is its structure?
How many are there on a plant?

These are useful questions but they appear not to tell a moving story. They adopt a static viewpoint. They tell us the state of the object of interest.

We can, on the other hand, ask: How does the length of the leaf change over time? i.e. how does the leaf grow in length? This will require us to study the length of the leaf perhaps on successive days, and compare the series of lengths in a suitable way--most probably we will plot a graph of the leaf lengths in a suitable way against time. This will tell us a story: how the leaf grows. Immediately an aspect of the behaviour of the leaf will be revealed. It may become possible to tell whether the leaf grows steadily, whether it starts slowly and then accelerates, whether it goes through a cycle of growth, rest, growth. . . . .

This other viewpoint is characterized by

(*i*) inclusion of the static viewpoint as a component, with the aspect of interest

(*ii*) comparison

(*iii*) criterion of comparison or dimension

Thus, we compare, over time—i.e. on successive days, the length of the leaf. The aspect of the leaf we chose was length (and we could have chosen breadth or the relation of breadth to length, i.e. shape). We compared successive lengths. We were thus considering the dimension of time. We studied the change in length of the leaf over time. And a story emerged. This latter point of view that incorporates a study of change over time or space, or over any particular dimensions, is the dynamic viewpoint. Its essence is continued comparison along some dimensions.

Two further viewpoints are worth consideration.

Serious scientific study aims at understanding, which embraces knowledge of the phenomenon in all its manifestations, as well as an appreciation of the internal processes or component reactions of the phenomenon, its causal aspects, how objects displaying the phenomenon react or respond to various factors: in a word, the description of the phenomenon and an understanding of its causal basis.

Technology includes the scientific study of a phenomenon, but goes on in particular to its exploitation or use for specific purposes.

Thus an understanding of the physiological processes underlying food storage in a crop plant, wheat, potato or cassava for example, constitutes a scientific study. The full exploitation of this knowledge, together with an understanding of suitable varieties for a particular region, times of planting, irrigation, machines for harvesting, suitable storage systems, etc., constitute the technology of agriculture.

These two viewpoints of understanding (science), on the one hand, control and use (technology), on the other, are two faces of the same coin of human curiosity and exploration. One feeds the other. Problems arising in technology lead to new scientific investigations which in turn may lead to improvements or innovations in technology.

(*ii*) *Concepts.* The idea of an insect may, at first be confusing as learners mistake spiders, scorpions and even millipedes for insects. But in time, as they learn from observations the true characteristic of insects, the ideas become firmly planted in their minds.

This is the way concepts are best learned or introduced to learners. This way allows a definition to arise out of descriptions of observations made during a familiarization process between subject and learner. It is agreed that this way produces the most lasting effects in the memory and the deepest understanding in the mind of the learner.

Thus a whole curriculum can be organised around the theme of " The Environment " using certain key concepts in science.

When we have pondered over phenomena and related ideas and experimented with them, observed them, possibly exploited them in various ways, or our thinking on them lead us to some ideas—call them distilled or powerful ideas—that we particularly find recurrently useful as aids to our thinking or as helps in summarising information or processes relating to the phenomena, or helps in further investigating the phenomena. These ideas form what are called concepts.

We may be studying a leaf from its first appearance as a tiny protrusion to its eventual fall off from the parent stem. If we get interested in the expansion of the leaf, we may talk of its growth and all the fine processes that may sustain the growth and functioning of the leaf. Should we be particularly interested in the greeness of the leaf we may get absorbed in the study of the chlorophyll in the leaf and the process of photosynthesis by which the leaf stores energy from the sun in suitable form for the plant to use—and for us humans also to feed on or burn. We may thus from the object, the green leaf, arrive at such concepts as:

growth of the leaf
differentiation of cell types and tissues of the leaf
photosynthesis
Stomatal movement
transpiration
adaptations and modifications of the leaf or water plants or desert plants
senescence
vegetative propagation by leaf cuttings
leaf changes indicative of diseases or mineral deficiencies
leaves in human nutrition

Whatever the starting phenomenon, we could arrive, in our searches at a host of distilled ideas or concepts.

With concepts (or even in the concepts of concepts) we may list other useful ideas

(*i*) further questions that occur to us

(*ii*) inventions, tools, machines, technologies that are based upon the phenomena we have studied.

It is useful to explore for a moment these things: symbols, concepts, inventions, methods, designs, plans, equipment, machines, factories, etc.

They fall into two groups:

(*i*) the intangible, ideas

(*ii*) concrete objects, devises, with defined purposes, goals.

Some, like symbols, methods, designs, blue-prints, have goals or purposes although they are intangible.

All of them are worth studying and using.

(*iii*) *Phenomena in the model*

The use of concepts in designing science activities as learning situations for students will necessarily lead to a consideration of natural phenomena which in turn can be new starting points for major explorations. The nuptial flight of termites is one such phenomenon which might arise from a consideration of " Insects " or " Reproduction ". . . Like the concept, phenomena can also form the basis of a construction of a whole set of science curricula materials that view the subject in a dynamic way.

We may describe as phenomena whatever objects we find around us—existing in our world, or whatever events take place in our world. In short, phenomena are whatever we can observe in our world. Thus a cloud together with any other things that look like clouds to us—perhaps the steam pouring out of a kettle, and the processes leading to its formation may be a phenomenon of interest to me or to a meteorologist. Similarly lightning and the processes leading to its occurrence or its effects, may be the phenomena of interest. The growth of a baby, the growth of a leaf, or the change in the course of a river could equally be the phenomenon of interest.

We may thus look on phenomena as generating concepts, further questions, and technologies through scientific and technological research or activities.

But it is not a one way process. It is a cyclic process. A set of phenomena may lead to certain concepts and activities. These in their turn may generate new phenomena. And so the cycle continues, with scientific knowledge growing and renewing itself.

Throughout our investigation, however, we need to consider various frames of reference. Treatment of this topic within the model should include units dealing with measurement of time, size, distance, shape, strength, etc. There should also be treatment of the relationship of different measures to one's understanding of observed phenomena.

To illustrate this, consider the two very basic frames of references given below, time and size:

TIME

Related Phenomena

Changes in a day	morning, noon, evening, night, activities at different times of day.
Seasonal changes in	temperature, appearances of plants and animals; people's activities during different times of year. (When they go to work, return from work, times for market, products at market.)

Apparent motion of sun as a measure of time; apparent motion and position of stars.

Measuring time	Use of events (e.g. the time it takes to cook certain meals for foods; time it takes to boil water).
Using distances to measure time	walking, running, riding a bicycle, both means.
Using other means	clocks, hour glasses; beats or periods (heart beat, pendulums, etc.)

Related Concepts

Type and rate of change provide feeling of time.

Time changes affect people's activities.

Related Activities

Children can demonstrate and describe various ways that have been used to measure time. Some activities are:

1. Light a candle; cover it with a transparent jar until the candle light goes out. Remove the jar and light the candle again, make sure it now has only ordinary air instead of 'burnt candle air'. Children can guess how long it will take to put the candle light out using the jar. They can face away from the candle and raise their hands when they think the candle light is out.

2. Children develop other ways of timing the candle light, e.g. using sinking tins, pendulums, making clocks that measure minutes, and other activities.

Related Readings

APSP Units: Measuring Time (Parts I and II);

Chima Makes a Clock;

Measurement

Pendulums

SIZE

Related Phenomena

Different lengths of time units;

Various children have different sizes of feet, hands, etc.

The school has different sizes of rooms;

There are different sizes of other things like tools, farms, gardens, homes, villages, cars and so on.

Related Concepts

Size is expressed in a variety of ways—e.g. linear distance, capacity; weight, and so on.

There are always differences in measurement taken by different people; experimental error.

Scaling, projection

Units used provide a frame of reference.

Chapter 16—Illustration of the Use of the Model

e.g. Growth as a Topic

In order to allow learning experiences to develop in this way the teacher will need to have certain conditions fulfilled beforehand or at the same time. She will need to do some background reading on the subject—concept or phenomenon—and will concentrate particularly upon those aspects that will provide questions leading to activities for learners to perform.

She will anticipate some of those activities and will make notes of some of the standard techniques and methods employed in performing these activities.

She will then make a list of reference sources to which she will direct the students' readings.

It should always be borne in mind that this section refers purely to preparation by the teacher for guiding students when they are actively engaged in building up experiences that will enable them to learn science in the way scientists do. It is assumed that the teacher already has these experiences and only wishes to revise her knowledge and refresh her memory, not to memorize facts and procedures for lecture and demonstration. If she does not have enough of the basic experiences then she would need to go through the relevant portions of the Handbook in order to develop and enrich her experiences to the point where she develops enough confidence to handle a class in the way recommended here.

The temptation to read up and lecture, adding only the token demonstrations or even the carefully selected activities for the learners to perform, should always be resisted. Over the years experience has shown that this method does not produce the sorts of permanent effects desired. It is for this reason that it must be eschewed.

Rather, the intention is to create for the students initial learning situations that will enable them to view their subject as part of an everchanging scenery in nature. They should be encouraged to observe the changes as they occur and to study on their own one or more lines of change. The above model can be used constructively for just this purpose. The following illustration will make this clear. We shall consider the concept of growth from a dynamic viewpoint.

To begin with, there is the background reading to be done. Its purpose is to look at the concept now from a teaching point of view; to ask oneself the question " How best can I introduce this subject so that it catches on and every student plunges enthusiastically into activities that will give them all a deep understanding of growth suitable for their level of study? "Even if the background reading does not provide any new information, it will certainly help to reveal fresh relationships between the varied experiences as the central concept is held in focus. This leads quite often to a decision to choose introductory activities for investigating the concept.

As you review your own experiences with the concept of growth you will quickly realise that growth is a concept in biology. So you may turn to some biology books to look up what they say about growth. You will then make some notes to the effect that growth is a kind of positive change in an object.

Growth is increase—the opposite of decrease, depletion, diminution. For some system to grow another system will be diminished. This is the everchanging pattern.

If you have practised with the SEPA Handbook you would have had a very varied set of experiences with the study of growth. Your first question is " which of these will best introduce the study in a dynamic way? "

First, you recognize that growth is a complex concept. It can be understood only after concepts of length, (height), size, weight, mass, (and changes in them) have been grasped. This is at an elementary level. At a higher level, further concepts like feeding, digestion, assimilation, metabolism, etc. have to be mastered for a real grasping of the growth concept. Therefore depending on the level for which you wish to design the lessons, you may wish to do some background reading on some of these concepts. For young children you will need to introduce newly germinated seedlings or even seeds which they themselves will germinate. The increase in length of the seedlings can be measured with a ruler and recorded from day to day. At the end of a week a bargraph will show clearly the idea of the growth of the seedlings.

Once this decision is made the important question of how to start the students off in a way that will generate enthusiasm for the study now has to be tackled.

One easy approach is to find out where they are to start with. For instance, you can raise the question " What are some of the things that we know can grow? "

A variety of answers have often resulted from such a question. Such for instance are the following:

—a boy's hair grows after being trimmed
—weeds grow again after weeding
—grass grows after mowing
—finger nails and toe nails grow out again after being pared
—puppies, chicks, kids, lambs all grow into dogs, chickens, goats and sheep
—seedlings grow into shrubs and trees
—children grow into adults

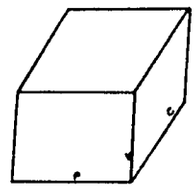
Then what else can grow? How about a village, a city, a school, the moon, daddies, pebbles, rivers? Can they grow? How can we find out?

Next, what happens when things grow? Let's find out with a few things. We can start with the germinated seedlings. How can we tell whether they grow? How can we tell by how much they grow?

These are questions that at once suggest activities. It would be interesting and rewarding to go on thinking of further questions that can suggest activities relating to growth or that illustrate the concept of growth. The answers that the students have given already touch upon phenomena like seedlings extending in length or height, mounds or piles of pebbles getting bigger by addition of more pebbles, and so on, till we come to daddies getting fatter so that their suits get tight.

What the model does is to help us relate in a systematic way the unfolding of the concept by examining these phenomena in situations that are varied, interesting and exciting. In this way a pattern of changes, or even some patterns emerge which are all co-ordinated and combined in the concept of growth.

This can be represented in a three-dimensional diagram as follows: where C represents the axis of concept, V that of viewpoint and P that of phenomena being examined and measured.



Growth: Extensions of the example used above:

Outline: *Related Concepts:* Measurement; Increase; Length; Mass; Time; Population; Rate; Ratio; Area; Volume; Size.
Activities for various levels of students
Techniques and Methods
Measuring and Recording Growth

While investigating the concept of growth and phenomena related to or involved in growth, the child will encounter problems such as measurement of growth, e.g. how to measure the growth of a flower or various parts of the flower; how to measure size, population, volume, area, or even determine the rate of growth. These, to name a few, are concepts which will easily and naturally develop from the study of growth.

Various activities can be designed to incorporate these concepts into the study of growth. Some activities for children of lower primary are:

(*i*) Piling up pebbles: the mound grows bigger, higher.
(*ii*) Inflating a baloon: it grows bigger.
(*iii*) Lining up match-sticks: the line grows longer.
(*iv*) Heaping up grains of sand, rice, etc., on a balance pan; the heap grows heavier.

Thus, the child sees that growth results in things becoming longer, or taller, wider, heavier, or even more numerous.

As the child enters upper primary, he will be able to relate to growth in a more specific manner. For example, consider the following activities for upper primary:

(*i*) Measuring how long the line of match-sticks gets.

(*ii*) Measuring how high the mound of pebbles or wet sand gets as an example of growth in height

(*iii*) Measuring how fast the level of water rises in a glass cylinder, jar, or bottle when water is added in drops—a slow increase; rate of growth

(*iv*) Measuring how heavy the heaps of sand get as more sand is added slowly—rate of growth

(*v*) Measuring how fast a bean seedling grows in height;

(*vi*) Measuring growth in area of leaves of seedlings

Activities for still older children are:

(*i*) Estimating growth of populations of towns, or of protozoa in culture

(*ii*) Weighing caterpillars

(*iii*) Measuring growth of moth or butterfly caterpillars feeding on two different food plants—relative rates of growth

(*iv*) Comparing rates of growth of bean and maize seedlings growing in the same pot;

(*v*) Measuring growth rates of marked leaves on the same branch;

(*vi*) Estimating a real increase of fungus growing in agar in a petri dish;

(*vii*) Considering what factors determine the growth rate, for instance,
the effect of
light on growth of seedlings
some salts on growth of plants, e.g. bean
absence of some salts on corn growth
vitamins on children's growth by library search
graphing the population growth of the city;
comparing the growth of the children in the school by age-weight and age-height relationships.

(*viii*) Discovering various methods of illustrating growth:
—a graph of population growth of a city, town or village
—growth of children in school, i.e. considering age-weight and age-height relationships.

Methods and Techniques

For simple measurement of

(1) *growth in length:* a metre ruler will suffice for activities like lining up match-sticks on a table and measuring the length;

(2) *area of leaf:* hold the leaf and paper together with a paper clip and trace the leaf on a piece of paper;

(3) *volume of water in a cylinder:* use a graduated cylinder or make your own by attaching a piece of graph paper to the outside of the container;

(4) *the rate of growth:* a measurement of length can be taken over a period of time. The time element can be measured by use of a pendulum, a water or stop-clock, or by just counting the days.

In order to measure and record growth, observe the following:

(1) Growth in length is measured by taking the length at the start, waiting for a convenient time, and taking the length again. Thus, for a young plant

Length at start	11 cm
Length after 3 days	16 cm
change (*increase*) in length	16—11 = 5 cm

Hence, plant growth at that point is 5 cm in 3 days

The same procedure is used to determine growth in height, width or girth*

(2) Similarly, one can determine the growth in weight: take the weight at the start (say, 6 gm) and again at the end (say, 8 gm). Thus, the growth of weight in that time will be

8—6 gm — 2 gm.

(3) Rate of growth implies measuring two different parameters— increase in size and increase in time. The increase in size divided by the increase in time will give the *rate of growth in unit time.* The increase is size for example:

starting time: 0 day starting length: 10 cm

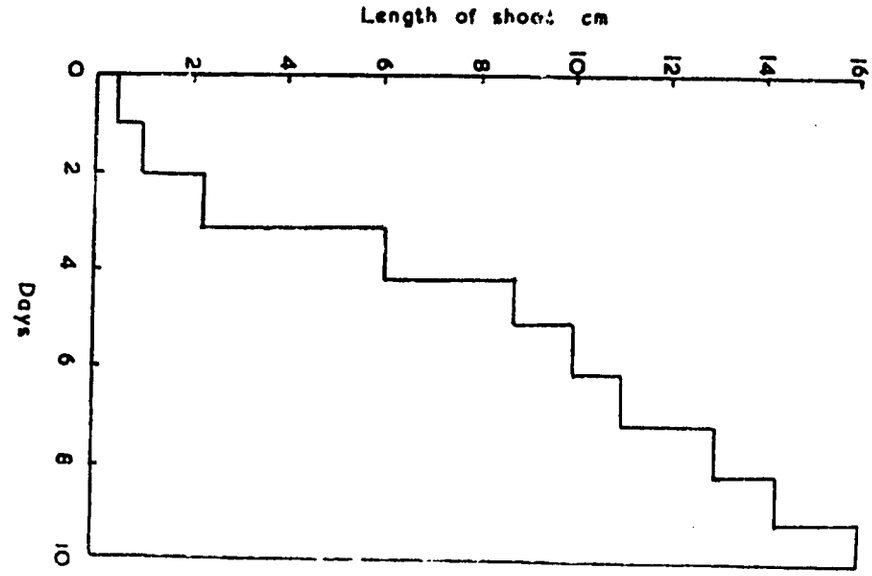
final time: 2nd day final length: 13 cm

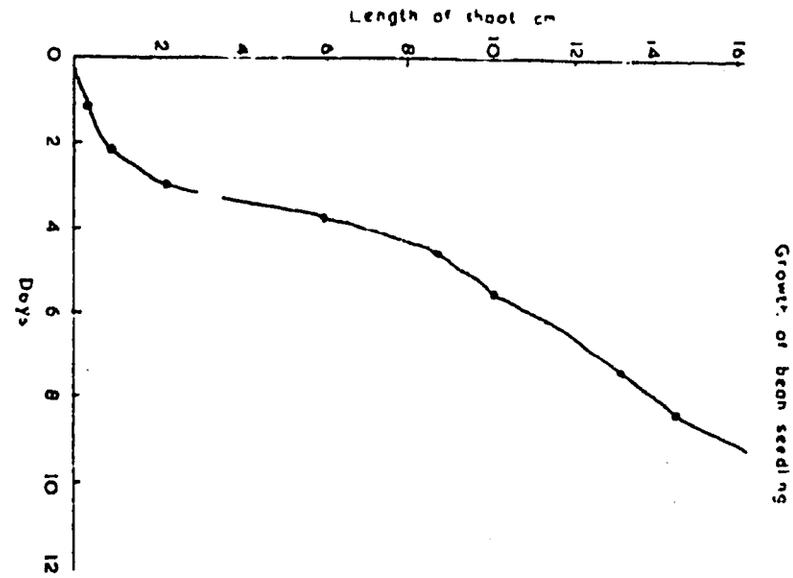
increase in time: 2—0=2 days

increase in length: 13—10 cm=3 cm

$$\text{Rate of growth } \left(\frac{3 \text{ cm.}}{2 \text{ days}}\right) = 1.5 \text{ cm a day}$$

(4) An easy way to illustrate growth at a glance is to use a graph such as the one given below.





Growth of bean seedling

(5) *For measuring growth of populations in a culture:* The Handbook gives procedures for culturing fruit-flies and fungi. The population of fruit-flies will be constant, but the individual larvae will grow in length and weight. The weights of 10 individual samples can be measured at intervals of 24 hours.

(6) For the fungi, the growth of individual colonies spreading over the surface of the agar will be given by estimating the area on graph paper.

This same technique can be used for tracing and estimating the growth of young leaves that have been marked for identification on a plant.

(7) For studying and measuring the effect of light on seedling growth, comparable seedlings are chosen such that they are similar in size and health (in appearance). Initial sizes are measured in height (cm) and one set is placed in the dark while the other set is placed in full light. After a day or two, their respective heights are measured again. Thus, the difference, or amount of growth, is obtained by substraction as shown above.

Needless to say, these are only a few methods and techniques that could be utilized in the activities listed above. However, more information on measurement can be found in the chapter " Mathematics as a Tool for Science " Section V Chapter 19. You may find these methods useful in the treatment of other topics as well.

Chapter 17—The Market as a Resource for Learning Science

In looking at the environment, one aspect that all children can relate to is the market. It is there that an abundance of information can be gathered, phenomena observed and curiousity generated. On a visit to the market a child will readily notice vegetables such as onions, pepper, okra, rice, garden eggs, groundnuts, tomatoes, etc., vegetable leaves like cassava leaves, potatoe leaves, green and the like. They will notice women selling palm oil, groundnut oil, coconut oil, etc. And of course, there will be fish, meat and various fruits for sale.

With so many possible avenues to explore a whole year could be spent investigating various concepts and phenomena related to the market.

Related Concepts:

Quantities or *measures* of palm oil, garri, beans, etc.;
How *profits* are determined (last price)
How oils are extracted? (oil extraction)
How do you cook potato leaves, cassava leaves, etc.? (cooking)
What are the different *varieties of rice* found in the market?
How often does each variety *yield* each year?
What foodstuffs sell faster than others and why?

Related Phenomena:

How long does it take rice to grow?
How are rice fields cultivated?
What measures must be taken to cultivate pepper, okra, cucumbers, yam, cassava, etc.?
Crop rotation, various species of fish?
Various uses for oil?

Below we list some activities for the market excursion and experiences that might result from the excursion.

Activity 1—What kinds of items can be found in the market?

Upon visiting a market have the children notice what things are being sold in the market —*viz.* onions, rice, pepper, fish, meat, cassava leaves, potato leaves, oranges, pawpaw, mangoes, salt, soap, etc., Have them determine which items always can be found in the market and which ones occur by season?

After this exercise the teacher can then evaluate the various areas of interest the students have and expand upon these. For example, Activities 2, 3, 4 and 5 are suggestions of such an expansion on their market excursion.

Activity 2—What various kinds of fish can be found in the market? Snapper, Barracuta, Sole, Groupa, Shinose, Lady, Bonga, Minnows.

After taking specimens of each have students list characteristics of each kind and then have them compare the differences. What features are similar. This can lead into discussions on bone structure, life span, mating habits, nutritional value, etc., of fish.

Activity 3—What different ways do we use palm oil?

By talking with the local women, children can discover several uses for palm oil. Among these will be the preparation of cassava leaves, potato leaves, stews, fried fish and soap.

Some students may want to investigate the processes of making soap as the people do locally from wood ash, ash from green plantain peels and cocoa pods. They may also discover that wood ash is used to drive away insect larvae which are harmful to potato and garden egg leaves. They can also experiment by using different oils in the preparation of soap.

Other students may want to investigate using palm oil for cooking. This activity can be used to utilize many of the other items seen in the market.

Activity 4—How is palm oil extracted?

The pupils could extract the oil themselves from the palm kernel. Then they may possibly want to visit an oil mill to compare their method of extraction with that of the oil mill. They may also want to compare this process with the processes for extracting coconut oil, groundnut oil, etc.

Activity 5—Various varieties of rice?

Have the children plant various varieties of rice that are found in the market. Let them compare their growth rates. This is an excellent opportunity to integrate science and mathematics with a practical application. The children could follow the growth of the plants and decide which variety will yield more. Which variety would be more profitable for the farmer to use.

Common Substances e.g. Wood, Metal, Rock

The basis of activity-oriented approach to the learning of science requires learners to be actively engaged in knowing more about their environment. Among other things, in the African environment are common substances that could be used as starting points in the learning of science.

Common substances have been chosen simply because they tend to have greater impact on children as a result of constant interaction. Secondly, common substances in the environment generate interest when children make conscious effort to learn more about them.

Thus topics on substances such as wood, metal and rock have been used as examples of how teachers can develop activities on common substances in the environment using the model discussed above.

Metals

Metals are common objects in the lives of everyone nowadays and they have become ubiquitous as man has spread over the globe. In the home, along the paths, on highways and by river's edge there are often pieces of metal or large cables of them carried on tall poles. Metal ships anchor at the harbours, metal towers broadcast the waves that come to our radio receivers. The antennas of these as well as their inner parts are made of metal.

So indeed are the pins and needles, the cups, spoons, pots and pans that are so necessary for providing us with sustenance and comfortable living. Indeed, the metals have entered into our bodies artificially as fillings or patches for teeth; and naturally as part of the make up of blood and other tissues.

Thus whichever way we try to look at the topic we find that we are closely linked to metals. It may thus form a natural point of departure from the wonder state into the "let's find out" state of viewing science. Thereupon the concept of metals takes on an ever widening character which anyone can begin to trace with a little effort and reflection.

Related Concept:

Solids; non-metals; oxidation; reduction; solution; electropositivity; conduction; thermal expansion; magnetism; electricity; metal fatigue, smelting; welding; alloys.

Related Phenomena:

Telephone cables carried on tall poles; a man on a bicycle along the path; a tinsmith at work; a blacksmith at the forge; welders making window frames; a local motor-mechanic's shop.

Activities:

Activity 1—Various kinds of metals

Some common metals: Iron, Copper, Zinc, Tin, Aluminium, Silver, Gold, Platinum, Lead, Chromium, Nickel.

Their colour, hardness, reaction with acids; Test with dilute acids (HCl, HNO_3 H_2SO_4)—with citric acid.

Using various sources like coins (copper, nickel, silver), nail (iron), cans (tin), cigarette wrappers (aluminium); roofing sheets (zinc); Record various uses to which they are put e.g. copper: electric and telephone cables; coins; car radiators, hot water pipes, etc.

Activity 2—Why some metals are preferred to others

Test for hardness: can lead be used to make a nail? What are the uses of soft metals? What are mixtures of metals; the precious metals and the story of Archimedes findings—a library study. Why are they precious?

Can iron be used as a battery plate? (or electrode)?

Metals that resist rusting; How can we find out which metals resist rusting, corrosion by acids and alkalis? Cleaning old metal-ware.

What properties will make a metal good for use as wire or electric cable? What properties will make a metal suitable for use as window or door frames?

Aircraft frames?
Tractors?
Railway tracks?
Brooches, Jewelry?
Cutlery?
Kitchen utensils?

Activity 3—Effect of heat on metals

Thermal conduction and expansion. Hold one end of a piece of metal about 30 cm long and place the other end over a flame. After a while you are forced to let go. The heat has been conducted to the other end of the metal.

Using an iron ring and ball investigate the thermal expansion phenomenon by heating the ring and letting the ball pass through. If you do not have the ring and ball try placing two irons rods end to end on suitable supports such that only a thin gap is left between them. Let wooden blocks at each end stop them from moving away from each other. Then put a flame under each rod and watch the gap between them. Do you see why there are such gaps along railway tracks ?

Activity 4—Solid and liquid metals

Obtain a piece of solder and heat it over the same flame as an iron rod. Do they behave in the same way?

The solder melts and turns into liquid and flows; but the iron does not. The " melting point " of the iron is higher, it needs more heating to make it melt.

On the other hand there's mercury, another metal that is normally in liquid form, and does not need heating to make it flow.

Exploratory activities with these metals could deal with soldering pieces of tin and other metals together to make useful items, e.g. alcohol burner, electric cables to battery terminals, etc.

For high-melting point metals for use at high temperatures soldering has proved unsuitable, so welding is used. But activities here may be limited initially to observation and discussion. The same flame which is used in welding metals together has been used also to cut through metals.

Activity 5 — Metals in solution: Electroplating

The wet battery is an example of the use of metals in solution. One can be made with a dilute acid (usually sulphuric acid), a copper plate and a zinc plate.

One metal can in certain situations drive out another metal from solution. This is the basis of electroplating. A piece of brass is electroplated with a layer of copper in a solution (electrolytes) of acid and copper sulphate. The brass is used as the cathode (positive pole) and a copper rod is used as the anode (negative pole). The arrangement is called a voltameter.

In nickel plating lead can be substituted for nickel as the anode and it will drive the nickel out of solution to plate a strip of copper at the cathode.

We can try either of these two arrangements to discover what are the best conditions for achieving a lasting result.

Activity 6 — Alloys in daily use

Solder, which was used in activity 4, is an alloy of tin and lead. You can make it by melting some tin and lead over a bunsen burner in the ratio of 1:1 by weight.

There are other alloys that it may be possible to try as well. Such for instance, is the electric fuse alloy which consists of lead, tin and bismuth in the proportion by weight of 17:5:2.5.

For other alloys you will need a furnace. African craftsmen have been making them for centuries as is seen in the bronze figures, brass trays and other art work in the markets.

Bronze is made from copper, tin and zinc in the ratio by weight of 80:5:15; and brass is obtained by changing the ratios to 72:4:24 which gives hard brass for casting figurines; or by leaving out the tin component and altering the proportions to 58 copper to 15 zinc.

Many interesting results are obtained in trying to produce these alloys.

Rocks

If we take a look at our environment we can find that almost everywhere there is soil and children play and do all sorts of things with the soil. One question that one can ask is, What is soil made of? Where do the particles of soil come from?

In answer to these questions, we may take a look at rocks: How they are formed and their interactions with other things around. Thus we may think of certain phenomena related to rocks. These are: weathering, with its accompanied chemical reactions of dissolved mineral and gases on rocks; Erosion: that may be caused by wind and moving water; Recycling of rocks and formation, etc.

In attempting to explain these phenomena, related concepts may rise, for which we may devise activities to enable pupils to appreciate their meaning.

Thus the topic ' Rock ' can be expanded in terms of related phenomena, concepts and suggested activities that pupils can carry out in this way.

Related Concepts

Related concepts arising from these phenomena are

Mineral
Weathering
Force
Expansion and Contraction
Fossils
Sedimentation, etc.

Related Phenomena

Some of the related phenomena may be:

Weathering—Chemical reactions of dissolved minerals and gases on rocks.
—Expansion and contraction of rocks due heating and cooling.

Erosion —Due to wind
—Due to moving water

Rock formation and reformation (Cycling of rock particles)

Changes in features of rocks

Other interactions.

Activity 1—Examining Rocks

(*a*) Pupils may collect and identify pieces of rocks in their school compound or somewhere else. What differences in structure do they observe?

(*b*) Pupils may dig pieces of rocks and find out how deep some of these are in the soil.

(*c*) They may weigh the different pieces.

(*d*) Pupils may break the rocks into smaller pieces. They may try to grind the smaller pieces into powder.

Activity 2—Comparing the powdered rock with sand

(*a*) Pupils may collect sand and compare the sizes of the particles of sand with those of the powdered rock. What is contained in the sand that may not be in the powdered rock.

(*b*) They may collect different types of soil and examine them with hand-lenses.
Note the differences and similarities between the different types. In what ways are the samples of soil different from the powdered rock?
What must be added to the powdered rock to look like any of the samples of soil?

Activity 3—Sedimentation

(*a*) Pupils may add water to the samples of soil and the powdered rock and let them stand for some time. They may note the layers of sediments in each container.

(*b*) Pupils may look out for any type of rock with layers. Compare the layers.

Activity 4—Rock formation

(*a*) Pupils may make bricks from the soil samples. (They may also use the powdered rock in the same way.)

(*b*) They may make bricks using mixtures of
(*i*) two soil samples
(*ii*) three soil samples
(The mixtures can be in different proportions).

(*c*) Pupils may burn some of the bricks and dry some in the sun. How can we tell when the bricks are well dried? What differences occur between the two ways of drying?

(*d*) In answering the question in activity 4 (*c*) the pupils will keep weighing the bricks, record the weights until they get constant weight from four or five different weighings.

Activity 5—Observing hardness in rocks.

Pupils may test the strength of the bricks in the following ways:

(*a*) Dropping each one from a height onto a hard surface

(*b*) Dropping a piece of heavy object from a height onto each brick.

(*c*) Splitting them by hammering a wedge into each of them.

In each case, pupils may take note of the mixtures that make a ' hard ' bricks. Compare these with the pieces of rocks broken in activity 1 (*d*).

Activity 6—Action of water on rocks (erosion)

(*a*) Pupils may put water by drop on the bricks at one palce and observe what happens.

(*b*) They may keep water running over the surface of the bricks and observe the effect.

(*c*) They may observe rocks on the sea shore or in the bed of stream.

Activity 7—Action of heating and cooling on rocks (weathering)

(*a*) Pupils may put sample of pieces of rocks in fire for say an hour and drop them suddenly in cold water and observe what happens.

(*b*) They can do this several times and then try breaking them into pieces as in activity 1 (*d*). What do they notice?

Activities like these can be devised to enable pupils to understand other phenomena related to what have been discussed before.

THE HOME

As a natural starting point for study few topics equal the home. It is something that everyone is familiar with, has some intimate knowledge of, is interested in and can talk about.

There is variety in the transactions taking place at home, so that the topic can be worked for long without inducing boredom or being worked out.

No matter what point we wish to start from, be it mathematics or numeracy, reading, social studies, creative writing, or science, the topic provides a valuable mine of starters and points of illustration. Here we shall look briefly at just a few of these to outline concepts that are related to home in a moving, dynamic viewpoint that opens up a vista of promising explorations in the world of science.

Concept: **Home**

Related concepts: Food, Nutrition, Sanitation, Hygiene, Fuel, Heating, Cooling, Family, Overcrowding, Health, Calories, Metabolism, Malnutrition.

Related Phenomena

Preparation of food; woman cooking (over charcoal or wood fire, gas fire, electric stove); food lying exposed to houseflies, (balanced) diet being served to a family (at table); child showing evidence of vitamin deficiency, e.g. Kwashiorkor.

Fire burning in compound, or inside house for heating; women carrying bundles of firewood home; washing;

Activities for lower primary

Collecting and naming samples of food items that contain mainly starch or sugar, mainly meat substance, mainly oil or fat, e.g. corn, cassava, yam, beans, sweet potato, sorghum, groundnut, palm oil, fish, beef, sausage, egg.

Observing how food items change on cooking.

Investigating with wood ash

—how much dissolves

—what is the residue

—is solution acid/sour or soapy?

—can we make our own soap?

Using a thermometer.

Constructing a thermometer.

Outline of further activities (for upper classes).

1. Determining the nature of food substances in an evening meal
   —Test for carbohydrates in bread, rice, yam, foofoo, corn, etc.
   —Test for protein in beans, fish, meat, egg;
   —Test for fats and oils.

2. Calculating the amount of energy (calories) taken in the food each day.

3. Determining the rate of digestion of a piece of bread by salivary juice:
   (*a*) in the mouth
   (*b*) in a test-tube.

4. Determining amount of heat given off in burning
   —1 kg firewood
   —1 kg charcoal

Estimating fuel use/needs for the home, village, city country; effect of forestry.

5. Investigations with wood ash
   —Acid or basic
   —What is pH ?
   —Using flower-juice/cabbage juice indicator—to show neutralisation
   —Making soap
   —Phosphate to the garden soil.

6. Culturing microbes found in the atmosphere, the breath, housefly's feet; agar culture.

7. Studying child-health and records of malnutrition.

8. Determining amount of water used each day in the home, in the classroom. Estimating water needs of community per day, per month, per year. Estimating water resources for the community:
   —reservoirs
   —lakes
   —rivers
   —rainfall
   —watershed

9. Constructing a balanced diet for family of six for breakfast and dinner, giving quantities and cost per month.

10. Determine effect of woodash solution on growth of phytoplankton in culture; phosphate pollution.

Methods and Techniques

1. Testing for classes of food substances: *see* tests in Section VI.

2. Rate of digestion of starch by salivary enzyme:
   —In the mouth the bread is chewed until all becomes sweet and practically liquid.
   —In the test-tube the mashed up bread (same as was chewed) is mixed with saliva and allowed to stand in warm water (38° C). It is tested for starch by adding a drop on a glass plate and mixing with a drop of iodine. Blue-black colour indicates starch present. Digestion is complete when starch absent.

3. Determining amount of heat given off in burning: The idea is to heat down quantities of water from room temperature to a final temperature reached when all the firewood or charcoal has been burnt. Usually we weigh the fuel before and after burning, and make sure too much of the water does not evaporate. It is best to have plenty of water so that the final temperature does not reach the boiling point.

   It is also advisable to protect the fire from wind action that would dissipate too much of the heat. Calculation of heat involved is as follows:

Initial temperature of water	25°C
Final temperature	85°C
Quantity of water	30 kg
Heat absorbed	30 x 60 kilocals
Initial weight of wood	2 kg
Final weight of wood	1.1 kg

   Weight of wood burnt 0.9 kg

   Energy given off in burning 1 kg wood:

   Kilocals

$$\frac{30 \times 60}{0.9} \quad 2000 \text{ kilocals.}$$

You can achieve greater accuracy if you take into account the heat absorbed by the container as well. But the calculations become a little more complex.

FERMENTATION

For a topic like this our model would include sub-topics like yeast, palm-wine, alcohols, vinegar, acids and bases; and the chemistry that these would lead to. Along another line of ideas would be respiration, carbondioxide, other break-down products of simple sugars, gases and so on to a study of the physics of gases. Still another line would take us to bread, baking, foods and so on. All these we can represent diagrammatically in a flow chart as has been suggested before.

Fermentation is a process that was used for a very long period before it was even slightly understood. In fact it was only during the last century that it was studied in a systematic way and its details gradually worked out in the first half of this century.

From earliest times fermentation had been associated with the making of food and wine. Fermented grain has been used to make various kinds of dishes which in some parts of Africa are popularly called *fufu* and *kenkey*. The leavened bread which is so widely used nowadays is made by a process of carefully controlled fermentation.

But the greatest skill in controlling fermentaion is seen in the making of wines. Indeed, it was the need for making better quality wines that led to the systematic study of the process by the French scientists last century. The task was given to the famous scientist Pasteur who had earlier established the microbes as the causal agents of infection. The studies of the Pasteur group led others to take an interest in the process of fermentation and it was later discovered that the process is linked with respiration.

Related Concepts

Some of the concepts related to that of fermentation are respiration, microbes, growth, metabolism, nutrition, acidity, pH.

Related Phenomena

Some of the related phenomena then would be a man tapping a palm tree for palm wine; a woman preparing the fufu for the evening meal; bakers kneading the dough for bread; and people sipping wine at a restaurant.

Anyone of these can form the starting point of activities in science if we would just ask some of the right questions about these phenomena. These need be only simple questions to start with—such as, " can we make fufu from cassava, or kenkey from maize? What will happen if we allow some palm wine in a bottle to ferment for about three days? How can we tell what gas is given off? " and so on. A few of these activities are given below.

Activity 1: Growing yeast

(*a*) From baker's yeast; can we grow a culture of yeast from baker's yeast? What does yeast look like under a microscope? Let us prepare some culture medium and innoculate it with some baker's yeast. (Instructions for preparing culture medium are given in Section IV). Then let us examine a drop on a slide under the microscope and draw samples of the yeast cells. What parts can be made out? Suppose we add a little dye solution to the slide—just one drop? What happens?

(*b*) If we can arrange to get some fresh palm-wine we can then collect some of the dregs. If a drop of this is examined under a microscope yeast cells can be discerned rather like those from baker's yeast.

These can then be grown in the same way as before.

(*c*) When the culture is growing well, sub-cultures can be prepared from them. It is possible, with these sub-cultures, to investigate some of the conditions that are necessary for good, healthy growth of the yeast.

Activity 2: Tracking down the organisms that ferment corn or maize

Having collected and cultured the organisms that ferment palm-wine we can try to collect and culture and identify those that ferment corn or cassava in a similar way. What are the necessary steps to go about doing this? Is grinding, grating or pounding a first step? How soon does the gas begin to bubble through? How long does it take for the organisms to grow in sufficient numbers for a collection to be made for culturing? Can a quantity of these micro organisms be examined under the microscope? Do they look like yeast? Try to culture them in the same medium used before.

Activity 3: Measuring fermentation rate at room temperature

If you are making fruit wine by fermentation it would be necessary for you to know how rapidly the fermentation process is taking place so that you can stop it at the required time.

The question then is how to measure fermentation rate at room temperatures? There are about three indices we can use to determine fermentation rate, namely:

—the amount of sugar used up,

—the amount of alcohol produced,

—the amount of gas evolved,

all in unit time.

Can you design a method for determining any one of these? Standard methods are given in Section VI.

Activity 4: Collecting and identifying the gas evolved during fermentation.

This activity derives directly from activity 3. Already, if the third alternative in activity 3 has been adopted, a method for collecting the gas would have been used. (*See* Section VI).

The next step would be to identify the gas; that is, to determine its nature and composition. For this certain tests are carried out on the gas so collected. It may, for instance, be tested with a glowing or burning splint. Does it burn more brightly or does it go out? It may be bubbled through lime water, (which can be made from burnt shells, if it is not otherwise available). Does the gas make the lime water cloudy? If collected in a cylinder does the gas expand out and become dispersed in the atmosphere or does it tend to sink to the bottom of the cylinder?

Activity 5: Determining the effect of bubbling air through a fermenting system

If you have been performing some of the above activities you would have had cause to wonder whether it is necessary to keep air out of the fermenting system in order to get the best results as quickly as possible.

One way in which to test this possibility is to try and bubble air through growing yeast in culture and measure the rate of fermentation. Activity 3 has already shown you how to measure the fermentation rate. Now, it is necessary to set up two sets of cultures. In one set no gas is bubbled through.

For instructions on how to bubble clean air through a culture see Section VI. Having done the experiment what can you derive from it as regards the following questions?

Does the passage of air through the system increase or decrease the rate of fermentation? Is air good or bad to be let into the system if you were fermenting fruit or corn? What lesson is to be learned by a wine industry.?

Activity 6: Making palm wine or other fruit wine

At this stage you would be in a good position to make wine from fruit of any kind, with a clear understanding of the processes going on in the system. What would you do to obtain wine from the fruit? Would it be necessary to add anything else? Set up one such system/preparation and allow it to ferment for a few days.

Try setting up another such preparation but add some baker's yeast to it. Examine both of them later. Which gives the stronger wine?

Try repeating the set-up, this time, adding some cane sugar to the preparation. What happens later? What would you say were the best conditions for making—

(*a*) dry wine

(*b*) Sweet wine

Activity 7: Making vinegar from citrus fruits (orange, lemon, grapefruit)

When a system is allowed to go too far in fermentation it is noticed that the alcohol itself begins to change into something else.

Try setting up one such system using fruits of the citrus family, like oranges, lemons, grapefruit. You may add some baker's yeast to get results fairly rapidly.

How long does it take for the odour to change to that of vinegar. Is the product all vinegar? Suppose you leave it for another week, will it continue to change still further? Try that and see.

How would you get pure vinegar out of it?

THE SCHOOL GARDEN, FARM (SHAMBA)

Garden (Vegetable or ornamental) and outline

Obvious starters:

Light	Is garden uniformly exposed to sunlight?
Water	How much falls in garden: are parts moist, others dry? Seasonal variation —effects on
Soil	Slope of land, position as regards insolation; soil type, properties, variation in garden; animal inhabitants of soil and their effects on soil (e.g. earthworm, termites)
Animals	In soil, around garden generally (snails, moth and butterfly larvae, moths, bees, birds): their activities.
Plants	Microscopic ones, large-herbs, shrubs, trees. Animals associated with these e.g. animals on tree bank, in tree cocoa visiting flowers.
Man	Activity in garden; what items does man put into garden; what does he take or get out of garden?

Concepts associated with garden

Life cycles of living things in garden; interdependence of living things in garden; growth; modes of nutrition: autotrophic versus heterotrophic organisms; (free living, saprophytes, parasites), weeds and their control; seasonal variation in plant and animal life; diseases of plants and their control; controlled experiments.

Possible Activities

Construction of the garden· possible special areas—vegetable garden, ornamental garden, pond, bird table, butterfly garden, potted plants.

Construction of vivarium, aquarium, etc. Tracing of life cycles of living things in garden. Tracing daily activity (movements, feeding sounds, etc.) of animals in garden.

Establishing seasonal changes in garden. Finding food of animals in garden.

Constructing herbarium and animal museum of all the living things (e.g. illustrating stores of life cycle and nest of animal). Raising products (decorative flowers, fruits, rooted cuttings) for use in home and school or for sale.

Practice of garden techniques: pruning, budding and grafting, making compost, rooting plants, layering.

Practice of field zoology: observing animal behaviour, making animals react to a stimulus; testing ideas in garden: e.g. does plant X grow well in shade or sunlight; does wood ash keep away termites without injuring the plants.

Characterising plants of the garden: e.g. as regards lighting, soil moisture, drainage, wind action, relative humidity.

Useful Instruments

Pickaxe, shovel, hand-shovel, handfork, penknife, ruler or tape measure, binoculars, handlens, watch, labels.

Useful References

Forest and Savana

IRVINE, F. R.: 1952 *West African Botany*, Oxford University Press

IRVINE, F. R.: 1934 *West African Agriculture: Soils and Crops*. Oxford University Press, London England

JEX-BLAKE, A. J.: 1957: *Gardening in East Africa:* A Practical Handbook, Longmans. Green & Co., London, New York, Toronto

West African Nature Series: On Birds, Butterflies

MACMILLAN, H. F., 1935: *Tropical Planting and Gardening*, Macmillan, London

Ecosystems: Air, Land, Water

The Concept of an ecosystem

Consider a township with its surrounding, farming, villages: people, plants and animals here are interdependent for food, shelter, possibly care, etc. All the animals and the human beings depend on the green plants of the area, whether wild plants or cultivated plants.

These plants in turn depend on the soil and the sunlight that falls on the area. Any area with its own characteristics set of interdependent and interacting entities, some living, some non-living, is called an ecosystem. Think of other ecosystems, and in each case, list the non-living and the living components. Also list pairs of the components and note in what ways one member of the pair depends on the other, or how the two interact—i.e. influence each other. Two aspects in which the interdependence of components of an ecosystem may easily be studied are—

food

shelter

Direct observation may disclose these.

These patient observations may show animals feeding on various parts of a plant, animals feeding on other animals, etc. (e.g. bees and ants collecting pollen from flowers of plant, sucking nectar from flowers; birds and lizards feeding on ants or butterflies; bigger birds e.g. hawk, feeding on smaller birds.

Possible questions to answer in relation to food are

1. What other animals depend on the primary producer (the green plant that first traps the sun's energy and stores it as plant material?)
2. What quantities are consumed?
3. Are preferences shown by the consumer?
4. Is there seasonal variation in the abundance or quality of the food and in the abundance of the consumers?

Every effort must be made to measure the rate of consumption as far as possible.

Parts of the food involving the action of micro-organisms way not be visible, but may, all the same, be demonstrated: satisfaction, fermentation may be detected by side effects such as smells, evolution of gases, growth of a layer of decay moulds and bacteria or oxygen in the medium.

Parts of the ecosystems may be imitated in the classroom or garden, e.g.

(*i*) termites may be kept in a termitarium

(*ii*) an aquarium (with submerged green plants and fish)

(*iii*) pests of stored foods may be observed in a suitable bottle or cage.

(*iv*) decay of leaves in moist soil (in classroom or garden)

(*v*) colonisation of a freshly exposed substratum (bread, milk, bare patch in the garden, etc.)

(*vi*) population growth

Extension to man. Food webs or lines indicating dependence should be followed as far as possible to man. Also the effects of man's activities on all components of the ecosystem should be studied, and, as far as possible, measured and evaluated. Suitable demonstrations of man's effort are—

(*i*) describe soils, making gully in erosion possible. Compare with less erosion on lawns, forest areas, or sides of railway track with protective plants (e.g. lemon grass)

(*ii*) dams, large artificial ponds

(*iii*) Factories that pour out effluents into the atmosphere (smoke), into rivers or ponds, spent oil from car repair shops or oil on beaches

(*iv*) deforestation. Can the forest be regenerated? How?

(*v*) modern crop production with fertilizers—are there any undesirable side effects? Do the fertilizers wash out into any ponds, and what happens then? Or with herbicides and pesticides.

Concepts under ecosystem

Environment, ecology, system, food web, primary producer, consumer, feedback, interaction, cycling, recycling, fluctuation in population size, resource, pollution, conservation, balance.

Some useful references

HOPKINS, B. 1965 *Heinemann Educational Book Ltd. London.*

OLANIYAN, C. I. O.: 1968 *Introduction to West African Animal Ecology. Heinemann London and Ibadan.*

OWEN, D. F.: 1966: *Animal Ecology in Tropical Africa, Oliver and Boyd,* Edinburgh and London

Air

In dealing with an ecosystem like air, it is necessary to understand its reality. Thus we may start with a question like: How do we detect the presence of air? What pieces of evidence do we find to make us believe that air is real?

In thinking about this, a number of concepts related to air come to mind. These are concepts of Pressure, Volume, Force, Density, Bouyance, Air Currents, Expansion and Contraction, Mass and Dissolution, Ventilation.

Related to these concepts are phenomena such as children flying kites, fanning charcoal fire, man using air in respiration, using air in wind instruments, air being used to drive a wind mill, filling fountain pen with ink, and drinking coca-cola with a straw.

Possible Activities

Activities that may be carried out to enable pupils to understand these concepts and their related phenomena have been listed below.

Activity 1: Detecting the presence of air

(*a*) Pupils may fan themselves and describe what they feel. Is there any difference in their feelings when they fan faster than before?

(*b*) Let pupils try filling a tumbler with water by pushing the tumbler up-side-down straight into the water. What do they observe when a piece of cloth or paper is tucked at the bottom of the tumbler before it is pushed into the water? What is in the tumbler that prevents the water entering? What happens when the tumbler is filled while it is still under the water?

(*c*) Let them try to fill a coca-cola bottle using a funnel that will sit right around mouth of the bottle. What do they observe when they raise the funnel a little?

(*d*) What is observed when small pieces of paper are thrown up?

(*e*) Let pupils tie one side of cover cloth round the waist and hold the opposite corners up and run with them. What difference do they notice when running with the cloth and without the cloth? Or let them run with an open umbrella held horizontally behind them.

Activity 2: Filling things with air

(*a*) Let the pupils inflate balloons and football bladder. How do the balloons feel before and after they are inflated? What happens when they are inflated more and more?

(*b*) What do we find when we fill an "empty" container with water? Pupils may try out filling a milk tin through one hole and observe what happens at the other hole. What else do they notice when one hole is closed and an attempt ismadeto fill it through the other?

(*c*) Activity 1 (*b*) can be carried out again here to find out how the tumbler gets filled.

Activity 3: Air can push things

(*a*) How can we use air to push objects? Pupils may try this out by making a model wind mill and observing how the airworks it. What happens when the wind blows stronger?

(*b*) They may try making light objects move by pumping air onto them.

(*c*) Let pupils try lifting heavy objects by placing them on a football bladder and inflating the bladder.

(*d*) Pupils can also make paper propellers and run around with them to find out how they are worked by the air. What changes occur when they run faster?

(*e*) Let pupils fly kites and observe the tension in the string attached to the kite. What happens when the length of the string is increased? A spring balance may be used to measure the tension in the string.

Activity 4: Air helps burning

(*a*) Let pupils make some charcoal fire in two different pots, fan one and leave the other and observe what happens.

(*b*) Pupils can light candle sticks and cover them with tumbler. They may note what happens and the time it takes to happen. What do they observe when they use tumblers of different sizes? They may tabulate the time for each tumbler and find out the relationship between the time and the size of the tumbler.

Activity 5: Air can support things (Bouyancy)

(*a*) Let pupils make paper gliders and throw them into the air, note the time taken for the gliders to come down to the ground.

(*b*) Pupils may perform *Activity 3* (*e*) again but this time they can let go the string attached to the kite and measure the time it will take to come to the ground.

(*c*) Pupils may also throw a piece of stone or log from a height to the ground and note the time taken to fall. What difference will be noticed when the log or piece of stone is tied to the handle of an open umbrella and dropped from that height? Activity 1 (*d*) can be done again to reinforce the idea of the supporting capacity of air.

Activity 6: Any drinkable liquid

(*a*) Let pupils take in any drinkable liquid through straw and describe what they do before they feel the liquid in their mouths. What would happen when the end of the straw in the liquid is pressed to the bottom of the container when sucking?

(*b*) Let pupils fill fountain pens with ink and compare the processes with those in (*a*). What actually happens when the lever is raised?

(*c*) Pupils may wet the inside of rubber suckers and press them over a smooth flat surface. What happens when the sucker is pressed? Compare the processes with those in (*a*) and (*b*) above.

Related Phenomena

Women and children carrying water from the stream; women fishing in the river; heavy clouds in the sky; hunters bringing home an antelope killed in the hunt; nests of weave birds hanging from a palm tree. Sunset over the savanna, exposed rock on a hillside; termite mounds along the path; animal foot-prints; wild flowers in bloom; sunbeams through the forest canopy; squirrels racing off into the bush.

Activities

Activity 1: Exploring the countryside

This will include observing and collecting samples of plants, animals, rocks, water in the area.

Initially a general look at the area noting vegetation, common plants; trees, shrubs, grasses, herbs, collection of samples of these for pressing and drying; identifying.

Then the insects and lizards which are the most common visible animals are noted, identified as far as possible.

Activity 2: Collecting and identifying animals; relating them to their habitats and associated objects or plants:

This is a systematic study arising from the preliminary explorations above. Here a particular group of animals is concentrated upon, e.g. millipedes, frogs, or butterflies.

Notes are made of

—the type of habitat; grassland, low bush, forest, river bank, river bed; under litter, below soil level.

—the particular objects they are associated with; trees, leaves, under boulders, or fallen logs; other animals.

—the condition in which they were found: feeding, coiled up; resting on rock, leaf or trunk of tree, shrub, etc. lying dormant, swimming, etc.; hunting or escaping from predators, forging, etc.

—how the animals live in their natural environment; in groups, individually, in organized colonies.

—population density in the area.

Activity 3: Studies in Aquaria

These could be undertaken even with aquaria made out of cartons and heavy plastic (*see* unit on Tilapia). The steps include constructing an aquarium or/and setting up an aquarium with water plants; stocking it with fish.

Introducing water snails to keep down algal growth.

Observing and recording behaviour of fish, e.g.

—male/female behaviour, courtship, mating, spawning, parental care;

—male/male and female/female behaviour, observing eggs, hatching, growth of young; studying growth rate of young by sampling the population.

Activity 4: Animals in the Wild

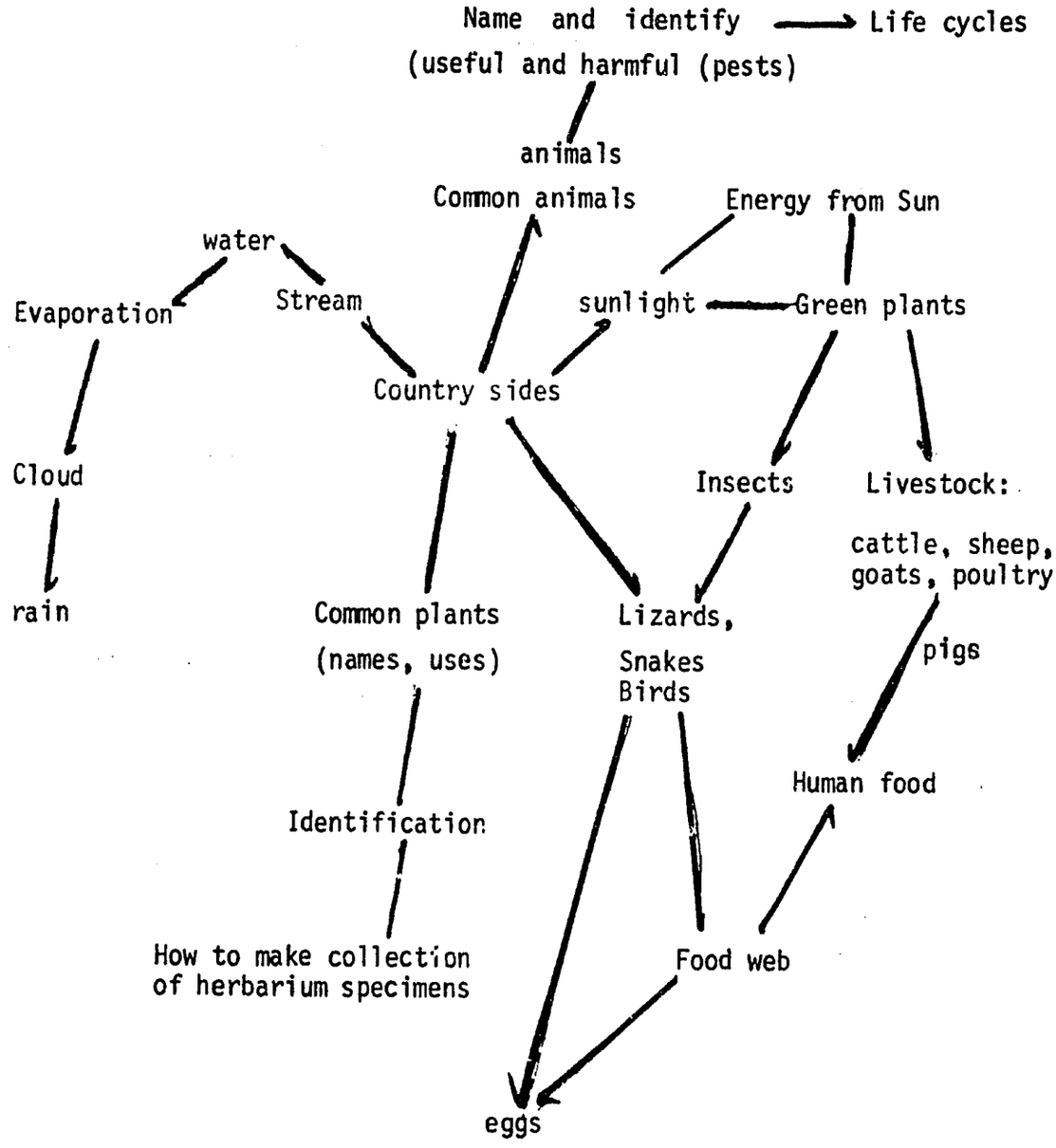
This could take the form of studies of

—a termite colony;

—an ant colony:

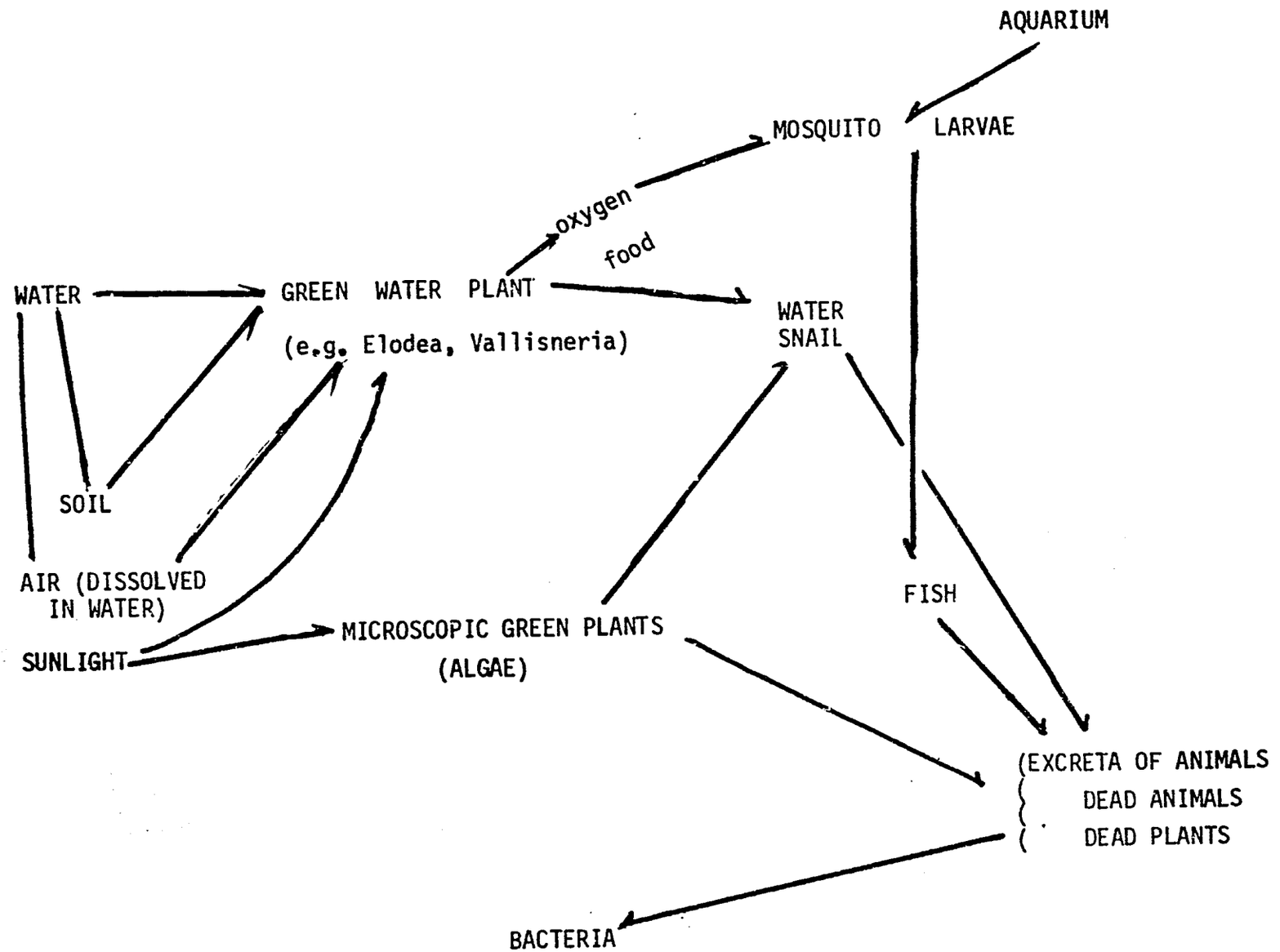
—spiders, woodroach, etc.

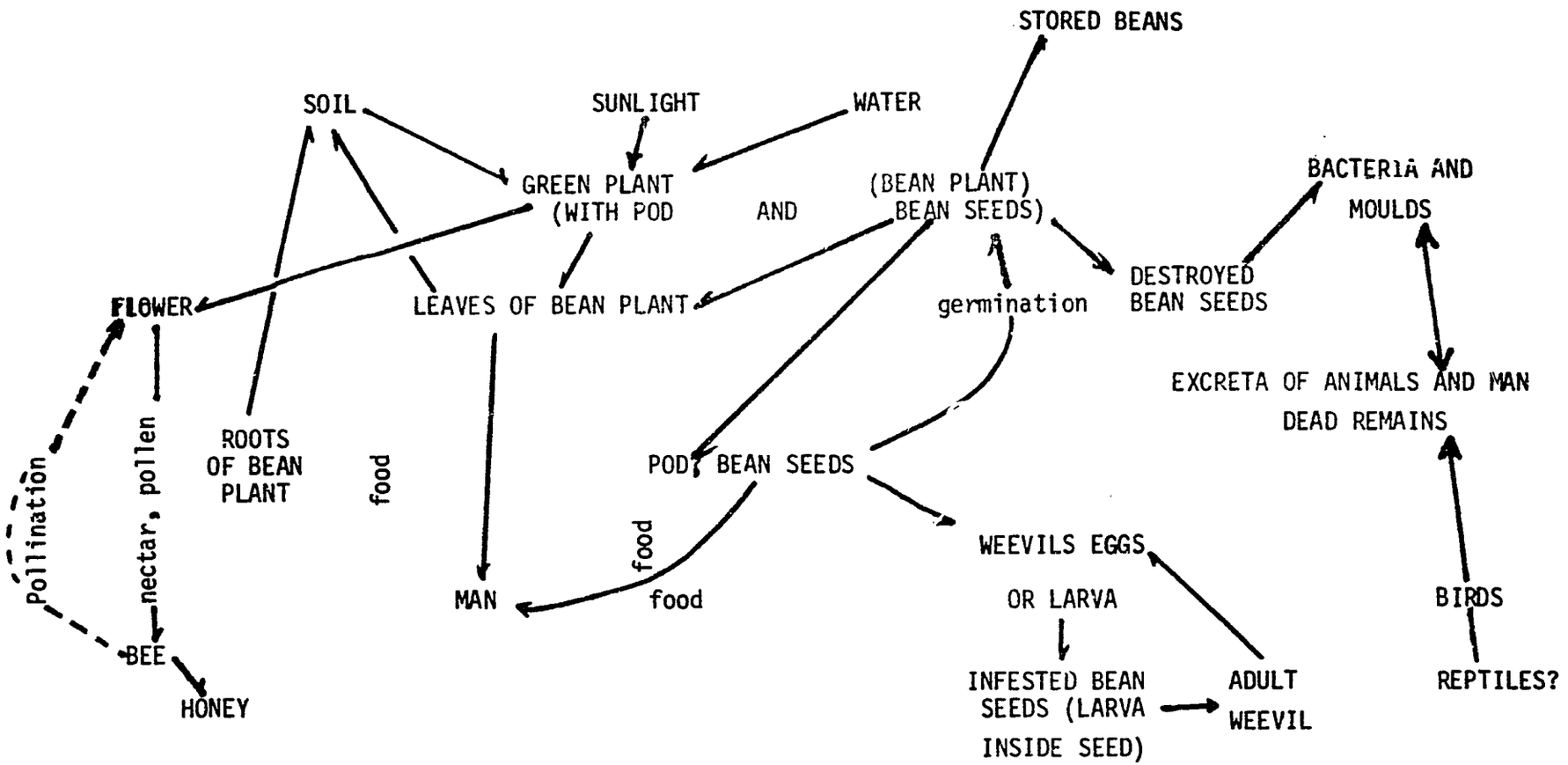
(vii) Countrysides is useful starting point for lower primary.



Related Concepts:

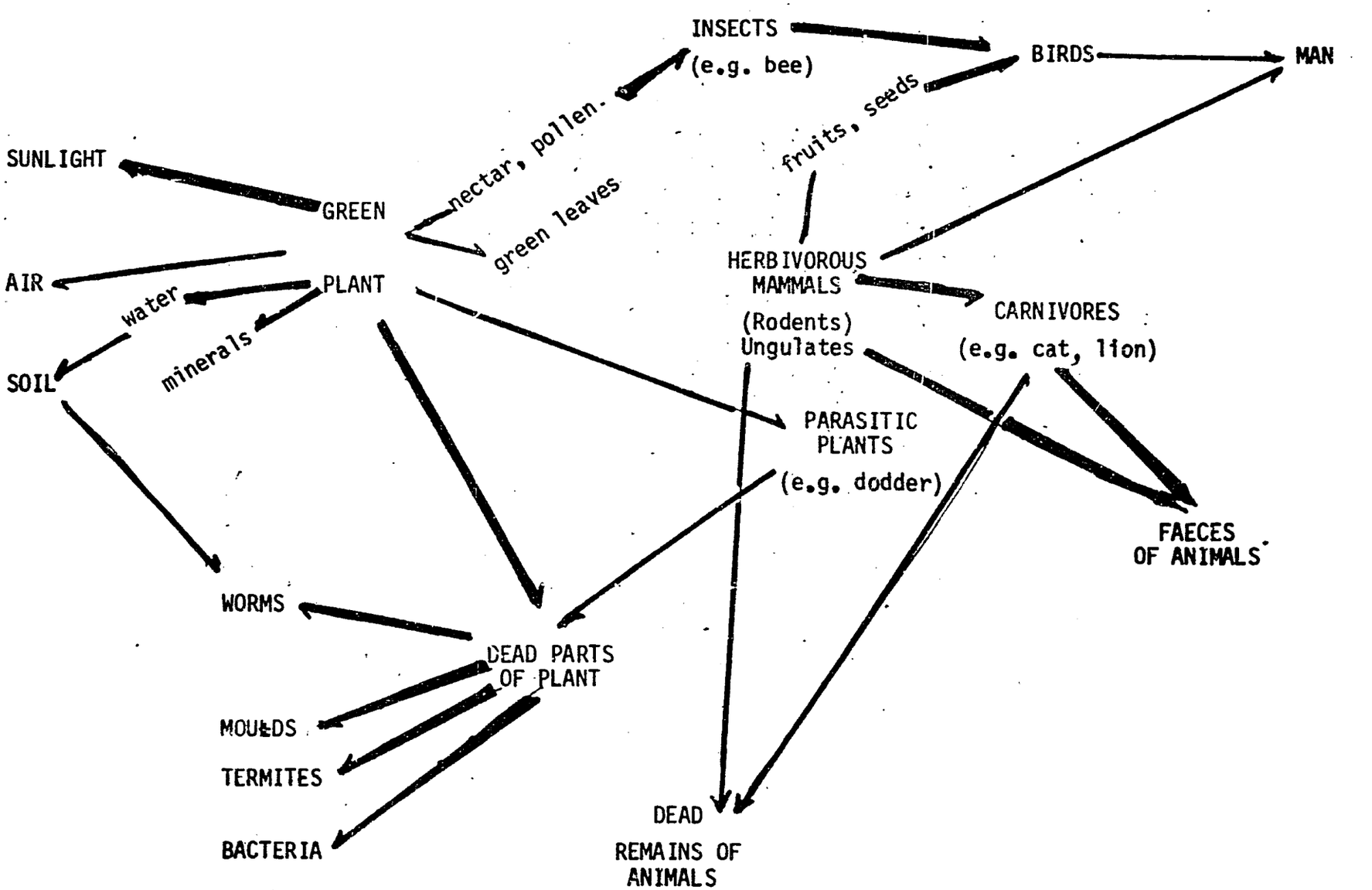
Nature, environment, sky, savanna, forest, sunlight, evaporation, animals, plants, life cycles, predators, food web, erosion, conservation, ecology, habitat, radiation, pollution.


AQUARIUM
MOSQUITO LARVAE
oxygen
food
WATER
GREEN WATER PLANT
(e.g. Elodea, Vallisneria)
WATER SNAIL
SOIL
AIR (DISSOLVED IN WATER)
SUNLIGHT
MICROSCOPIC GREEN PLANTS (ALGAE)
FISH
(EXCRETA OF ANIMALS
DEAD ANIMALS
DEAD PLANTS
BACTERIA



influence, not part of food web

FOREST OR SAVANNA



along the lines of observations on

—how many forms of individual's, there are
—how many different populations
—how to tell the sexes
—what they feed on
—what feeds on them
—the nests—of what composed, its pattern of construction, etc.

Activity 5: Cryptozoic Forms (those that shun exposure to day light)

Many soil animals are in this group.

They can be obtained for study by taking samples of soil and either softening them or treating them in a funnel under strong light.

The different kinds of animals can be recorded for each kind of soil, thus, e.g.

Nature of Soils	*Kinds of Animals*	*Number of kinds*
Moist Loam	Earthworms, millepedes	10
Dry, Sandy	Crickets, anti-lions	10
Wet Clay		
Dry Laterite		
Wet Laterite		
Dry Loam		
Wet Sandy		

Collection of seeds of various kinds

—seed coatings, pods.
—variation in number and kinds of seeds in pods.
—germination of seeds
—optimum conditions for germination

POLLINATION

FIRST ACTIVITIES WITH FLOWERS

BY

E. LAING

This is an example of a topic written up from the guidelines given here.

CONTENTS

Note to Parent or Teacher

Why?

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To Kofi, Efua and Kwamena

Note to Parent or Teacher

You may wonder what the aim of this guide is. As to method or approach, it is simply to induce the child to try out things to see what happens, to put his ideas to the test of experiment—he would thus discover a few things for himself and increase his confidence in his own ability to explore the world around him and to reason about what he finds. As to facts, the basic vital information he will acquire is a knowledge about the two important parts of the flower, the pollen (the male cells), and the ovules (that will become seeds) in the ovary. He will learn that the transfer of pollen by various agents to the stigma is important in the reproduction of many plants, especially many that we use for food or other purposes. If, after he has played with a few flowers he attempts pollinating and comes to appreciate from his own attempts that pollination may lead to seed formation, my efforts will have been amply rewarded. I will be happier still if he goes on next to making pollination a means of further exploration, for example to find out what happens when two varieties that differ in flower colour are crossed—what flower colour is displayed by the next generation?

Your role will be one of a supporter and instigator: keep asking the child: how, when, what, where, why? Remind him to sketch (in his own simple way) the shape of the flower, what he did, what happened, what insect he found at the flower, what it was doing, etc. If he is able to do so, let him count and measure as well and note his results. From time to time let him repeat an experiment to see whether he gets consistent results. Most important let him *compare*, for example, pollinated flowers versus unpollinated, or pollinated immediately flower opened versus pollinated when the flower was closing, or self-pollinated versus cross-pollinated. Encourage him to select what to compare. He will then be well on his way to getting his own answers to questions he puts to nature.

The child requires next to nothing by way of equipment for these activities. He would find a hand lens useful but not essential.

In the early stages he should find large flowers easier to handle than tiny ones. He may also find it easier to work with those produced in large numbers or those that fruit profusely.

Why?

Why this little guide? It is to help you in your first steps at finding out for yourself by putting questions to nature. In so doing, you may come to learn some standard names of parts or processes of the plant. To help you in this, there are notes at the end of this guide. You may also come to know some facts. This is also useful. But these are not the primary aim of this work. The primary aim is to encourage you to find out answers to questions which you yourself put to nature. You will find that there is no end to the questions you can ask. You will have very good friends in the five questions: Where? When? How? Why? What? Keep using them, and look for answers in the responses or replies from your experiments and observations.

I have chosen a part of the plant, the flower, and a process, pollination, which are important in the reproduction of the plant. Reproduction is how the plant or a living thing makes more individuals like itself—how one plant forms many seeds which can give rise to many other individuals like the parent plant.

This process of reproduction is very interesting in itself: and the biologists are still finding new things about it. It is also a process that the plant-breeder uses in making new varieties of plants, perhaps by crossing the two that he has already. It is quite possible that in your own activities you will produce a new variety which nobody has seen before, and which may be useful as a decorative plant or as a new variety of a crop plant.

Notes

As you may try out many things at the same time, it is useful for you to make notes to remind you of your original questions, what you did, how you did it, what you found and what it means—and, very often, what new questions strike you.

Thus you may have to label a flower. You can make small tags (jewel tags) out of pieces of string and cardboard. See figure Note on the tag what you did to the flower and the date (and sometimes the time of day—if you think it matters). An example of a note on such a label is ' selfed 20/12/74 ', to remind you that you self-pollinated the particular flower on the given date. Should you write in ink or pencil? Decide for yourself by comparing these. You may find both biro ink and pencil equally useful. You should however look out when your label touches the ground or gets moist, as various animals (termites, snails—can you find others?) may eat up your label.

In some cases you may be able to write directly on a part of the flower that will not be lost during the development of the fruit. I have written with biro on the green corolla tube of *Crinum glaucum* or the ovary of *Crinum ornatum* in this way.

You should make simple, brief notes in your notebook. It is essential that you note down whatever you do immediately you do it, or whatever you find, rather than hope you will remember it later. Leave your mind free to think out what results mean or to think up new questions or experiments.

Examples of entries in a notebook are:

1.	20.12.74	6.15 a.m.	honeybees at flower of Crinum Ornatum D. collecting pollen;
2.	20.12.74	7.00 a.m.	6 flowers of *Crinum Ornatum* F pollinated with pollen from *Crinum ornatum* H.

From time to time you may wish to follow the growth in size of a flower as it develops, or an inflorescence (the bunch of flowers) or a fruit. You may find it useful to measure the length with a ruler at the same time on successive days, and to plot a graph of your results, of length on the y axis, and time on the x axis.

Another useful way of recording your observations is by simple well-labelled sketches or drawings. You can add further notes indicating the scale of your drawing, or other interesting features such as colour changes, presence of animals, smell, change in position of stigma, etc. There is almost no limit to what you can put down in your notes: whatever you find which you think interesting can be put down. As time goes on, you will be able to decide which findings are relevant or which are likely to be of use later even if they did not immediately appear relevant.

Finding Out (The Exploration)

1. The powder (pollen) and the baby seeds (ovules).

There are two things we should get to know very well for our finding out work.

First the powder (pollen) which may be blown from the flower by the wind or which may be collected by various insects, especially the honey-bee, or other animals. This powder is usually clearly exposed, and may therefore be found easily. Quite often, when you handle a flower, you get some of it on your hands. Its proper name is pollen—such little bit is a pollen grain. Whenever you pick a flower, search carefully until you find the box (anther) that contains the pollen.

Second is the baby seeds (ovules). These are usually in a box (ovary) that is right at the centre of the flower. This box (ovary) is usually the largest thing in the centre. Find it, open it up, and look for the tiny, rounded baby seeds (ovules). You should find the ovary and the ovules of each flower you pick. The ovary is usually topped by a slender part that ends in a rounded or a divided tip, the stigma.

Once you can find the anther and the stigma of any flower you pick, you are ready to make more discoveries.

Activity 1: For your first finding out, collect about five different open flowers. Now search through each, looking both with the naked eye and with your hand lens to find the anthers with their pollen, and the ovary with the stigma and the ovules. Draw what you find quickly, naming all interesting parts, and adding notes on such interesting aspects as size, shape, colour, numbers, etc.

For example you may find that the pollen grains differ in size: some may be larger, perhaps each being easily seen with the naked eye, while others are so small that you need your hand-lens to make the single grains out clearly. You may attempt to measure their size, by placing a number of them in a straight line against a millimetre rule or scale. Or you may place small quantities side by side on a card, examine with your hand-lens, and decide which flower has the largest grains, which is the second largest and so forth.

Another way of summarizing your results is to present them in a table, e.g.

	Flower A	*Flower B*	*Flower C*
Common name (other names)	Hibiscus	? (Convolvulaceous	Tribulum
Showy part	red	white	yellow
Pollen box			
colour	orange	white	yellow
size (unopened)	1 mm	2 mm	3 mm
Pollen			
Colour	yellow	white	yellow
size	5 make 1 mm	10 make 1 mm	10 make 1 mm
Stigma			
branches	5	1	1
colour	reddish purple	white	greenish-yellow
size	2 mm	2 mm	1 mm
shape	rounded	elongated	rounded
Ovary			
length	7 mm	3 mm	3 mm
chambers	5	3	
Ovules			
number	many	3	
size			

You should yourself select the aspects to be compared or drawn. You will be helped here by placing corresponding parts side by side and asking yourself: when I look at this part, e.g. stigma, do these two flowers look alike or not? If they differ, how do they differ? Which is larger? Exactly what is the size or diameter, of each one, if we measure with our ruler? And so on. You are thus exploring and recording your own findings, so that you can later remind yourself about your findings or tell a whole story about each flower to others. Your notes will also help you compare your own findings with those of your friends.

Activity 2: Mark an unopened large flower which appears to be about to open in a suitable way: you may label it, tie a string or grass blade around it, or mark the stalk or outer part with a biro pen. Note the size and appearance, and the time in your notebook. After half an hour or an hour take another look at the flower: make a note of your findings. Continue for as long as possible, if possible well into the night.

Visit to a garden or a farm

How many different kinds of flowers can you find?

Can you make out the pollen and stigma of each kind of flower?

Are there animals visiting the flowers? What do they do at each flower? Do they like p articular flowers? When do they come to the flowers?

Activity 1:

If the owner of the garden or farm will allow you, hand pollinate a few flowers in various ways: for example self-pollinate five red and five white varieties, also cross-pollinate. Save the seeds, sow and find out what flower colour types you get.

Activity 2:

If you cannot visit a garden or farm make a small garden yourself, get maize or beans (or other seeds used as food) from your mother, sow and try out the pollinations.

Remember to make notes of everything as you go along.

Activity 3: How the various parts of the flower grow up to the time of opening of the flower.

Find a plant with many flowers in a bunch: find a bunch with flowers at various stages of growth—some very tiny, others larger.

Start from an open flower: separate the parts: either arrange these parts or draw them to show (*a*) the relative sizes and (*b*) the relative positions of the parts. Pay attention particularly to the anthers (pollen box), the stigma and the ovary.

Next take a flower that is about to open, and dissect it as before. Draw the parts to correspond with those of the open flower. Keep comparing these two flowers so that you may clearly notice the changes between the two stages.

Do this for smaller and smaller flowers.

Now write or say in your own words what happens to each part of the flower between the tiniest bud you studied the open flower. Were these changes in colour, size, shape? Did some parts bend or straighten out? Did some parts of an organ lengthen far more than other parts of the same organ? Which parts underwent the greatest or the most striking changes?

Where you can, take measurements and work out ratios, and present them in suitable tables and graphs to bring out your findings.

Repeat this activity on other plants (of a different species).

Is the pattern of change the same? In what ways is it different?

Activity 4: Follow the changes in (*a*) a flower that has not been pollinated (*b*) a flower that has been pollinated as you did in the previous activity, until such time as the fruit becomes ripe.

Sketch the stages, and make notes on changes you find.

Where you can measure, work out ratios, tabulate and graph, do so.

Pay attention particularly to

(*a*) the flower stalk

(*b*) the ovary and its parts

Here also you should compare two different species, perhaps one that gives a dry fruit and one that gives a fleshy fruit.

In your notes, try to bring out both how alike the two species are and how they differ.

Further:

The following activities require the use of a microscope:

1. The formation of the anther
2. Pollen mother cell meiosis
3. The formation of the ovary and ovules
4. Pollen form and structure
5. Pollen germination and growth on the stigma
6. Fertilization
7. Development of the seed after fertilization

Further exercises on pollination:

1. Intraspecific crosses
   Miriabilis
   Vigna
2. Interspecific crosses
   Solananeae: any flowers in this family
   Malvaceae: any flowers in this family
3. Incompatibility
   Ipomoea
   Cacao
   Rubiaceae: any flowers in this family
4. Surgical interference
   (*a*) Decapitation of style
   (*b*) Intraovarian pollination
5. Shortcircuiting of fertilization
   (*a*) hormone application
   (*b*) pollination with strange pollen

References

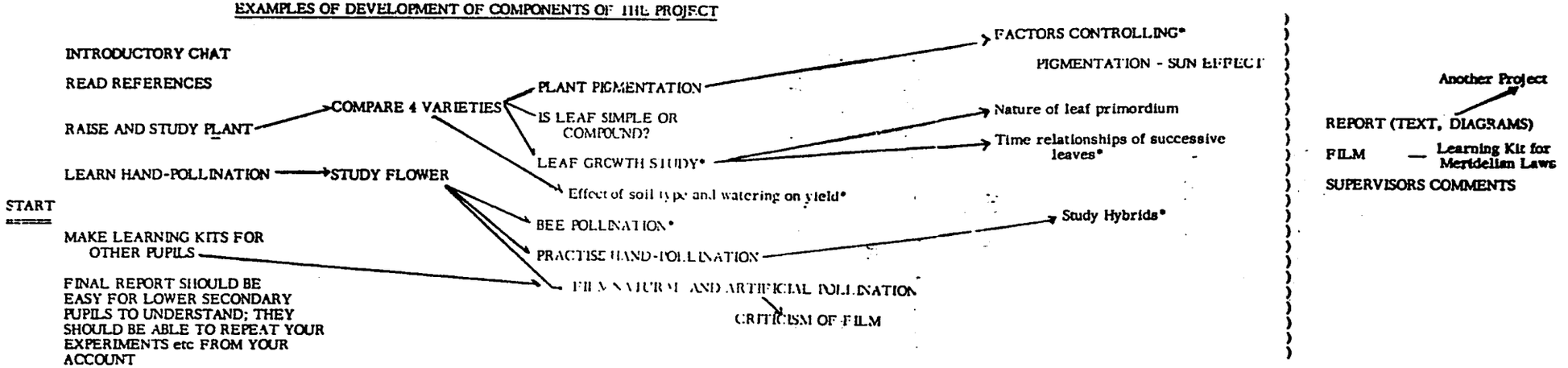
FREE, J. B. 1970. *Insect Pollination of Crops*. Academic Press, London and New York

PERCIVAL, MARY S. 1965. *Floral Biology*. Perganon Press, Oxford.

PROCTOR, M. AND YEO, P. 1975. *The Pollination of Flowers*. Collins, London.

LAWRENCE. W. J. C. 1965. *Practical Plant Breeding*. Allen and Unwin, London.

EXAMPLES OF DEVELOPMENT OF COMPONENTS OF THE PROJECT

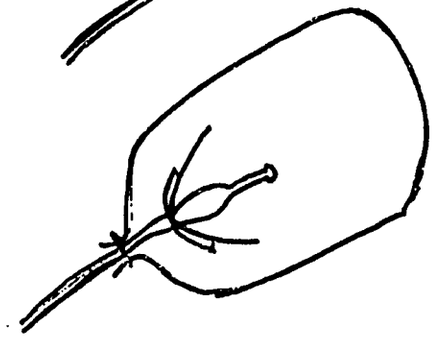


Key

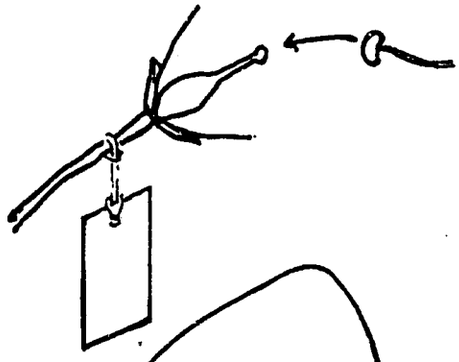
CAPITALS: PROPOSAL CARRIED OUT
SMALL LETTERS: PROPOSAL NOT CARRIED OUT
*: PROPOSAL MADE BY PUPILS

unopened flower

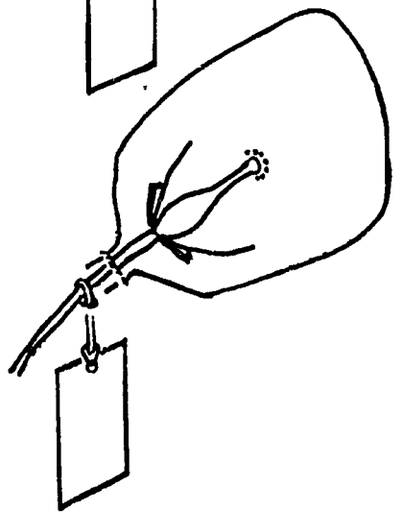
flower gently opened (shown in L.S.)
anthers removed (emasculated)
before they open to show pollen



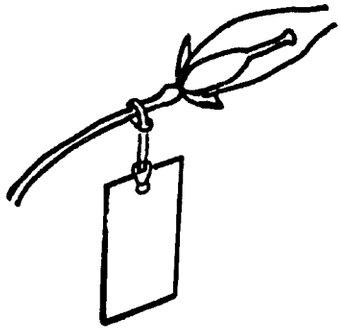
bagged (to prevent insects or wind
bringing in unwanted pollen)



pollination when flower opens by
itself; labelled

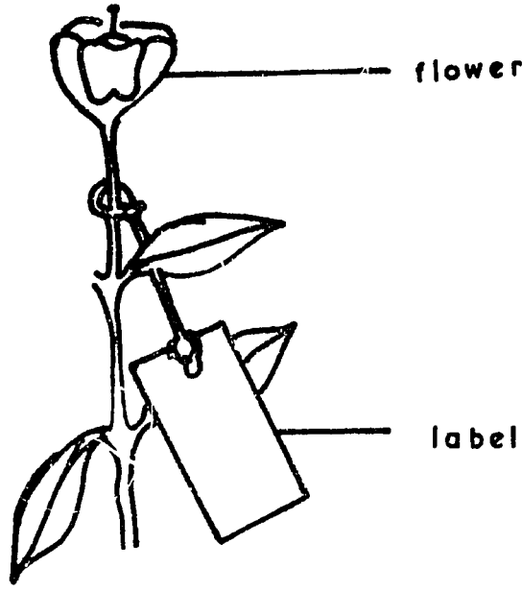


flower bagged again
(to keep out unwanted pollen)

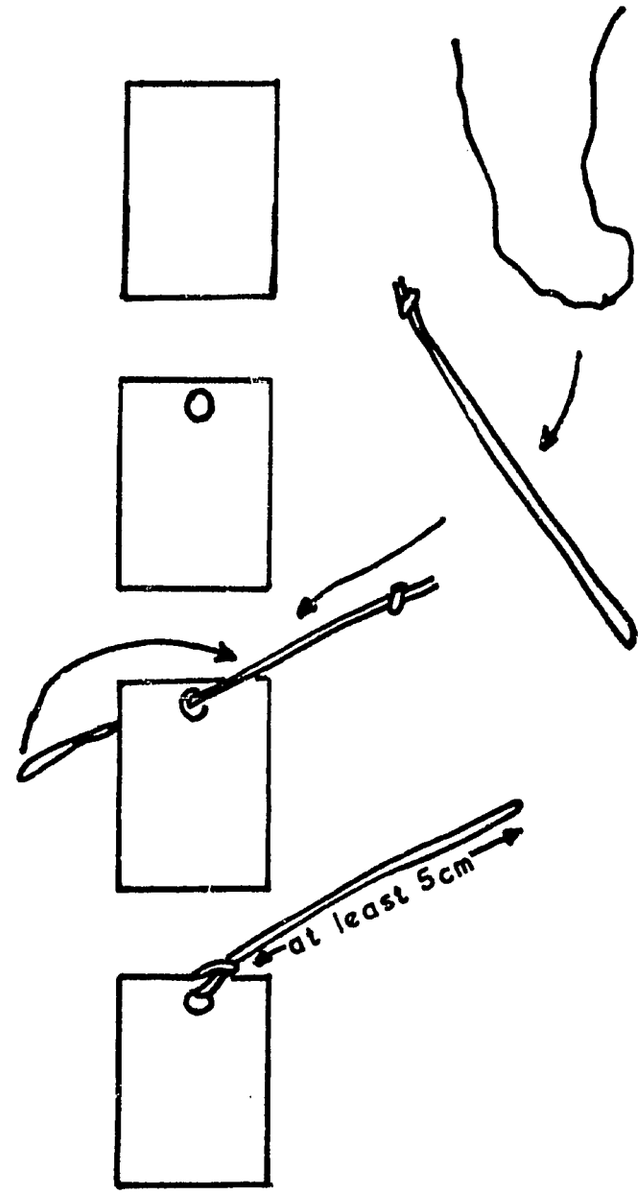


bag removed when safe:
fruit now developing

How to pollinate a flower

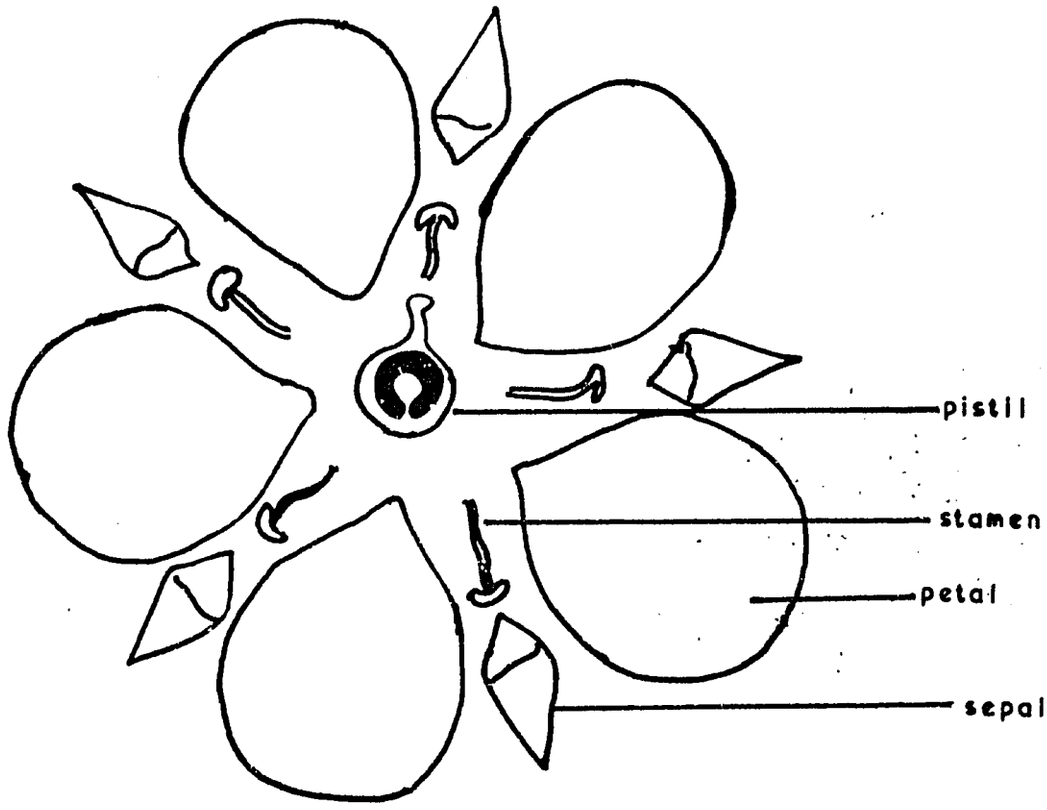


A labelled flower



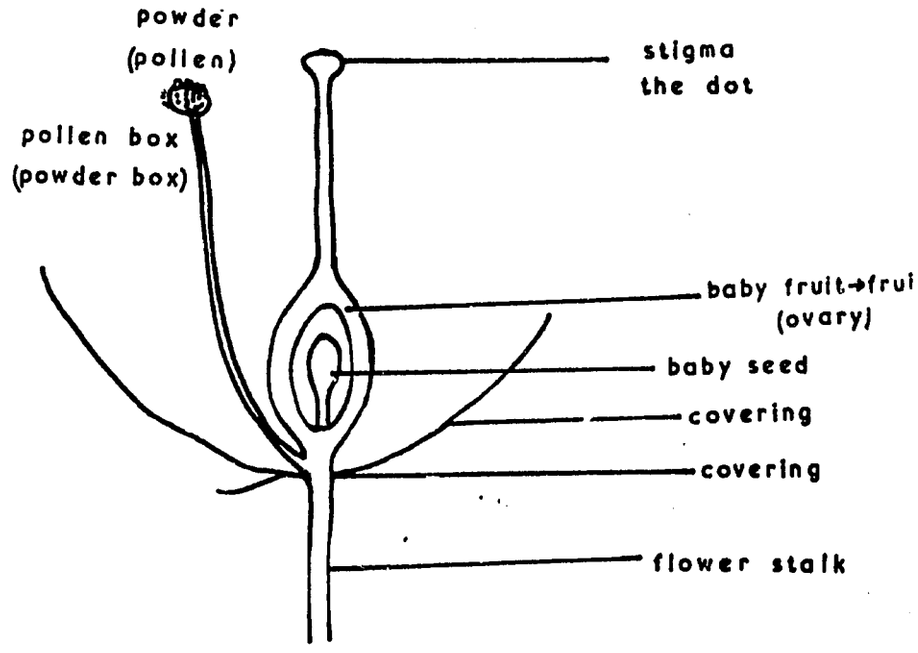
Making a label

Suggested size of tag: at least 1cm. x 2cm. String: the hanging position to be at least 5cm.

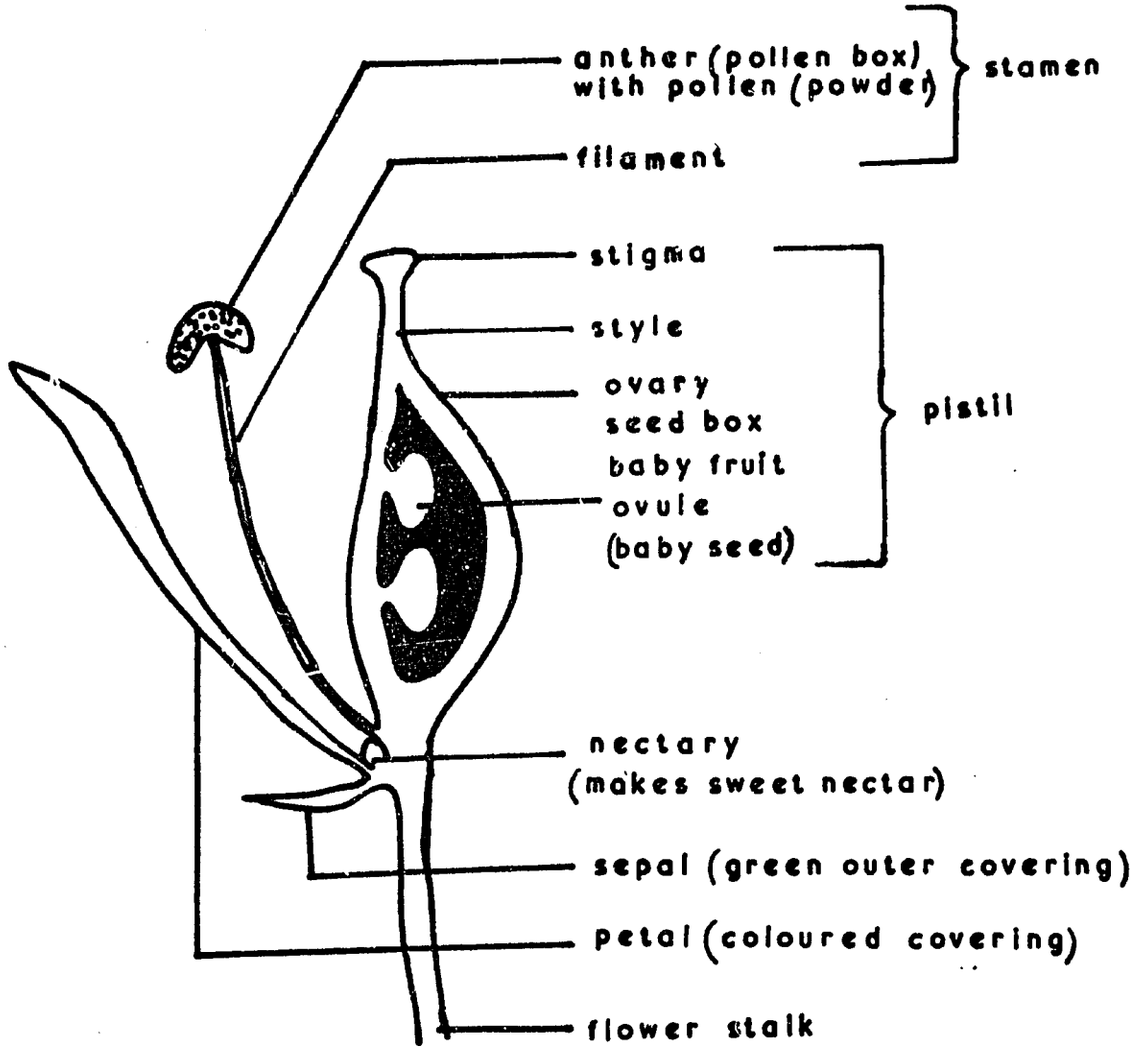


An 'exploded' flower showing the parts

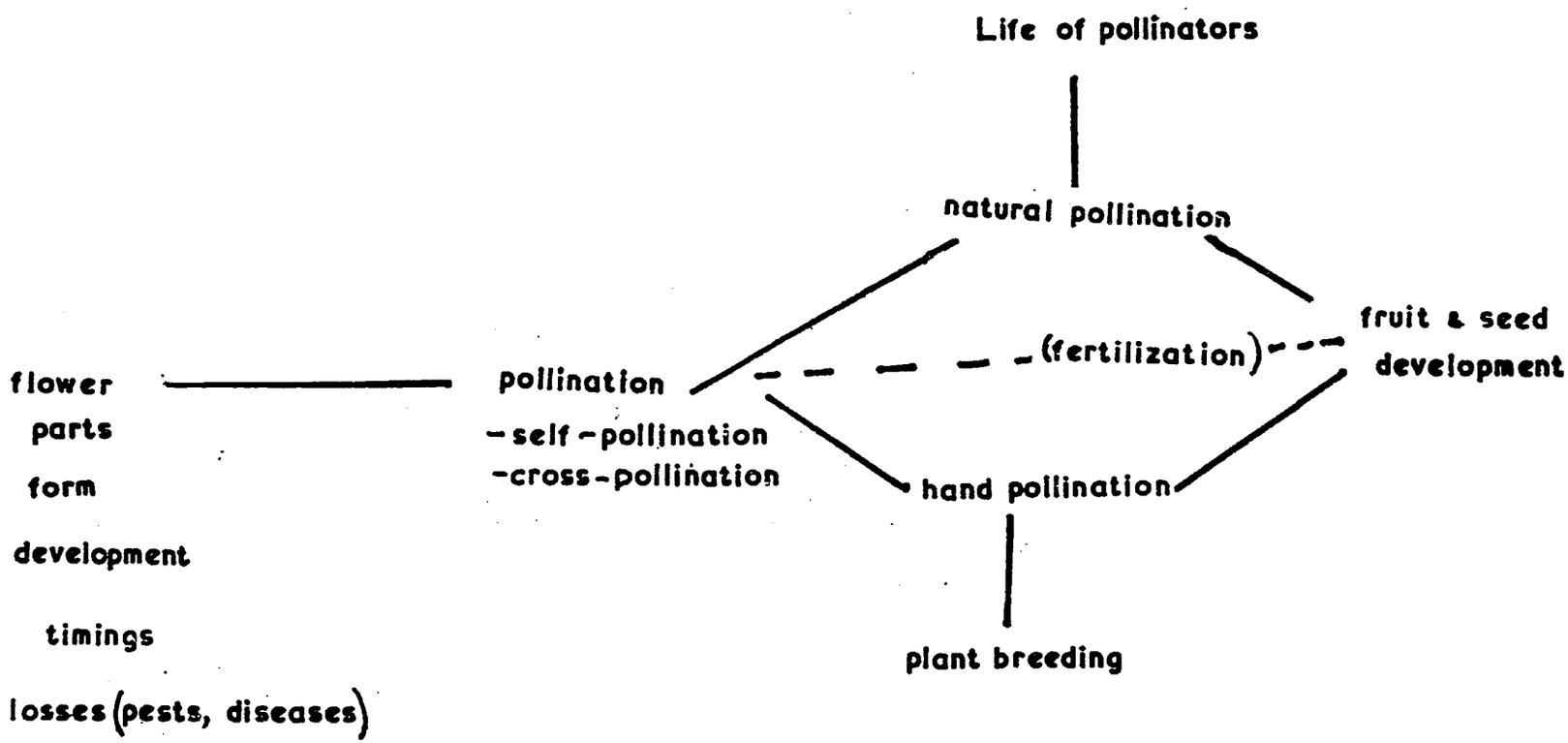
Floral parts First stage (Vocabulary)



to pollinate: to place the pollen on stigma



Simplified flower showing parts



A possible scheme relating topics on pollination

5--Resources

CHAPTER 18

(i) INTRODUCTION: RESOURCE SUPPORT

It has often been argued that the materials for teaching this way are not available. It should be recognized that they will long remain unavailable unless we decide to do something about them. The moment we begin to collect small items together as part of the teaching-learning instruments, we will begin to overcome the problem of lack of materials.

This applies to hardware as well as to software and to ideas. In relation to the hardware, preference should always be given to either the " home-made " items or to those commercial items that can easily be dismantled and put together again. The important point is that they should enable the learner to understand the principles and the working of the mechanisms from practical experience. In this way the learner can develop a correct perspective of the performance of the equipment as well as a working knowledge of how to maintain it.

If, in the present situation, one has to wait until the manufactured products become available in sufficient numbers to all schools and colleges, then one will have to wait indefiniely. Experience has shown that only very limited quantities will be available because of the high costs; and even these will not be used to maximum advantage because of either ignorance to how to use some items, or shortages arising through damage or losses; or inability to carry out repairs of minor or major faults arising from climatic or storage problems.

This brings us to the question of building up the laboratory.

(ii) BUILDING UP YOUR LABORATORY

No matter where you work you will find the need ultimately to build up your own laboratory to suit your approach to the study of science. There will be items lacking that are a must. There will be items present that you may need to add to. Whatever the case may be there is usually the need to build up your laboratory into a more fitting situation for work and study.

In circumstances where no room has been provided to house a laboratory the obvious solution is initially to set aside one corner of the c'assroom; and for storage of materials to use part of the space along the corridor or part of a shed.

As the pressure for space grows the administrators will become convinced of the need for additional space for a laboratory and will take further steps to provide it.

Where there is already a laboratory to begin with, all one needs to worry about is making it as effective as possible. For a start it might have been equipped to serve as an elementary science laboratory or a junior science laboratory, or senior science laboratory or advanced integrated science laboratory. If the last mentioned, then the job of building up would be minimal. For then it will already have the standard items of equipment, apparatus and supplies to approach the activity-based teaching of science. There will be the usual balances, microscopes, lenses (hand and table), measuring cylinders, burettes, pipettes, beakers, flask, batteries thermometers, aquaria, bridges, burners, tripod stands, germination pots and several other items.

We are concerned here with those situations in which the above items are lacking or grossly inadequate; and there is a pressing need for improvisation of some of them. This is where important questions arise concerning cheap or free sources of useful materials that can be altered slightly to suit one or more of the many purposes for which the items of equipment or apparatus may be needed.

One needs to sound a note of caution here though. The teacher cannot be expected to take on the major responsibility of constructing classroom equipment for a full class. It is too much to ask of one person already burdened with heavy involvement in exciting teaching and learning situations. It is enough that the ability to improvise is developed and the tendency is allowed to remain active. The students would learn to develop similar attributes and the stock of materials produced will grow in time.

One way to get round the problem if financial provisions are inadequate, would be to go over designs with teachers of woodwork and metalwork so that some of the items requiring minimal or no calibration can be produced during those lesson periods, or as part of students' project work.

Better still, the technical education unit of the school can take on production of selected items on a more careful level of workmanship over a period (even of years). More accurate work will then result. Furthermore, the technical staff will be more accustomed to the workings of some of the materials to be improvised and they could provide many useful ideas and suggestions for improvisation; not to mention selection of suitable materials.

At this stage it may become necessary to start collecting various bits of odds and ends which could be put to possible use with or without alterations. These will need to be classified in various ways after the initial sorting. Plenty of shelf space would be needed for display of the items in order to make it easier to locate individual pieces when needed. If specially constructed shelves are full, it would be useful to stack wooden boxes together to increase storage space especially of items like scissors, hammers, chisels, screw-drivers, spanners and pliers. Pins nails and small screws, nuts and bolts, washers, and similar small items can be sorted out in small boxes in drawers.

Students can add to the collection as time goes on.

Instructions for making some simple tools can be found in the Unit " Tools for the Class room ". Further tools can be made from designs in the " Unesco Handbook for Science Teachers " and in the " Handbook for Science Teachers " put out by the US Peace Corps and the Indian Ministry of Education.

Some of the materials needed can be obtained free of cost. Such for instance are

—binding metal strips for making scalpels, forceps, scissors, battery clips, springs;
—empty tins for making burners, germination pots, tripod stand;
—empty bottles for making beakers, funnels; lenses;
—fused electric bulbs for making boiling flasks, electrodes;
—cardboard boxes and cartons for making aquaria; storing small articles;
—cast off toys for extracting wheel and axle components, clockwork mechanisms, small motors.

Then there are other items that will need to be bought but can be obtained relatively cheaply from local stores, markets or junkshops. Such are items like bolts and nuts, asps and staples, adhesive tapes, electric cables, old motors and dynamos, to provide copper wires, magnets and carbon brushes; lenses. Further details on these can be obtained from Section VI Chapter 24 SOURCES OF MATERIALS. Thus it is clear that over a period of a few years a fairly effective laboratory can be built up at a relatively small cost.

CHAPTER 19—MATHEMATICS AS A TOOL FOR SCIENCE
OUTLINE

(i) Planning of Investigations, use of mathematical models
- (*a*) Lattices
- (*b*) tree diagrams
- (*c*) permutations and combinations
- (*d*) sets and subsets

(ii) Standard Units (the metric system)
- (*a*) meaning of measurement
- (*b*) changing the size of units
- (*c*) Scientific notation

(iii) Analysis
- (*a*) Speed of the earth's spin
- (*b*) Sand for the Googol
- (*c*) Additional intrigues

(iv) Tables and Graphs

(*a*) Growth (logarithmic, exponential)

(v) Sampling techniques

(vi) Some useful formulas and tables

1. Planning of Investigations, Use of Mathematical Models

In Science we are many times faced with so much information and data that it is difficult to make conclusions or generalizations. By the same token we are sometimes faced with such an insufficient amount of data that conclusions and generalizations are equally difficult to come up with.

In either case, we can minimize the difficulty by good planning and selection of good models. While we may not ever get the exact strategy or find the appropriate model, we will at least have something to use and test if we have been systematic.

Mathematics provides us with the type of structures that we need. The whole study of lattices in mathematics helps us set up situations in such a fashion that all combinations are accounted for.

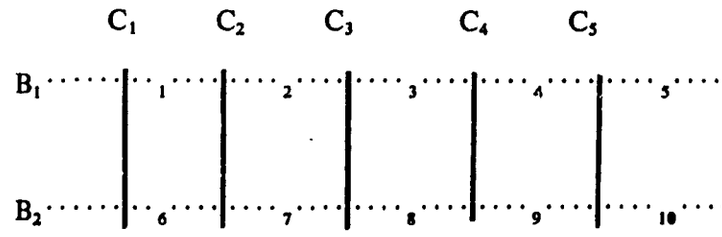
A lattice is merely a grid such as the one indicated below. In this example below we have four different kinds of bean plants. We wish to test how they survive in three different conditions: total sunlight (S) total wetness (W), and total darkness (D).

The lattice

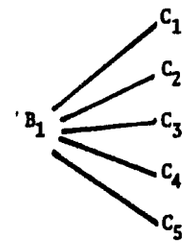
```
        ........ B 1....... B 2....... B 3....... B 4.........
S
        ..........x.........x.........x.........x.........
W
        ..........x.........x.........x.........x.........
D
        ..........x.........x.........x.........x.........
```

From the lattice we see that there are 12 different conditions to observe. Using the lattice we are sure that we have exhausted all cases.

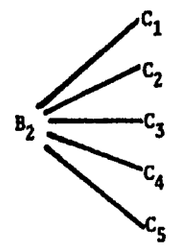
As another example suppose you have 2 bulls and 5 cows on a farm. How many different ways can they mate. The lattice below gives us the result easily.



There are 10 possible matings. Another mathematical model for this is a *tree* diagram as suggested below.



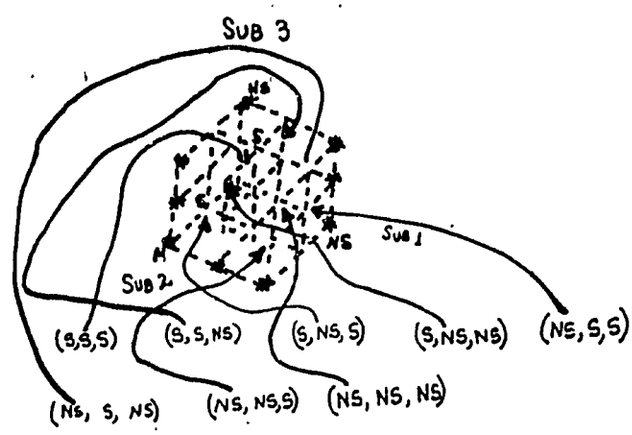
10 matings in all



We could have also used a tree diagram for the first example. Give it a try, you will see that there are 12 conditions as obtained before.

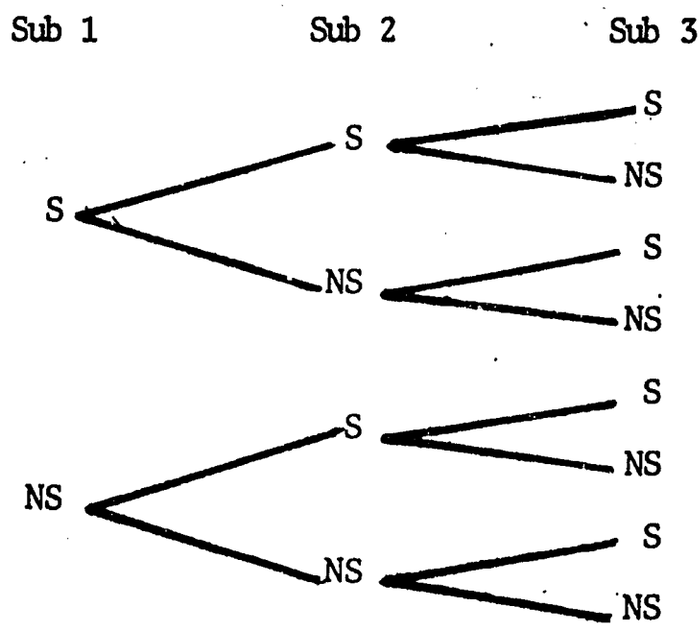
The lattice has its limitations as a model because it is two dimensional. We can use three dimensional models and they are in fact employed; however, they are sometimes hard to interpret. For example, suppose a chemist has three substances that he must test to see if there is salt contained in them. There are several different things that could occur: all three could have salt contained in them; the first two could have salt while the last does not; the second could have salt while the first and last do not; etc.

A model for this could be a cube as indicated below on a three dimensional lattice. The intersection points indicated would be all the possible outcomes of testing the three substances for salt.



S = salt present
NS = NO salt

This same result could be obtained by a very simple tree diagram.



To get the same set of ordered triples we merely follow along each branching of the tree.
$\{S,S,S\}$, $\{S,S,NS\}$, $\{S,NS,S\}$, $\{S,NS,NS\}$, $\{NS,S,S\}$, $\{NS,S,NS\}$, $\{NS,NS,S\}$ $\{NS,NS,NS\}$.

This makes the point that the choosing of a simple and appropriate model is essential in setting up scientific investigations. It should also be clear that a lattice could not be employed at all if the situation were four dimensional. The tree diagrams could, of course, be used for any dimension.

Here is a slightly different example with an appropriate mathematical model. Suppose we have two seeds, we could plant each by themselves or cross the two plant to form a hybrid plant.

Mathematically speaking we could say we have a set $\{S_1, S_2\}$. The sets we could plan are $\{S_1\}$, $\{S_2\}$ and $\{S_1, S_2\}$. How many different combinations and plantings could we have from a set of three seeds. We are now analysing the set $\{S_1\}$, $\{S_2\}$, $\{S_3\}$. The subsets are

$\{S_1\}$, $\{S_2\}$, $\{S_3\}$, $\{S_1, S_2\}$, $\{S_1 \quad S_3\}$, $\{S_2 \quad S_3\}$ and $\{S_1, S_2 . S_3\}$

This question can go on as far as you like. The numbers obtained so far are listed below: (Of course there is one non-empty subset for a set with one member).

Number in Set	Subsets
1	1
2	3
3	7
⋮	⋮
⋮	⋮

With a little experimentation it can be seen that the next number in the sequence is 15 the next 31, the next 63, the next 127, etc. The table can easily be extended by noting the differences.

Number in set	Subsets difference
1	1
	2
2	3
	4
3	7
	8
4	15
	16
5	31
	32
6	63
	64
7	127

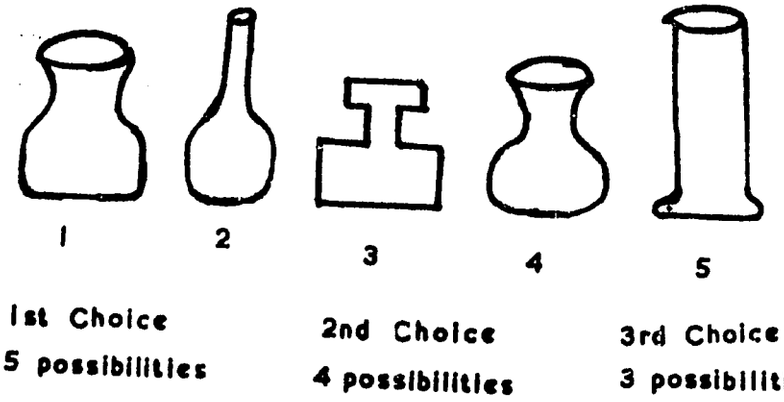
These differences are the powers of 2; therefore, the number of non-empty subsets is given by powers of two minus 1 i.e., 2^n-1. Hence, the mathematical model in this situation is the expression 2^n-1.

Note (the total number of subsets of a given set with n elements is given by the expression 2^n.

This, of course, includes the empty set, $\{\ \}$

As a last example suppose a chemist has 5 chemicals on hand and wishes to know what reactions he will obtain by mixing the five of them three at a time. The question is: just how many mixtures can he make?

We can analyse this situation by using numbered bottles as suggested below. To begin with, we have 5 choices for the first of the three to be mixed. After this bottle has been chosen we are left with four choices for the second choice of the three. and finally we have 3 left for our third choice.



This suggests that there are 5 x 4 x 3 = 60 different ways to mix the five chemicals 3 at a time. This is what we in mathematics call a permutation of five things taking 3 at a time. There is a formula for this written $^nP_r = \frac{n!}{(n-r)!}$. In our case we have $^5P_3 = \frac{5!}{(5-3)!} = \frac{5 \times 4 \times 3 \times 2 \times 1}{2 \times 1} =$ 5 x 4 x 3 = 60. Which is what we obtained before.

If the chemicals above are such that the order in which they are mixed makes no difference, then we do not have to consider as many cases. Any three bottles that we choose, say 2, 4 and 5, can be arragned in several different ways, but they would produce the same result. We list these below:

2	4	5
2	5	4
4	2	5
4	5	2
5	2	4
5	4	2

This indicates that each group of three occurs 6 times. When the order does not matter, what we have are called *combinations* as opposed to permutations.

This all implies that we have $\frac{60}{6} = 10$ combinations of 5 things taken 3 at a time. The mathematical formula for this is: $^nC_r = \frac{n!}{r!\,(n-r)!}$

In our case we have $^5C_3 = \frac{5!}{3!\,(5-3)!} = \frac{5 \times 4 \times 3 \times 2 \times 1}{3 \times 2 \times 1 \times 2 \times 1} = 10$

Whenever, we are doing experiments of combinational nature, we can use the two basic formulas developed above as models. It should be clear from this discussion that if we are interested in mixing all five chemicals and the order in which they were mixed makes a difference then the number of possible mixtures would simply be 5 x 4 x 3 x 2 x 1 = 5!. If we had *n* number, of chemicals it would be *n*!.

There are many other examples that could be cited. However, only experience and a sound background in mathematics will put one in a position to come up with appropriate models. As we go on in this chapter we will cite another example very different from the ones above and also suggest models that might be employed.

ii. Standard Units (The Metric System)

Since time began man has been interested in the questions " How far it is from one place to another? " " How large a particular area is? " (a field, a village, city, a country) and " How much space is contained in a cave? a hut? a house? a building? a tomb? an oven? a bowl? "

The three basic questions have to do with linear (1 dimension), 2 dimensional, and 3 dimensional measures. The most important thing to keep in mind is that the unit of measure must be of the same dimension as the entity that is to be measured.

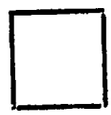
For example, to measure the length of a line we must use a unit length of line. The basic unit sometimes used is the centimeter. Its length is shown below:

1 centimeter

The line below can be measured by using the unit

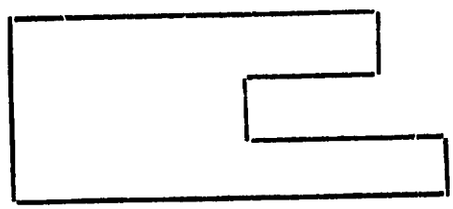
7 centimeters

To measure a two-dimensional area we could use as a basic unit a square with a centimeter on a side.



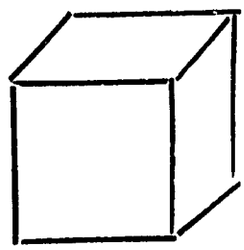
1 square centimeter

We use this unit to measure the two dimensional area below

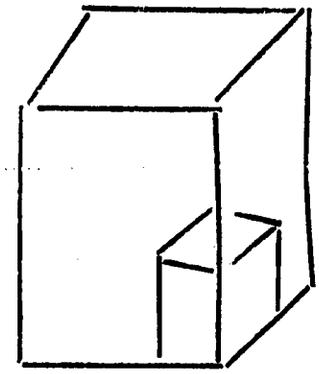


12 square centimeters

To measure a three-dimensional space we could use as a basic unit a cube with a centimeter on an edge.



Finally, this unit is employed to measure the three-dimensional space below,



80 cubic centimeters

It is sometimes inconvenient to measure with centimeters, square centimeters or cubic centimeters. We therefore have both smaller and larger units that are related.

1 centimeter	=	10 millimeters
1 decimeter	=	10 centimeters
1 meter	=	10 decimeters
1 kilometer	=	1000 meters
1 square centimeter	=	$10 \times 10 = 10^2 = 100$ square millimeters
1 square decimeter	=	100 square centimeters
1 square meter	=	100 square decimeters
1 square kilometer	=	$1{,}000 \times 1{,}000 = 1{,}000^2 = 1{,}000{,}000$ square
1 cubic centimeter	=	$10 \times 10 \times 10 = 10^3 = 1{,}000$ cubic millimeters
1 cubic decimeter	=	1,000 cubic centimeters
1 cubic meter	=	1,000 cubic decimeters
1 cubic kilometer	=	$1{,}000 \times 1{,}000 \times 1{,}000 = 1{,}000^3 = 1{,}000{,}000{,}000$ cubic m.

When numbers are quite large as in the case of the square meters and cubic meters above we use a shorter way of indicating these numbers. This is what we call *scientific notation.* 1,000,000 is written as 1.0×10^6 and 1,000,000,000 is written as 1.0×10^9.

If a number is very small we employ negative exponents. For example: $0.1 = \frac{1}{10} = 1.0 \times 10^{-1}$

$.01 = \frac{1}{10 \times 10} = \frac{1}{100} = 1.0 \times 10^{-2}$, $.001 = \frac{1}{10 \times 10 \times 10} = \frac{1}{100} = 1.0 \times 10^{-3}$. Do you see that 0.000001

$= \frac{1}{1000000} = 1.0 \times 10^{-6}$ and $.000000001 = \frac{1}{1000000000}\ 1.0 \times 10^{-9}$.

The number in question does not have to use only 1's and 0's to be written in scientific notation. For example $2987652 = 2.987652 \times 10^6$ and $.00004853 = 4.583 \times 10^{-5}$.

iii. Analysis

The ideas and methods of mathematics allow us to analyse and solve scientific problems. A good science teacher can use the environment and even the earth and solar system as a source for teaching materials. The environment is certainly relevant to all of us. If we, as teachers, train ourselves to observe the dynamic surroundings, we will always have a very natural laboratory.

Below is a problem for your consideration:

In West Africa a fascinating phenomenon to watch is how quickly the sun disappears at sunset, when you look out at the horizon of the sea. The question is: " Just how fast does the sun actually disappear? " What we are really asking is " How fast is the earth spinning on its axis? ' We know that the earth spins once in about 24 hours.

The radius of the earth is about 6356.6 kilometers. Therefore, using $C = 2\pi$, we can calculate the approximate circumference of the earth.

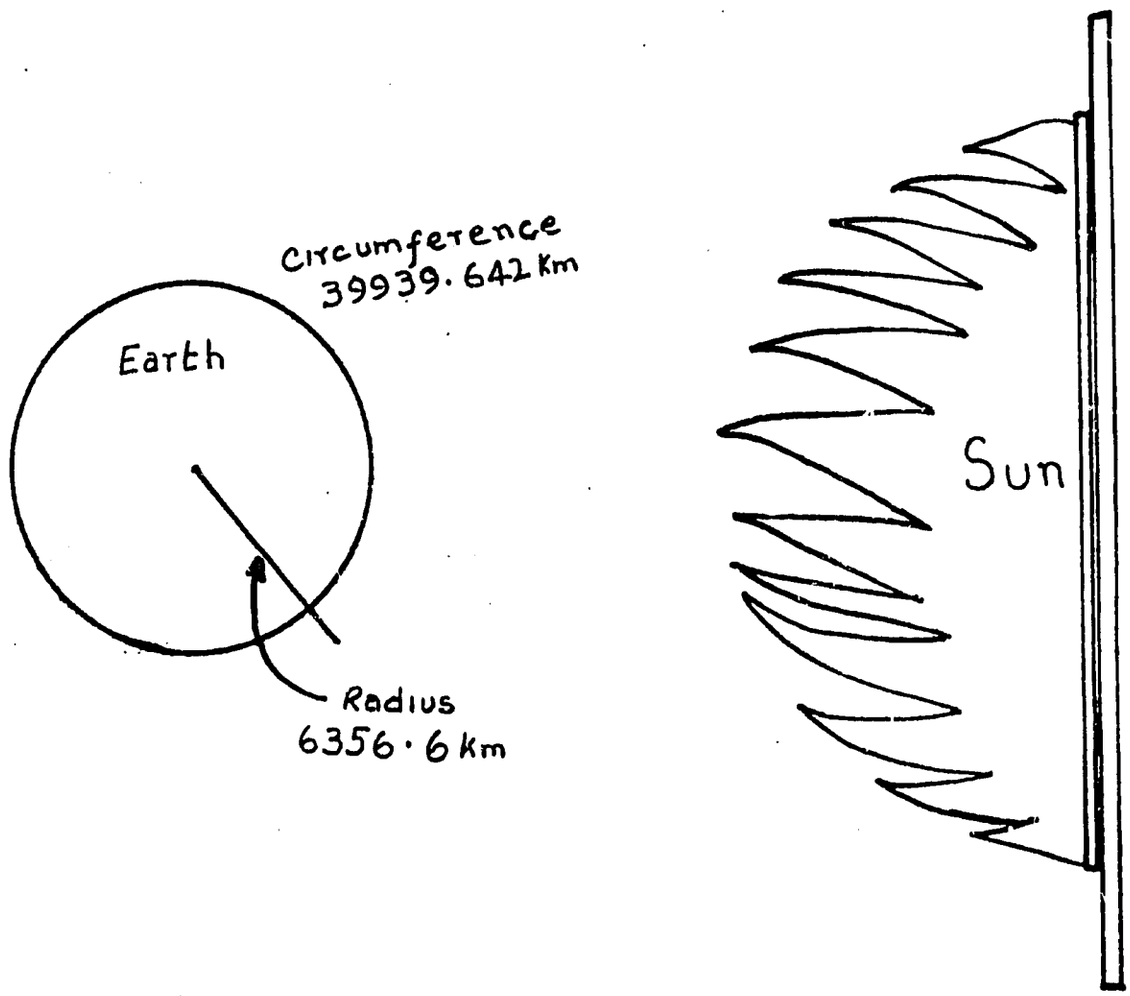
$$C = 2\pi r = 2 \times 3.14159 \times 6359.6$$
$$C = 39939.642$$

Therefore, the rate of movement or speed can be calculated using the formula:

$$\text{Distance} = \text{rate} \times \text{time}. \quad (D = rt) \text{ or } r = \frac{D}{t}$$

$$\therefore \quad r = \frac{39939.642}{24} = 1665.152 \text{ km/hr}$$

No wonder the sun seems to disappear quickly. It is the earth which is spinning away from it at a rate of 1665.152 kilometers per hour. This rate is about twice as fast as that of a jet airplane.



There are many other moving heavenly bodies. The teacher may be interested in calculating the speed of the moon in its orbit around the earth, the speed of the earth around the sun, the speed of other planets around the sun, as well as the speed of their respective spins.

NOTE: "≐" means for approximately equal to.

Here is another question to analyse using the earth as a reference.

Question: If we count all the grains of sand on all the beaches on the earth, would the total sum be greater than a *googol* which is defined to be 1.0×10^{100} ?

Consider the earth being made up entirely of sand. This would, when calculated, give us a number larger than the number of grains of sand on all the beaches on earth.

Even though the earth is not an exact sphere, we may assume that it is to obtain an approximation as to the number of grains of sand it takes to make up the earth.

The volume of a sphere is given by: $V = \frac{4}{3}\pi r^3$. Therefore,

$$V = \frac{4}{3} \times 3.14159 \times (6356.6)^3$$

$$V = \frac{4}{3} \times 3.14159 \times (6.3566 \times 10^3)^3$$

$$V = 1075.8775 \times 10^9$$

$$V = 1.0758775 \times 10^{12} \text{ cubic killometers}$$

From section (ii) we can see that 1 cubic kilometer $= 1.0 \times 10^9$ cubic meters, 1 cubic meter $= 1.0 \times 10^3$ cubic decimeters, 1 cubic decimeter $= 1.0 \times 10^3$ centimeters. Therefore, 1 cubic kilometer $= 1.0 \times 10^9 \times 10^3 \times 10^3 = 1.0 \times 10^{15}$ cubic centimeters.

This allows us to write the volume of the earth in terms of cubic centimeters.

$$V = 10758775 \times 10^{12} \times 10^{15} = 1.0758775 \times 10^{27} \text{ cubic centimeters}$$

A grain of sand is between .3 and 1.0 millimeters. Or we can say that a grain is about .65 millimeters. Since there are 10 millimeters in a centimeter we divide .65 into 10 to see how many grains of sand it takes to make up a centimeter.

$10 \div .65 = 15.384615$. So in a cubic centimeter we would have about 3641.3286 grains of sand. ($3641.3286 - 15.384615^3$).

Multiplying this number by V in terms of cubic centimeters gives us the number of grains of sand it would take to make up the entire earth. Let N be this number of grains.

$$N = 3.6413286 \times 1.0758775 \times (10^3 \times 10^{27})$$

$$N = 3.9176235 \times 10^{30}$$

It is clear then that the googol (1.0×10^{100}) is much larger than the quantity of grains of sand it would take to make up the earth. Thus, it is also larger than the total amount of grains of sand on all beaches on earth.

There are again many other questions to explore that have to do with the earth as a whole. Use your imagination and you will surely come up with many ideas. Consider the questions below:

Question 1: There are about 4.0×10^9 people in the world. If they were to all hold hands would there be enough people to go completely around the earth at the equator?

Question 2: With the number of people mentioned in Question 1, is there enough space in Sierra Leone for everyone to stand? (Assume there are no mountains or lakes—all space is available for standing.) What about Liberia?

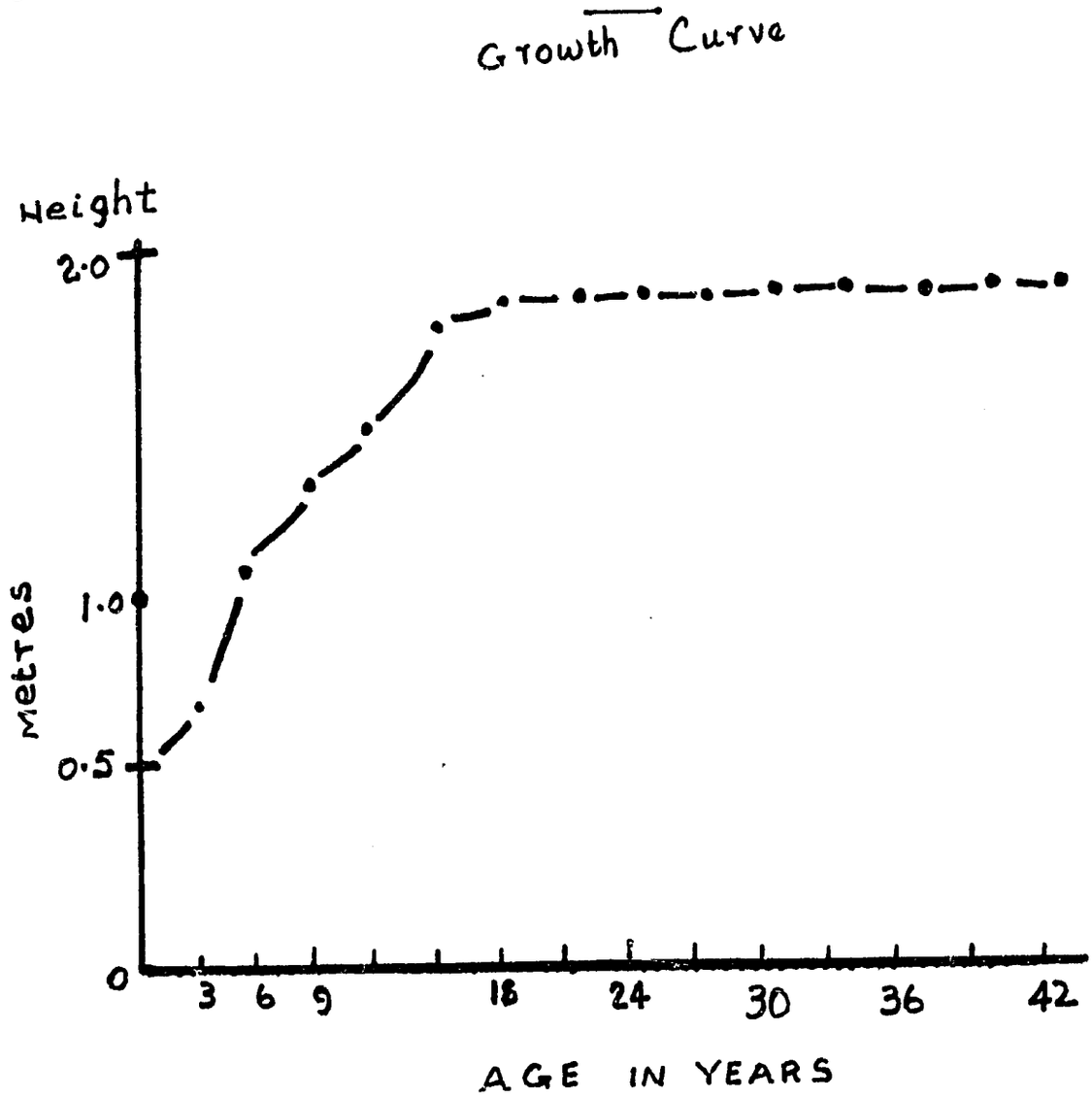
Question 3: What size cube in cubic meters would be needed to contain all the people on earth?

(iv) Tables and Graphs (Growth)

There has already been in Chapter 16 a lengthy discussion of growth. We wish here to expand some of the ideas explored there.

Tables and graphs are indispensable tools for scientific investigations.

Here are a table and an accompanying graph of the growth of a particular individual. You might want to do a table and graph of your own growth. This could also be a project for your students. Once you have several people's graphs, a comparison can be made of the growth curves.



At best, a graph gives only approximations. However, if one is careful about choosing the scales, it will be reasonably accurate. It's value is that one can get a good idea of a situation at a glance. On closer examination one can get an even better idea of the pattern or trend. In fact there is always something new to find out if a graph is studied. For example: we can see that there is more growth between the ages of 15 and 18 than between 18 and 21. There is also a good deal of growth between age 0 and 3. What other things do you notice from the graph? How does your own growth curve compare to the one given?

The reader should go back to the earlier chapter on growth and attempt drawing graphs of the growth of hair, weeds, grass, finger nails, puppies, etc. You will see that many of these things have the same general growth curve as that of human beings. In fact a mathematical model for growth of humans is the function $y = ln\, x$. Which actually means, that $e^y = x$. e is the base of the natural logarithms. The value of e is 2.718, correct to 3 decimal places. We give the graph of the logarithmic function $y = lnx$ on the next page.

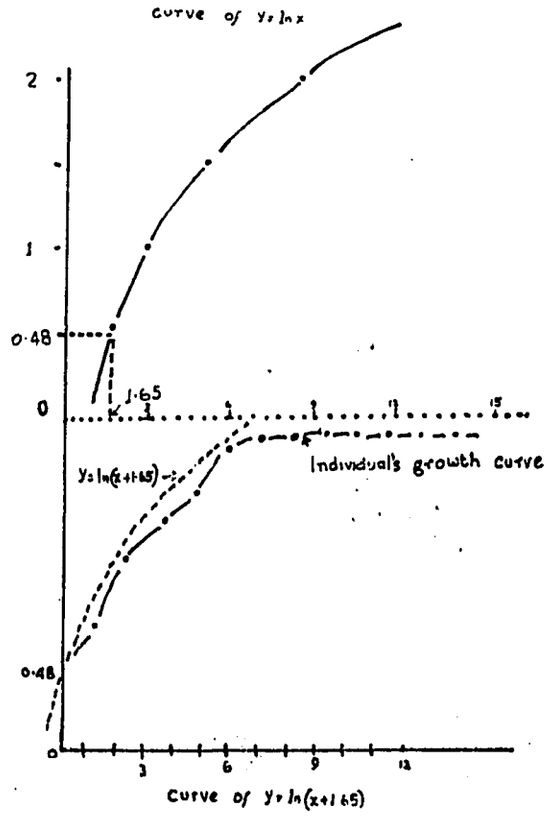
The scale on the y-axis has been adjusted so that the curve, which is normally quite flat, will fit the growth curve of the person. We could achieve the same results by leaving the scale unadjusted and changing the function to $y = 5\ lnx$. In fact, we can always introduce a k factor in the logarithmic function to adjust the curve to fit the specific growth curve we are analyzing. The general function we use is therefore $y = k\ lnx$, where k is the adjustment factor.

By calculating the x value for $y = .48$ in $y = ln\, x$, which is about 1.65, (this can be looked up in a natural log table) we can use the formula $y = (x + 1.65)$ to shift the curve over to the left. This then gives us an idea just how well a form of $y = ln = 1.65$ the logarithmic curve fits the data for an individual's growth.

Table of x and y values for $y = lnx$.

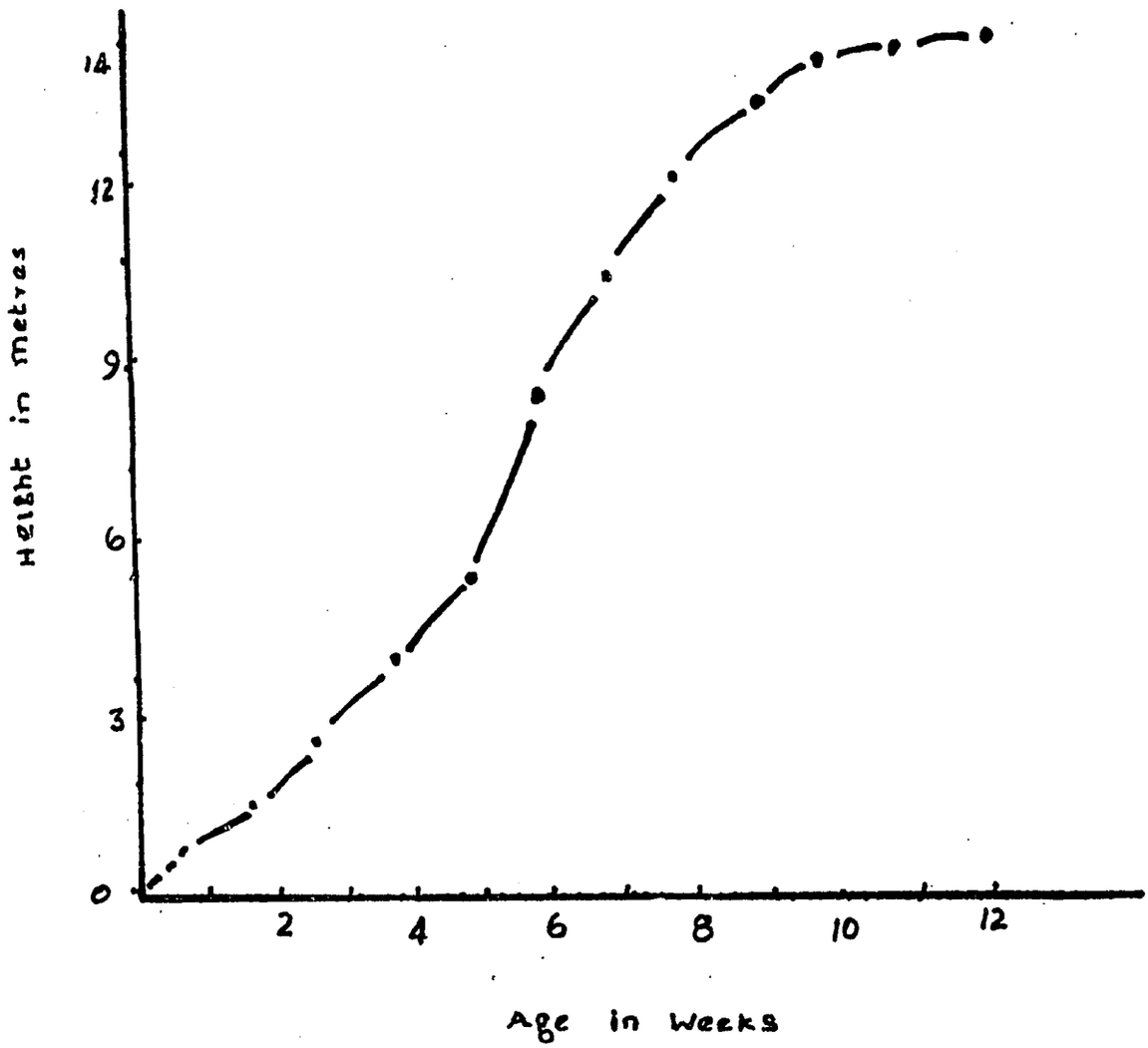
x	1	$e^{.5}$	e^1	$e^{1.5}$	e^2	$e^{2.5}$	e^3 . . .
y	0	.5	1	1.5	2	2.5	3 . . .

Note: From the graphs below, you will notice that the logarithmic curve does not flatten out as does our growth curve. People at some point stop growing. However, while the person is growing it should be clear that the growth curve is quite close to the logarithmic curve.



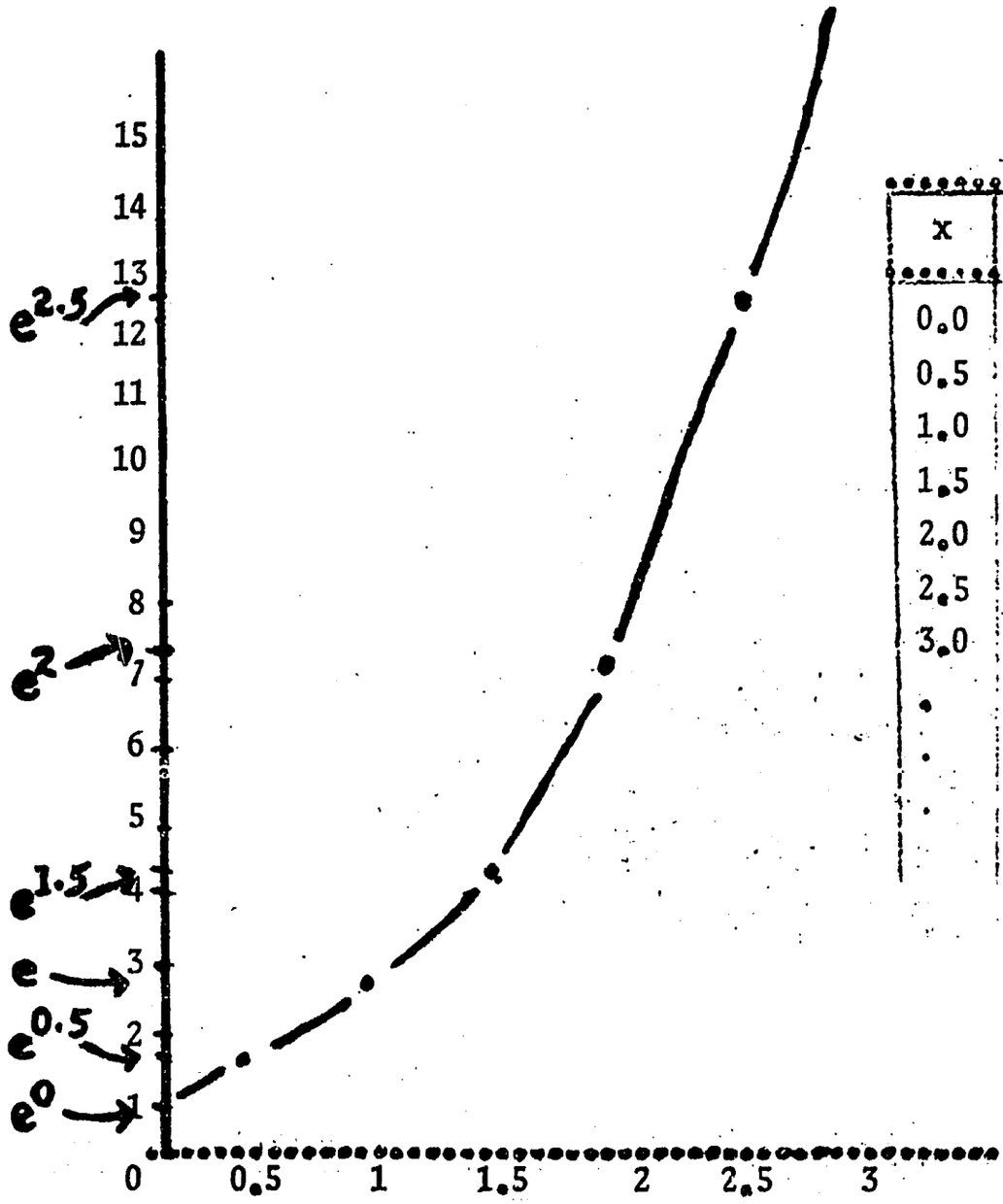
Some other objects and plants grow at quite different rates and patterns. The logarithmic curve cannot be used as a model in these cases. For example, the height of a stem of bamboo was measured from the time the sprout came up. We again present a table and accompanying graph.

Age in Weeks	1	2	3	4	5	6	7	8	9	10	11	12	. . .
Height in meters	7	1.5	2.5	4.0	6.2	8.3	10.2	12.0	13.2	13.8	1.41	14.2	. . .



The bamboo eventually stops growing, and we get the same flattening of the curve that we get with a person's growth. However, the rate of growth is much faster. This type of growth is termed exponential and a mathematical model for this is the function $y=e^x$. Again the e is the base of the natural logarithms. A graph of this function is given immediately below.

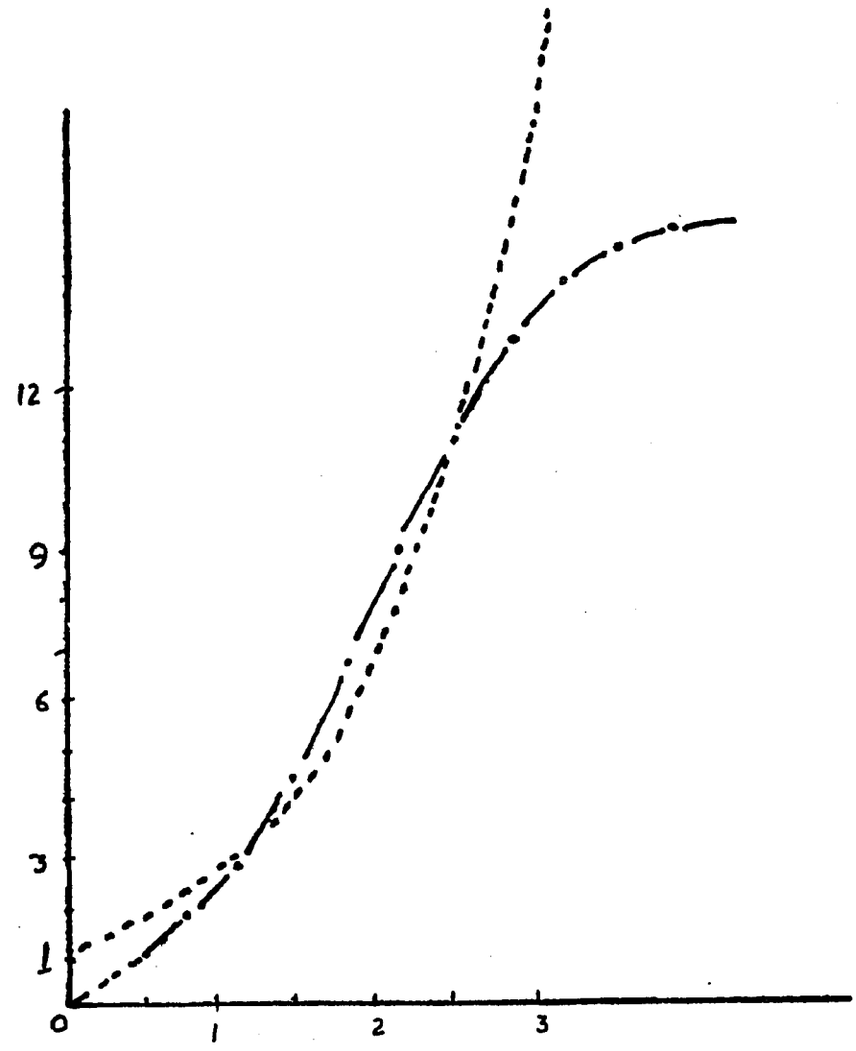
Graph of $y=e^x$



x	y
0.0	1.0
0.5	$e^{0.5}$
1.0	$e^{1.0}$
1.5	$e^{1.5}$
2.0	$e^{2.0}$
2.5	$e^{2.5}$
3.0	$e^{3.0}$
.	.
.	.
.	.

We have deliberately chosen the scale on the horizontal axis in such a way that 1 on this graph is equal to three on the graph of the bamboo growth. This gives us a very close fit. Mathematically this means that we have introduced a factor of 1/3 into the function $y=e^x$. There will always be some constant k to allow us the facility to find a suitable model for this exponential growth. In this case $k=1/3$.

There will always be some constant k to allow us the facility to find a suitable model for this exponential growth. In this case $k = \frac{1}{3}$.



Graph of $y = ke^x$

The general thing to remember is that exponential growth is of the form $y = ke^x$.

Note: (The exponential function is what is called the inverse function of the logarithmic function and vice versa. To graph one function from the data of the other, we merely interchange the ordered pairs. Pairs for $y = \ln x$ are

(1.0), ($e^{0.5}$, 0.5), (e, 1), ($e^{1.5}$, 1.5), (e^2 , 2) ..... ;

Pairs for $y = e^x$ are (0,1), (0.5, $e^{0.5}$), (1, e) (1.5, $e^{1.5}$), (2, e^2 ....)

(v) Sampling Techniques

The scientist endeavours to gather information about the world in which we live. In order to do this he must collect data. This data must be carefully processed and analyzed if he is to come up with valid conclusions. However, no one is able to collect all of the data that the world has to provide. There is neither time, nor money, nor energy for a complete look at all aspects of the world.

With this being the state of affairs, we must rely on sampling only portions of what surrounds us. From these portions we try to make conclusions about all the rest. If we are interested in a certain type of bird, we study a small number of these birds. In this case our frame of reference is all of this type of bird which in statistical terms is called the *population*.

In order to obtain a good sample, conditions must be laid down that will ensure that the sample is reliable. Having done this, it is further required to know how far it can be relied upon. The question is: " How big should the sample be to have sufficient confidence of being able to reach a correct conclusion" ?

Statistical sampling rests upon the assumption that the selection of the individual sample has been done in a *random* way. Random sampling implies that the chance of any one member of the population being included in the sample should be the same for any other in the population. This is the only way to remove all possibility of bias due to poor selection. Random or Probability sampling removes any element of personal choice.

The teacher can easily make what is called a table of random numbers. All that you need to do is put in a bag 10 small slips of paper, each having one of the numbers from this set (0, 1, 2, 3, 4, 5, 6, 7, 8, 9) . Shake the bag, pull a slip, record the number, and return the slip to the bag. Repeat this process as long as you like to build as large a table as you wish.

Once you have the random numbers table you can use it as a tool for random sampling. For example, suppose you have 150 specimens of butterflies and you are interested in analysing colour patterns of their wings, etc. You do not have time to explore all 150 (the population) so you decide to take only a sample to explore.

TABLE OF 200 RANDOM NUMBERS

61	22	64	33	71	83	30	50	23	05
01	61	25	35	87	89	53	35	34	65
02	09	39	82	74	40	69	03	04	95
98	00	23	11	92	99	82	82	35	07
03	99	12	29	93	71	50	33	13	22
29	56	29	84	17*	27	66	35	46	42
94	03	39	52	49	30	76	86	53	55
48	03	09	97	42	08	97	92	00	29
04	40	98	54	35	88	68	39	79	91
45	06	61	14	31	38	00	14	41	90
12	13	18	26	21	12	96	88	01	15
00	84	71	68	07	95	71	88	01	72
18	36	80	94	87	41	42	16	87	40
16	64	33	06	19	31	91	55	66	12
83	81	30	51	43	63	89	08	98	66
21	27	31	57	40	60	75	96	16	86
31	15	57	80	78	79	27	34	25	63
86	48	99	72	28	95	25	84	30	50
35	01	74	20	41	84	47	70	04	45
15	87	19	42	15	44	52	02	66	22

Suppose you wish to choose a representative sample of 10 per cent; that is 15 of the 150. You assign a number to each of the 150 specimens using the set (0, 1, 2, 3, ..., 149). You can go to the random number table and start anywhere you like (close your eyes and put your pencil point on the table). Once you have a starting place, pick the numbers three at a time. If the three digit number you choose is less than 150 then record it as one of the ten choices. If not divide the number by 150 and record the remainder. Continue this process until you have 15 numbers.

For example start at 727*

```
      4
    ----
150)727
    600        record 127
    ----
     127
```

the 9th number is 768

```
      5
    ----
150)768
    750        record 18
    ----
     18
```

The 2nd number is 663

```
     4
    ---
150)663
    600        record  63
    ---        ---------
     63
```

The 3rd number is 546

```
     3
    ---
150)546
    450        record  96
    ---        ---------
     96
```

To 4th number is 642

```
     4
    ---
150)642
    600        record  42
    ---        ---------
     42
```

The 5th number is 940

```
     6
    ---
150)940
    900        record  40
    ---        ---------
     40
```

The 6th number is 339

```
     2
    ---
150)339
    300        record  39
    ---        ---------
```

The 7th number is 524

```
     3
    ---
150)524
    450        record  74
    ---        ---------
     74
```

The 8th number is 930

```
     6
    ---
150)930
    900        record  30
    ---        ---------
     ---       ---------
     30
```

The 10th number is 653

```
     4
    ---
150)563
    600        record  53
    ---        ---------
     53
```

The 11th number is 554

```
     3
    ---
150)554
    450        record 104
    ---        ---------
    104
```

The 12th number is 803

```
     5
    ---
150)803
    750        record  53
    ---        ---------
     53
```

The 13th number is 099

```
                record  99
                ---------
```

The 14th number is 742

```
     4
    ---
150)742
    600        record  142
    ---        ---------
    142
```

The 15th number is 086

```
                record  86
                ---------
```

(*See table above, follow the pattern started).

The 15 specimens we are to examine are those numbered 127, 63, 96, 42, 40, 39, 74, 30' 18, 53, 104, 53, 99, 142, 86.

It should be clear from this example that the table can be used for any size sample. The table itself can always be expanded merely by selecting more slips from the bag.

Sometimes even a random sample will produce bias. For example, if we wish to get an idea of the height of athletes in general, the sample that we take may possibly include only basketball players. These men are generally tall because of the nature of the sport. They would not be representatives of all athletes in terms of height even though the method of drawing the samples may have been conceptually correct.

Where there are well-defined categories within a population to be sampled, the possibility of an unrepresentative sample can be avoided by taking a pre-determined number of sample units for each stratum. This type of sampling is called *Stratified Sampling*.

For example if we wish to determine generally the height of adult male athletes in Kenya we could take a random sample of 100 soccer players, 50 basketball players, 75 tennis players, 50 track men, and 150 cricket players. This would give us the kind of cross-section of athletes that a mere random sample of 450 athletes would not necessarily yield. The number of each stratum is usually determined as a reflection of the size of each population.

Even in the example of the butterflies that we took above, it is possible that the 15 that we chose are all of the same general type. This may or may not be a problem if we still have a variety of colours that is representative of all butterflies. The point to be emphasized is that the investigator must understand the nature of the problem he is dealing with.

Another variation of simple random sampling is what is called *mutt-stage sampling*. This is done to limit the number of *areas* actually sampled. If it is done properly mutt-stage sampling can be made to yield a sample such that every member of the population has the same chance of being chosen. Given that the individuals of the populatons can be categorized in a number of ways, a pre-determined number of individuals can be drawn for each category.

For example, consider trying to gather information about the snakes of the world. We could first choose a number of countries at random. Within each country, we further choose a number of states or provinces, and finally within each province choose randomly a number of districts or counties. We would then study the sample of snakes from these districts.

There is also a type of useful sampling that is not really based on randomness. It is termed *Quota Sampling*, which allows us to implement a greater degree of stratification. Selection within the quotas is not randomnised. The selection is left to the judgement of the investigator. Quota controls help to spread samples more so than random sampling.

For example, someone interested in the mating habits of the animals of a certain region could observe a number of bush cats, a number of grasscutters, a number of sheep, a number of goats, a number of dogs, a number of ducks, a number of chickens and a number of cows.

(vi) Some useful formulas, weights, measurements and equivalents

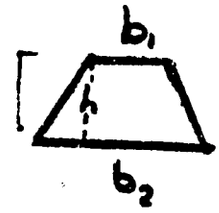
(1) Area of a square

$A = S^2$; Perimeter, $P = 4s$

2) Area of a rectangle

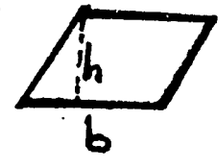
, $A = \ell \times w$; Perimeter, $P = 2(\ell + w)$

3) Area of a trapezoid



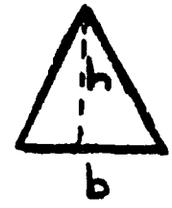
, $A = \frac{(b_1 + b_2)}{2} \times h$; Perimeter; $P = 2a + b_1 + b_2$

4) Area of a parallelogram



, $A = b \times h$; Perimeter, $P = 2(a + b)$

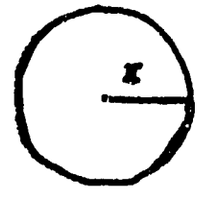
5) Area of triangle



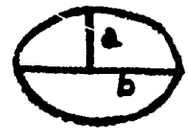
, $A = \frac{1}{2}b \times h$; Perimeter, $P = a + b + c$

$\pi = 3.14159$ (correct to 5 decimal places)

6) Area of circle



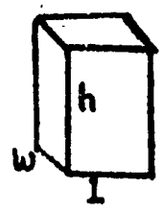
, $A = \pi r^2$; circumference, $C = 2\pi r$

7) Area of an ellipse 

, $A = \pi ab$; length, $L = \pi(a + b)$

8) Volume of a cube

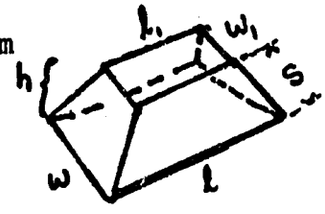
, $V = e^3$; surface area, $S = 6e^2$

9) Volume of a prism 

, $V = \ell \times w \times h$ = surface area, $S = 2(\ell \times h + \ell \times w + w \times h)$

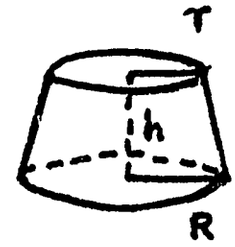
10) Volume of a pyramid

, $V = \frac{1}{3}\ell \times w \times h$, surface area, $S = w(2 \times s + \ell)$

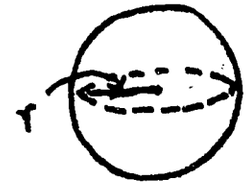
11) Volume of a frustum of a pyramid 

$V = \frac{h}{3}(\ell w + \ell_1 w + \ell_1 w_1)$, surface area, $S = h(\ell_1 + \ell + w_1 + w) + \ell w + \ell w_1$

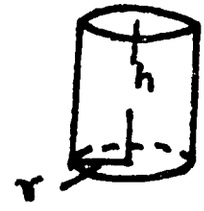
12) Volume of a frustum of a cone, $V = \frac{\pi h}{3}(R^2 + Rr + r^2)$; surface area, $S = \pi r(s + r) + \pi R(s + R)$



13) Volume of a sphere, $V = \frac{4}{3}\pi r^3$, surface area, $S = 4\pi r^2$



14) Volume of a cylinder, $V = \pi r^2 h$; surface area, $S = 2\pi r\ (r + h)$



15) Volume of a cone, $V = \frac{1}{3}\pi r^2 h$; surface area, $S = \pi r\ (s + r)$

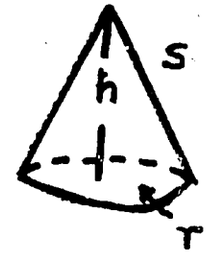


TABLE I

WEIGHTS AND MEASURES

Measures of Length

10 millimetres (mm)	—	1 centimetre (cm)
10 centimetres	—	1 decimetre (dm)
10 decimetres	—	1 metre (m)
10 metres	—	1 decametre (dam)
10 decametres	—	1 hectometre (hm)
10 hectometres	—	1 kilometre (km)
10 kilometres	—	1 myriametre (mn)

Measures of Surface

100 sq. millimetres (mm2)	—	1 sq. centimetre (cm^2)
100 sq. centimetres	—	1 sq. decimetre (dm^2)
100 sq. decimetres	—	1 sq. metre (m^2)
100 sq. metres	—	1 sq. decametre (dam^2)
100 sq. decametres	—	1 sq. hectometre (hm^2)
100 sq. hectometres	—	1 sq. kilometre (km^2)

Measures of Volume

1,000 cu. millimetres (mm3)	—	1 cu. centimetre (cm^3)
1,000 cu. centimetres	—	1 cu. decimetre (dm^3)
1,000 cu. decimetres	—	1 cu. metre (m^3)

Measures of Capacity

10 millilitres (ml)	—	1 centilitre (cl)
10 centilitres	—	1 decilitre (dl)
10 decilitres	—	1 litre (l)
10 litres	—	1 decalitre (dal)
10 decalitres	—	1 hecto litre (hl)
10 hectolitres	—	1 kilolitre (kl)

Note: 1 cc is not equal to 1 ml

Measures of Weight

10 milligrams	—	1 centigram
10 centigrams	—	1 decigram
10 decigrams	—	1 gram
10 grams	—	1 hectogram
10 hectograms	—	1 kilogram
1,000 kilograms	—	1 metric ton

Linear Measure

12 inches (in)	—	1 foot (ft)
3 feet	—	1 yard (yd)
5½ yards	—	1 rod (rd)
16½ feet	—	1 rod
320 rods	—	1 mile (mi)
1,760 yards	—	1 mile
5,280 feet	—	1 mile
6 feet	—	1 fathom

Square Measure

144 square inches (sq. in)	—	1 square foot (sq. ft.)
9 square feet	—	1 square yard (sq. yd.)
304 square yards	—	1 square rod (sq. rd.)

Square Measure

144 square inches (sq. in.)	—	1 square foot (sq.ft)
9 square feet	—	1 square yard (sq.yd)
30¼ square yards	—	1 square rod (sq. rod)
160 square rods	—	1 acre (A)
640 acres	—	1 square mile (sq.mi)
1 square mile	—	1 section (US)
36 square miles	—	1 township (US)

Cubic Measure

1,728 cubic inches (cu.in.)	—	1 cubic foot (cu.ft)
27 cubic feet	—	1 cubic yard (cu.yd)

Wood Measure

16 cubic feet	—	1 cord foot (cd.ft)
128 cubic feet 8 cord feet	—	1 cord (dc)

Table of Counting

12 units	—	1 dozen (doz.)
12 dozen	—	1 gross (gro.)
12 gross	—	1 great gross (gt.gro)
24 sheets of paper	—	1 quire
20 quires or 480 sheets		1 ream

Avoirdupois Weight

7,000 grains (gr)	—	1 pound (lb)	
16 ounces (oz)	—	1 pound	
100 pounds	—	1 US hundredweight (cwt)	
112 pounds	—	1 British hundredweight (cwt)	
2,000 pounds	—	1 US ton (T)	
2,240 pounds	—	1 US gross ton, 1 British ton	

Troy weight (for precious metals, jewels, etc.)

24 grains	—	1 pennyweight (dwt)	
20 pennyweights	—	1 ounce	
12 ounces	—	1 pound	
437½ grains	—	1 ounce	Avoirdupois
7,000 grains	—	1 pound	Avoirdupois
480 grains	—	1 ounce	Troy
5,760 grains	—	1 pound	Troy

Apothecaries' weight

20 grains	—	1 scruple
3 scruples	—	1 dram
8 drams	—	1 ounce
12 ounces 5,760 grains	—	1 pound

Apothecaries liquid measure

60 minims	—	1 fluid dram
8 fluid drams	—	1 fluid ounce
16 fluid ounces	—	1 pint
8 pints	—	1 gallon

Measure of Time

60 seconds	--	1 minute (min)
60 minutes	--	1 hour (hr)
24 hours	—	1 day (da)
7 days	---	1 week (wk)
365 days or 12 months (mo)		1 year (yr)
10 years	—	1 decade
10 decades	—	1 century

Liquid Measure (US)

4 gills (gi)	—	1 pint (pt)
2 pints	—	1 quart (qt)
4 quarts	—	1 gallon
231 cu, in.	—	1 gallon
31½ gallons	—	1 barrel
1 liquid quart	—	57.7 cu. inches

Dry Measure (US)

2 pints (pt)	—	1 quart (qt)
8 quarts	—	1 peck (pk)
4 pecks	—	1 bushel (bu)
32 quarts	—	1 bushel
2,150.4 cubic inches	—	1 bushel

Liquid and dry measure (British)

2 pints (pt)	—	1 quart (qt)
4 quarts		1 gallon (gal)
2 gallons	—	1 peck (pk)
4 pecks	—	1 bushel (bu)
8 bushels	—	1 quarter (qr)
1 quart	—	69.318 cubic inches
1 gallon	—	277.274 cubic inches

Household Measures

1 teaspoon	—	5 cc
3 teaspoons	—	1 tablespoon
16 tablespoons	—	1 cup
2 cups	—	1 pint

Miscellaneous

1 US gallon of water weighs 8.33 pounds
1 British gallon or water weighs 10 pounds
1 cubic foot of water weighs 62.3 pounds
1 British billion means 1 million millions
1 US billion means 1 thousand millions
1 British trillion means 1 million billions
1 US trillion means 1 thousand billions or
1 US trillion -- 1 British billion

EQUIVALENTS

1 inch	—	2.54 centimetres
1 foot	—	30.48 centimetres
1 quart (US liq.)	—	0.9464 litre
1 quart (US dry)	--	1.101 litres
1 quart (British)	—	1.1351 litres
1 pound av.	—	0.4536 kilogram
1 centimetre	—	0.3937 inch
1 metre	—	39.37 inches
1 litre	—	1.051 quarts (US liq.)
1 litre	–	0.9081 quart (US dry)
1 litre	—	0.8809 quart (British)
1 kilogram	—	2.205 pounds

LOGARITHMS OF NUMBERS

	0	1	2	3	4	5	6	7	8	9	Differences								
											1	2	3	4	5	6	7	8	9
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12	0792	0828	0864	0899	0934	0969	1004	1038	1072	1106	3	7	10	14	17	21	24	28	31
13	1139	1173	1206	1239	1271	1303	1335	1367	1399	1430	3	6	10	13	16	19	23	26	29
14	1461	1492	1523	1553	1584	1614	1644	1673	1703	1732	3	6	9	12	15	18	21	24	27
15	1761	1790	1818	1847	1875	1903	1931	1959	1987	2014	3	6	8	11	14	17	20	22	25
16	2041	2068	2095	2122	2148	2175	2201	2227	2253	2279	3	5	8	11	13	16	18	21	24
17	2304	2330	2355	2380	2405	2430	2455	2480	2504	2529	2	5	7	10	12	15	17	20	22
18	2553	2577	2601	2625	2648	2672	2695	2718	2742	2765	2	5	7	9	12	14	16	19	21
19	2788	2810	2833	2856	2878	2900	2923	2945	2967	2989	2	4	7	9	11	13	16	18	20
20	3010	3032	3054	3075	3096	3118	3139	3160	3181	3201	2	4	6	8	11	13	15	17	19
21	3222	3243	3263	3284	3304	3324	3345	3365	3385	3404	2	4	6	8	10	12	14	16	18
22	3424	3444	3464	3483	3502	3522	3541	3560	3579	3598	2	4	6	8	10	12	14	15	17
23	3617	3636	3655	3674	3692	3711	3729	3747	3766	3784	2	4	6	7	9	11	13	15	17
24	3802	3820	3838	3856	3874	3892	3909	3927	3945	3962	2	4	5	7	9	11	12	14	16
25	3979	3997	4014	4031	4048	4065	4082	4099	4116	4133	2	3	5	7	9	10	12	14	15
26	4150	4166	4183	4200	4216	4232	4249	4265	4281	4298	2	3	5	7	8	10	11	13	15
27	4314	4330	4346	4362	4378	4393	4409	4425	4440	4456	2	3	5	6	8	9	11	13	14
28	4472	4487	4502	4518	4533	4548	4564	4579	4594	4609	2	3	5	6	8	9	11	12	14
29	4624	4639	4654	4669	4683	4698	4713	4728	4742	4757	1	3	4	6	7	9	10	12	13
30	4771	4786	4800	4814	4829	4843	4857	4871	4886	4900	1	3	4	6	7	9	10	11	13
31	4914	4928	4942	4955	4969	4983	4997	5011	5024	5038	1	3	4	6	7	8	10	11	12
32	5051	5065	5079	5092	5105	5119	5132	5145	5159	5172	1	3	4	5	7	8	9	11	12
33	5185	5198	5211	5224	5237	5250	5263	5276	5289	5302	1	3	4	5	6	8	9	10	12
34	5315	5328	5340	5353	5366	5378	5391	5403	5416	5428	1	3	4	5	6	8	9	10	11
35	5441	5453	5465	5478	5490	5502	5514	5527	5539	5551	1	2	4	5	6	7	9	10	11
36	5563	5575	5587	5599	5611	5623	5635	5647	5658	5670	1	2	4	5	6	7	8	10	11
37	5682	5694	5705	5717	5729	5740	5752	5763	5775	5786	1	2	3	5	6	7	8	9	10
38	5798	5809	5821	5832	5843	5855	5866	5877	5888	5899	1	2	3	5	6	7	8	9	10
39	5911	5922	5933	5944	5955	5966	5977	5988	5999	6010	1	2	3	4	5	7	8	9	10
40	6021	6031	6042	6053	6064	6075	6085	6096	6107	6117	1	2	3	4	5	6	8	9	10
41	6128	6138	6149	6160	6170	6180	6191	6201	6212	6222	1	2	3	4	5	6	7	8	9
42	6232	6243	6253	6263	6274	6284	6294	6304	6314	6325	1	2	3	4	5	6	7	8	9
43	6335	6345	6355	6365	6375	6385	6395	6405	6415	6425	1	2	3	4	5	6	7	8	9
44	6435	6444	6454	6464	6474	6484	6493	6503	6513	6522	1	2	3	4	5	6	7	8	9
45	6532	6542	6551	6561	6571	6580	6590	6599	6609	6618	1	2	3	4	5	6	7	8	9
46	6628	6637	6646	6656	6665	6675	6684	6693	6702	6712	1	2	3	4	5	6	7	7	8
47	6721	6730	6739	6749	6758	6767	6776	6785	6794	6803	1	2	3	4	5	5	6	7	8
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49	6902	6911	6920	6928	6937	6946	6955	6964	6972	6981	1	2	3	4	4	5	6	7	8
50	6990	6998	7007	7016	7024	7033	7042	7050	7059	7067	1	2	3	3	4	5	6	7	8
51	7076	7084	7093	7101	7110	7118	7126	7135	7143	7152	1	2	3	3	4	5	6	7	8
52	7160	7168	7177	7185	7193	7202	7210	7218	7226	7235	1	2	2	3	4	5	6	7	7
53	7243	7251	7259	7267	7275	7284	7292	7300	7308	7316	1	2	2	3	4	5	6	6	7
54	7324	7332	7340	7348	7356	7364	7372	7380	7388	7396	1	2	2	3	4	5	6	6	7
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LOGARITHMS OF NUMBERS

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57	7559	7566	7574	7582	7589	7597	7604	7612	7619	7627	1	2	2	3	4	5	5	6	7
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59	7709	7716	7723	7731	7738	7745	7752	7760	7767	7774	1	1	2	3	4	4	5	6	7
60	7782	7789	7796	7803	7810	7818	7825	7832	7839	7846	1	1	2	3	4	4	5	6	6
61	7853	7860	7868	7875	7882	7889	7896	7903	7910	7917	1	1	2	3	4	4	5	6	6
62	7924	7931	7938	7945	7952	7959	7966	7973	7980	7987	1	1	2	3	3	4	5	6	6
63	7993	8000	8007	8014	8021	8028	8035	8041	8048	8055	1	1	2	3	3	4	5	5	6
64	8062	8069	8075	8082	8089	8096	8102	8109	8116	8122	1	1	2	3	3	4	5	5	6
65	8129	8136	8142	8149	8156	8162	8169	8176	8182	8189	1	1	2	3	3	4	5	5	6
66	8195	8202	8209	8215	8222	8228	8235	8241	8248	8254	1	1	2	3	3	4	5	5	6
67	8261	8267	8274	8280	8287	8293	8299	8306	8312	8319	1	1	2	3	3	4	5	5	6
68	8325	8331	8338	8344	8351	8357	8363	8370	8376	8382	1	1	2	3	3	4	4	5	6
69	8388	8395	8401	8407	8414	8420	8426	8432	8439	8445	1	1	2	2	3	4	4	5	6
70	8451	8457	8463	8470	8476	8482	8488	8494	8500	8506	1	1	2	2	3	4	4	5	6
71	8513	8519	8525	8531	8537	8543	8549	8555	8561	8567	1	1	2	2	3	4	4	5	5
72	8573	8579	8585	8591	8597	8603	8609	8615	8621	8627	1	1	2	2	3	4	4	5	5
73	8633	8639	8645	8651	8657	8663	8669	8675	8681	8686	1	1	2	2	3	4	4	5	5
74	8692	8698	8704	8710	8716	8722	8727	8733	8739	8745	1	1	2	2	3	4	4	5	5
75	8751	8756	8762	8768	8774	8779	8785	8791	8797	8802	1	1	2	2	3	3	4	5	5
76	8808	8814	8820	8825	8831	8837	8842	8848	8854	8859	1	1	2	2	3	3	4	5	5
77	8865	8871	8876	8882	8887	8893	8899	8904	8910	8915	1	1	2	2	3	3	4	4	5
78	8921	8927	8932	8938	8943	8949	8954	8960	8965	8971	1	1	2	2	3	3	4	4	5
79	8976	8982	8987	8993	8998	9004	9009	9015	9020	9025	1	1	2	2	3	3	4	4	5
80	9031	9036	9042	9047	9053	9058	9063	9069	9074	9079	1	1	2	2	3	3	4	4	5
81	9085	9090	9096	9101	9106	9112	9117	9122	9128	9133	1	1	2	2	3	3	4	4	5
82	9138	9143	9149	9154	9159	9165	9170	9175	9180	9186	1	1	2	2	3	3	4	4	5
83	9191	9196	9201	9206	9212	9217	9222	9227	9232	9238	1	1	2	2	3	3	4	4	5
84	9243	9248	9253	9258	9263	9269	9274	9279	9284	9289	1	1	2	2	3	3	4	4	5
85	9294	9299	9304	9309	9315	9320	9325	9330	9335	9340	1	1	2	2	3	3	4	4	5
86	9345	9350	9355	9360	9365	9370	9375	9380	9385	9390	1	1	2	2	3	3	4	4	5
87	9395	9400	9405	9410	9415	9420	9425	9430	9435	9440	0	1	1	2	2	3	3	4	4
88	9445	9450	9455	9460	9465	9469	9474	9479	9484	9489	0	1	1	2	2	3	3	4	4
89	9494	9499	9504	9509	9513	9518	9523	9528	9533	9538	0	1	1	2	2	3	3	4	4
90	9542	9547	9552	9557	9562	9566	9571	9576	9581	9586	0	1	1	2	2	3	3	4	4
91	9590	9595	9600	9605	9609	9614	9619	9624	9628	9633	0	1	1	2	2	3	3	4	4
92	9638	9643	9647	9652	9657	9661	9666	9671	9675	9680	0	1	1	2	2	3	3	4	4
93	9685	9689	9694	9699	9703	9708	9713	9717	9722	9727	0	1	1	2	2	3	3	4	4
94	9731	9736	9741	9745	9750	9754	9759	9763	9768	9773	0	1	1	2	2	3	3	4	4
95	9777	9782	9786	9791	9795	9800	9805	9809	9814	9818	0	1	1	2	2	3	3	4	4
96	9823	9827	9832	9836	9841	9845	9850	9854	9859	9863	0	1	1	2	2	3	3	4	4
97	9868	9872	9877	9881	9886	9890	9894	9899	9903	9908	0	1	1	2	2	3	3	4	4
98	9912	9917	9921	9926	9930	9934	9939	9943	9948	9952	0	1	1	2	2	3	3	4	4
99	9956	9961	9965	9969	9974	9978	9983	9987	9991	9996	0	1	1	2	2	3	3	3	
	0	1	2	3	4	5	6	7	8	9	1	2	3	4	5	6	7	8	9

NAPIERIAN (NATURAL) LOGARITHMS

	0	1	2	3	4	5	6	7	8	9
1·0	0·0000	0·0099	0·0198	0·0296	0·0392	0·0488	0·0583	0·0677	0·0770	0·0862
1·1	0·0953	0·1044	0·1133	0·1222	0·1310	0·1398	0·1484	0·1570	0·1655	0·1740
1·2	0·1823	0·1906	0·1989	0·2070	0·2151	0·2231	0·2311	0·2390	0·2469	0·2546
1·3	0·2624	0·2700	0·2776	0·2852	0·2927	0·3001	0·3075	0·3148	0·3221	0·3293
1·4	0·3365	0·3436	0·3507	0·3577	0·3646	0·3716	0·3784	0·3853	0·3920	0·3988
1·5	0·4055	0·4121	0·4187	0·4253	0·4318	0·4383	0·4447	0·4511	0·4574	0·4637
1·6	0·4700	0·4762	0·4824	0·4886	0·4947	0·5008	0·5068	0·5128	0·5188	0·5247
1·7	0·5306	0·5365	0·5423	0·5481	0·5539	0·5596	0·5653	0·5710	0·5766	0·5822
1·8	0·5878	0·5933	0·5988	0·6043	0·6098	0·6152	0·6206	0·6259	0·6313	0·6366
1·9	0·6419	0·6471	0·6523	0·6575	0·6627	0·6678	0·6729	0·6780	0·6831	0·6881
2·0	0·6931	0·6981	0·7031	0·7080	0·7129	0·7178	0·7227	0·7275	0·7324	0·7372
2·1	0·7419	0·7467	0·7514	0·7561	0·7608	0·7655	0·7701	0·7747	0·7793	0·7839
2·2	0·7885	0·7930	0·7975	0·8020	0·8065	0·8109	0·8154	0·8198	0·8242	0·8286
2·3	0·8329	0·8372	0·8416	0·8459	0·8502	0·8544	0·8587	0·8629	0·8671	0·8713
2·4	0·8755	0·8796	0·8838	0·8879	0·8920	0·8961	0·9002	0·9042	0·9083	0·9123
2·5	0·9163	0·9203	0·9243	0·9282	0·9322	0·9361	0·9400	0·9439	0·9478	0·9517
2·6	0·9555	0·9594	0·9632	0·9670	0·9708	0·9746	0·9783	0·9821	0·9858	0·9895
2·7	0·9933	0·9969	1·0006	1·0043	1·0080	1·0116	1·0152	1·0188	1·0225	1·0260
2·8	1·0296	1·0332	1·0367	1·0403	1·0438	1·0473	1·0508	1·0543	1·0578	1·0613
2·9	1·0647	1·0682	1·0716	1·0750	1·0784	1·0818	1·0852	1·0886	1·0919	1·0953
3·0	1·0986	1·1019	1·1053	1·1086	1·1119	1·1151	1·1184	1·1217	1·1249	1·1282
3·1	1·1314	1·1346	1·1378	1·1410	1·1442	1·1474	1·1506	1·1537	1·1569	1·1600
3·2	1·1632	1·1663	1·1694	1·1725	1·1756	1·1787	1·1817	1·1848	1·1878	1·1909
3·3	1·1939	1·1969	1·2000	1·2030	1·2060	1·2090	1·2119	1·2149	1·2179	1·2208
3·4	1·2238	1·2267	1·2296	1·2326	1·2355	1·2384	1·2413	1·2442	1·2470	1·2499
3·5	1·2528	1·2556	1·2585	1·2613	1·2641	1·2669	1·2698	1·2726	1·2754	1·2782
3·6	1·2809	1·2837	1·2865	1·2892	1·2920	1·2947	1·2975	1·3002	1·3029	1·3056
3·7	1·3083	1·3110	1·3137	1·3164	1·3191	1·3218	1·3244	1·3271	1·3297	1·3324
3·8	1·3350	1·3376	1·3403	1·3429	1·3455	1·3481	1·3507	1·3533	1·3558	1·3584
3·9	1·3610	1·3635	1·3661	1·3686	1·3712	1·3737	1·3762	1·3788	1·3813	1·3838
4·0	1·3863	1·3888	1·3913	1·3938	1·3962	1·3987	1·4012	1·4036	1·4061	1·4085
4·1	1·4110	1·4134	1·4159	1·4183	1·4207	1·4231	1·4255	1·4279	1·4303	1·4327
4·2	1·4351	1·4375	1·4398	1·4422	1·4446	1·4469	1·4493	1·4516	1·4540	1·4563
4·3	1·4586	1·4609	1·4633	1·4656	1·4679	1·4702	1·4725	1·4748	1·4770	1·4793
4·4	1·4816	1·4839	1·4861	1·4884	1·4907	1·4929	1·4951	1·4974	1·4996	1·5019
4·5	1·5041	1·5063	1·5085	1·5107	1·5129	1·5151	1·5173	1·5195	1·5217	1·5239
4·6	1·5261	1·5282	1·5304	1·5326	1·5347	1·5369	1·5390	1·5412	1·5433	1·5454
4·7	1·5476	1·5497	1·5518	1·5539	1·5560	1·5581	1·5602	1·5623	1·5644	1·5665
4·8	1·5686	1·5707	1·5728	1·5748	1·5769	1·5790	1·5810	1·5831	1·5851	1·5872
4·9	1·5892	1·5913	1·5933	1·5953	1·5974	1·5994	1·6014	1·6034	1·6054	1·6074
5·0	1·6094	1·6114	1·6134	1·6154	1·6174	1·6194	1·6214	1·6233	1·6253	1·6273
5·1	1·6292	1·6312	1·6332	1·6351	1·6371	1·6390	1·6409	1·6429	1·6448	1·6467
5·2	1·6487	1·6506	1·6525	1·6544	1·6563	1·6582	1·6601	1·6620	1·6639	1·6658
5·3	1·6677	1·6696	1·6715	1·6734	1·6752	1·6771	1·6790	1·6808	1·6827	1·6845
5·4	1·6864	1·6882	1·6901	1·6919	1·6938	1·6956	1·6974	1·6993	1·7011	1·7029

NAPIERIAN (NATURAL) LOGARITHMS

	0	1	2	3	4	5	6	7	8	9
5·5	1·7047	1·7066	1·7084	1·7102	1·7120	1·7138	1·7156	1·7174	1·7192	1·7210
5·6	1·7223	1·7246	1·7263	1·7281	1·7299	1·7317	1·7334	1·7352	1·7370	1·7387
5·7	1·7405	1·7422	1·7440	1·7457	1·7475	1·7492	1·7509	1·7527	1·7544	1·7561
5·8	1·7579	1·7596	1·7613	1·7630	1·7647	1·7664	1·7681	1·7699	1·7716	1·7733
5·9	1·7750	1·7766	1·7783	1·7800	1·7817	1·7834	1·7851	1·7867	1·7884	1·7901
6·0	1·7918	1·7934	1·7951	1·7967	1·7984	1·8001	1·8017	1·8034	1·8050	1·8066
6·1	1·8083	1·8099	1·8116	1·8132	1·8148	1·8165	1·8181	1·8197	1·8213	1·8229
6·2	1·8245	1·8262	1·8278	1·8294	1·8310	1·8326	1·8342	1·8358	1·8374	1·8390
6·3	1·8405	1·8421	1·8437	1·8453	1·8469	1·8485	1·8500	1·8516	1·8532	1·8547
6·4	1·8563	1·8579	1·8594	1·8610	1·8625	1·8641	1·8656	1·8672	1·8687	1·8703
6·5	1·8718	1·8733	1·8749	1·8764	1·8779	1·8795	1·8810	1·8825	1·8840	1·8856
6·6	1·8871	1·8886	1·8901	1·8916	1·8931	1·8946	1·8961	1·8976	1·8991	1·9006
6·7	1·9021	1·9036	1·9051	1·9066	1·9081	1·9095	1·9110	1·9125	1·9140	1·9155
6·8	1·9169	1·9184	1·9199	1·9213	1·9228	1·9242	1·9257	1·9272	1·9286	1·9301
6·9	1·9315	1·9330	1·9344	1·9359	1·9373	1·9387	1·9402	1·9416	1·9430	1·9445
7·0	1·9459	1·9473	1·9488	1·9502	1·9516	1·9530	1·9544	1·9559	1·9573	1·9587
7·1	1·9601	1·9615	1·9629	1·9643	1·9657	1·9671	1·9685	1·9699	1·9713	1·9727
7·2	1·9741	1·9755	1·9769	1·9782	1·9796	1·9810	1·9824	1·9838	1·9851	1·9865
7·3	1·9879	1·9892	1·9906	1·9920	1·9933	1·9947	1·9961	1·9974	1·9988	2·0001
7·4	2·0015	2·0028	2·0042	2·0055	2·0069	2·0082	2·0096	2·0109	2·0122	2·0136
7·5	2·0149	2·0162	2·0176	2·0189	2·0202	2·0215	2·0229	2·0242	2·0255	2·0268
7·6	2·0281	2·0295	2·0308	2·0321	2·0334	2·0347	2·0360	2·0373	2·0386	2·0399
7·7	2·0412	2·0425	2·0438	2·0451	2·0464	2·0477	2·0490	2·0503	2·0516	2·0528
7·8	2·0541	2·0554	2·0567	2·0580	2·0592	2·0605	2·0618	2·0631	2·0643	2·0656
7·9	2·0669	2·0681	2·0694	2·0707	2·0719	2·0732	2·0744	2·0757	2·0769	2·0782
8·0	2·0794	2·0807	2·0819	2·0832	2·0844	2·0857	2·0869	2·0882	2·0894	2·0906
8·1	2·0919	2·0931	2·0943	2·0956	2·0968	2·0980	2·0992	2·1005	2·1017	2·1029
8·2	2·1041	2·1054	2·1066	2·1078	2·1090	2·1102	2·1114	2·1126	2·1138	2·1150
8·3	2·1163	2·1175	2·1187	2·1199	2·1211	2·1223	2·1235	2·1247	2·1258	2·1270
8·4	2·1282	2·1294	2·1306	2·1318	2·1330	2·1342	2·1353	2·1365	2·1377	2·1389
8·5	2·1401	2·1412	2·1424	2·1436	2·1448	2·1459	2·1471	2·1483	2·1494	2·1506
8·6	2·1518	2·1529	2·1541	2·1552	2·1564	2·1576	2·1587	2·1599	2·1610	2·1622
8·7	2·1633	2·1645	2·1656	2·1668	2·1679	2·1691	2·1702	2·1713	2·1725	2·1736
8·8	2·1748	2·1759	2·1770	2·1782	2·1793	2·1804	2·1815	2·1827	2·1838	2·1849
8·9	2·1861	2·1872	2·1883	2·1894	2·1905	2·1917	2·1928	2·1939	2·1950	2·1961
9·0	2·1972	2·1983	2·1994	2·2006	2·2017	2·2028	2·2039	2·2050	2·2061	2·2072
9·1	2·2083	2·2094	2·2105	2·2116	2·2127	2·2138	2·2148	2·2159	2·2170	2·2181
9·2	2·2192	2·2203	2·2214	2·2225	2·2235	2·2246	2·2257	2·2268	2·2279	2·2289
9·3	2·2300	2·2311	2·2322	2·2332	2·2343	2·2354	2·2364	2·2375	2·2386	2·2396
9·4	2·2407	2·2418	2·2428	2·2439	2·2450	2·2460	2·2471	2·2481	2·2492	2·2502
9·5	2·2513	2·2523	2·2534	2·2544	2·2555	2·2565	2·2576	2·2586	2·2597	2·2607
9·6	2·2618	2·2628	2·2638	2·2649	2·2659	2·2670	2·2680	2·2690	2·2701	2·2711
9·7	2·2721	2·2732	2·2742	2·2752	2·2762	2·2773	2·2783	2·2793	2·2803	2·2814
9·8	2·2824	2·2834	2·2844	2·2854	2·2865	2·2875	2·2885	2·2895	2·2905	2·2915
9·9	2·2925	2·2935	2·2946	2·2956	2·2966	2·2976	2·2986	2·2996	2·3006	2·3016

Nap. Logs

CHAPTER 20 PART I—TECHNIQUES

There are several ways of looking at techniques in the practical aspect of Science. One school of thought has it that a way of doing things to enable someone to achieve the desired result is referred to as technique. Another school of thought however, considers technique as a way of carrying out an activity with minimum effort and time so as to achieve the desired result.

It seems quite clear that the latter school of thought can be considered more in practical work in science.

Techniques in science vary over a wide range of activities. Our description would be limited to techniques in collecting, preserving and displaying plants and animals, rocks, minerals and fossils. Other techniques discussed in this resource book include handling and improvising basic tools, care of chemicals, magnets, cells and accumulators.

These techniques are however useful when they are related to practical activities in the laboratory and on field trips. Mastery of these techniques may be developed over a long period of practice. Therefore, reading over the series of techniques is not enough. What matters is actually to carry out the activities over and over again.

It must be borne in mind that collecting without any facility for preserving and storing is almost sure to be wasteful. Therefore, it is necessary to be ready to handle specimens before collecting.

The success of a class field trip can be evaluated by what the pupils learn rather than by the number of specimens collected. Students may learn a great deal in the study of lizards by activities involving locating, hunting, capturing and observing the specimens. Therefore collection may be made but at the same time these specimens should be conserved, either by letting the live ones loose or rearing or preserving the specimens.

COLLECTING AREAS

Plants and animals live in places to which they are adapted. Although this factor seems obvious, the physical and biological factors which govern their distribution do not appear to be obvious; therefore tutors should be aware of

- the physical factors which make up the habitat in which he will make the collection.
- how these physical factors affect the plants and animals and thus serve as permitting or limiting factors in distribution.
- how these physical factors inhibit the metabolic or reproductive activities of those organisms to be collected before predicting where to collect them.

It is where the tutor recognises the physical factors which dominate a given habitat and couple this his with knowledge of habitat requirements of plants and animals that he would be able to achieve any satisfaction.

Although each group of plants and animals may require similar techniques of collecting, preserving, rearing, culturing, observing, and displaying, this chapter is aimed at unearthing specific techniques for the groups, with some general cross-references that may be looked for.

In general, the three major e ozones or spheres where biological specimens may be collected are

- Marine or Oceanic zones
- Terrestrial zones
- Aquatic or Fresh-water zones

(i) HANDLING PLANTS

MARINE ALGAE

Materials

Materials needed for this group of algae are

Plastic bucket or bags

Rubber band

Pocket knife

Protected Thermometer

Mason's hammer

Chisel

Collecting Techniques

Whenever possible collect a series of specimens of each species making sure to get mature well formed plants.

In the intertidal and accessible areas carefully remove the specimen by slipping a pocket knife underneath the hold-fast. Put the delicate forms in vials or small plastic nags with small quantity of water.

Carefully select the specimen of encrusting algae which grow on small single rocks or form part of rocks that can be easily dislodged with chisel and hammer. Be sure to collect other plants that grow on other plants (Epiphytes).

Sometimes after several marine storms great quantities of sea weeds are loosened from their substrata and are transported in towards the shore. Wild rows of weed will occur along the beach and tide pools will be filled with loosened specimens. Such time is good for collection since one can get those hard to obtain specimen at that time.

Collection may be made on sandy beaches as well as rocky coasts as the flora may vary off shore from place to place.

Preservation

The final processing and preservation of marine algae should be done as quickly as possible to prevent colour change. When specimens are to be preserved in liquids they ought to be put in a dark place until the time of transfer.

The specimen can be preserved in formalin about 93 parts to 3 parts of glacial acetic acid. The vials containing the specimen should be tightly corked and sealed and placed in a large bottle which in turn is sealed. The bottle is then stored in a dark place to prevent colour change and rapid evaporation.

Note: Return rocks to their normal positions if they are overturned.

Mounting

Smaller specimens of marine algae should be mounted directly. Most of these will glue themselves to the herbarium sheet during drying. The exposed surface should be covered with muslin or cloth to prevent the specimen from sticking to the dryers, when found dry the cover can be removed.

Very flimsy specimens must be floated on to the herbarium sheet in the following way.

The specimen is floated in a large pan of sea water. The herbarium sheet is carefully slid beneath the specimen, and slowly lifted from the water with the plant intact. The excess water is drained off by soaking in a piece of rag and the specimen covered with cloth and pressed.

If a plant press is used it is necessary to ensure that the pressure is light so that undue flattening will not occur. One may also dry specimens by stocking, ventilators, blotters, and as described in the case of higher plants. Then place a piece of plywood with a moderate amount of weights on the top. The pressure on the press may be increased as drying progresses but should never be equal to that used for higher plants.

Large fleshy specimens of the red and brown algae should be dried by spreading in the shade until they are dried but still flexible. Then they are again soaked in sea water for say ten minutes to retain their original shape; they can then be placed on a herbarium sheet, covered with a piece of cloth and pressed as described earlier. Specimens that do not attach themselves to the mounting card may be treated as in the case of higher plants.

Slide Techniques

In the identification of algae it is essential to make temporary slides from time to time, to demonstrate the cellular structure of various parts of the plant.

The arrangement of cells and thickness of the various tissues are frequently characteristic of families, genera and species.

Whole fragments of plants may be mounted in and sea water under cover slip for study. Cross-sections may also be made by holding the plant down in one hand and slicing very thin sections with razor blade. If the specimen is fleshy and large and therefore difficult to slice it should be allowed to dry before slicing the section. When the cross-section is returned to a slide in a drop of sea water it will assume its natural proportions and be ready for study. Usually no stain is needed since fresh or dried materials contain their natural pigments.

Specimens for permanent slide mount should first be killed in 5 per cent formalin and then washed in fresh water to remove the fixative. The specimen is then stained with acid fuchsin or aniline blue on the slide; it is acidified and excess stain is washed out. The surplus water is then blotted away and 60 per cent solution of clear corn syrup is added. It is allowed to stand for 24 hours in a dust-free place and then the evaporated syrup is replenished with an 80 per cent solution.

For a thinner specimen, a cover slip may be placed on it at this stage then stored in a flat position. Thicker specimens may be allowed to stand for 24 hours longer, then a slight additional quantity of 80 per cent syrup is added along with the cover slip. After a month or two such slides may be considered permanent.

FRESH-WATER ALGAE

The members of this group are usually small and delicate as compared to the marine species. Therefore living cultures are preferred to preserved specimen.

Collecting

Small specimens are collected directly into bottle or vials provided with just enough pond water to cover the specimens. Containers filled with water will soon show colonies of algae settling down while larger specimens may be separated off into a plastic bag or rolled into wet news-paper.

Submerged objects in ponds, lakes and streams provide excellent habitat for algae. Rocks, bits of wood and other debris should be examined for presence of green or brown colouration. These colourations should be scraped off with a double penknife or finger nail into vials.

Culturing

Specimens brought from a field trip should immediately be transferred to clean culture dishes. The original water should accompany the specimen or an aged aquarium water may be substituted. Water may be boiled to destroy other organisms before dispensing (tap water should not be used).

In culturing fresh-water algae it is necessary to allow much aeration. Thus overcrowding should be avoided and the ratio of surface area to volume of water should be favourable. Artificial light may be provided although direct sunlight should be avoided.

For a short-term culturing nutrients are not necessary, but are required if the culture is to be maintained over a long period of time. Plant-food tablets may be added from time to time. A soil nutrient solution for culturing the fresh-water algae may be made by mixing about 200 grams of farm soil for each litre of pond water, then boil to sterilize, filter and cool. This can be dispensed for the culture medium.

Preservation

For liquid preservation the collection is poured off and 3 to 5 per cent formalin is added in a vial and stored away in a dark place in air tight containers. The more delicate specimens may be mounted on slides as described for sea-water algae.

Fungi

Fungi constitute a group of primitive plants devoid of chlorophyll. Without photosynthesis the fungi must manufacture their food by breaking down organic matter such as dead plant and animal tissues or by parasitic activity. Therefore they are always located where the source of food is although they occur in terrestial as well as marine and fresh-water habitats.

This group of plants includes Bacteria, Lichen molds, yeasts, mushrooms, poth-balls, etc. Only certain fungi are collected and preserved in the real sense of the word. For bacteria and many of the molds the only truly suitable preparation of the various specimens is in living culture.

BACTERIA AND MOLDS

Collecting

Sterilized cotton-tipped swabs are excellent for collecting bacteria. On moist and semi-moist surfaces these swabs may be applied directly; they should be moistened with sterilized water when applied to dry surfaces. The swab is rubbed back and forth over the surface being sampled then streaked across an agar plate or slant test-tube. Ensure that the same surface of the swab applied to the collecting surface is applied to the culture medium.

When innoculating or transferring a culture to a petri dish, the dish must be set on a table and the lid is lifted only enough to permit the introduction of the swab or wire hook, then the innoculum is streaked back and forth and the valves closed after the process is completed.

The upper valve must never be lifted off in such a way as to draw air currents into the dish. Similarly the lips of the dish must not be touched and the swab must be burnt or put into a disinfectant immediately after use.

It is necessary to turn the petri dish up side down when innoculating to prevent droplets of water from collecting on the lid and falling back on the colonies.

To innoculate a slant tube of agar, the swab is contaminated from the designed source. Then holding the slant horizontally with the left hand, the cotton stopper is removed by grasping it with the little finger of the right hand. The mouth of the slant tube is run through the flame once or twice and then the innoculum is streaked across the surface. The mouth of the tube is reflamed and stopped with the cotton.

Air-borne bacteria and mold are sampled by opening two petri dishes with nutrient agar and exposing them to the air for say 30 minutes or more. The lids are then replaced and one is incubated at room temperature while the other is incubated at body temperature (37 C).

Pure Culture Technique

One seldom collects a pure culture of bacteria in nature. Rather, dozens of species intermingled within the original sample. may be collected. These species may be isolated by using the pure culture techniques.

Streak Plate Technique

If the initial sample was cultured on an agar plate or slant, enough new sterile agar plates should be provided (usually more than the number of species evident in the initial culture).

In transferring these species the wire is flamed until it is cherry red, cooled and then part of an isolated colony is picked up by carefully opening the lid, and then transferred from the initial culture to the new petri dish as described before.

This process is repeated with all of the apparent different colonies on the initial culture plate. Finally the plates are incubated for 24 to 48 hours until new colonies develop a strong growth. If it becomes apparent that more than one colony is present in any of the new cultures the process is repeated until pure colonies have been obtained for all species.

The Pour-Plate Technique

This technique may be used with either broth culture or agar cultures. One tube of sterile, distilled water and four sterile agar tubes with sufficient agar for one plate each are obtained. The agar is melted and allowed to cool. A wire loop is flamed, cooled and used to transfer one of the stock culture to the distilled water by swishing the needle through the water. The culture is mixed into the water by rolling the tube back and forth about dozen times.

The agar tubes are marked '1' '2', '3'. and 'control', and two loops of the water solution are transferred to tube '1' and the tube rotated to mix up. Two loops of the water in 'tube '1' are transferred to tube '2' mixed up and two loops transferred to tube 3'. Finally the tubes are unstopped and their mouth flamed one at a time. Then the content of each tube is poured into a petri dish marked with a corresponding number. The content of the 'control' being poured into a sterile dish. The plates are then incubated from 24 to 48 hours. The colonies may then be recultured as described earlier.

STAINING

Simple smear and stain technique

Several clean slides are prepared and two loops of sterile water are transferred to the centre of one. The loop is flamed and used to transfer bacteria sample. This is mixed and spread upon the slide. The slide is held with a wire clip and passed across a gas flame two to three times at moderate speed.

The underside of the slide is flamed to evaporate the water and fix the bacteria to the slide. Then the fixed bacterial is flooded with one of the stains and allowed to stand for the required amount of time. (Crystal Violet 5 to 60 seconds, Methylene Blue 1 to 2 minutes.)

Finally, the slide is washed with distilled water directing a gentle stream above the fixed bacteria. When the stain no longer streams from the bacterial mass the slide is drained, blotted with soft tissue paper and is ready for observation under the oil immersion microscope.

LICHENS

Collecting

The following materials may be needed during the collection of Lichens.

Plastic bags
Pen-knife
Pick and Chisel

Note: It is important to flame the loop and the mouth of each agar tube before and after each transfer to avoid contamination.

Lichens that grow on trees and bushes, mosses and the like, are removed from the substrate when possible or collected attached to small portions of the substrate. Care should be taken to obtain at least some of the rhizoids and attach them to their substate. It must be remembered that when digging lichen directly from the soil, they should be washed to free the rhizoids from the soil.

The species that grow on rock surfaces are more difficult to collect, however, a small sample may be collected directly by looking over the terrain. Others may be conveniently sampled with chisel by placing the chisel in such a way as to fracture off a thin section of rock.

Preservation

The dirt, insects and other debris are thoroughly washed from the lichens. They are then wrapped up in a cheese cloth, tied with strip and dried in a warm room. They are stored in boxes containing naphthalene balls or paradichloro benzene to control insects pests. When required for study the dried lichen, including the cheese cloth is soaked to regain its freshness. They may be redried and remoistened as often as they are required for study.

MUSHROOMS

Collecting

Depending on the locality, mushrooms and other higher fungi may appear continuously. Careful records should be kept concerning the weather conditions preceding and during the appearance of different species in order to record seasonal succession of the fungi.

A box or picknic basket could be used as a collecting receptacle. (The fleshy species will be crushed and destroyed if they are collected in a plastic bag or similar receptacle.)

In addition to a cardboard box with ropes handles, some smaller boxes should be taken along for handling the delicate forms and some soft paper and string for wrapping individual collections.

A fairly large knife or trowel for digging specimen from the soil may be taken along a wood chisel or may be used for removing specimens from banks and other wooden substrate. Care must be taken to ensure that all of the structures surrounding the base of the mushroom where it enters the soil. In no case should the stem of a mushroom be cut off at the ground line. Attempt must be made to collect large series and also get all the stages of development from the bottom stage on up to the fully nature specimens.

Preservation

The woody specimens are simply dried, fumigated and stored in boxes or other suitable containers along with their field data. Fleshy fungi on the other hand cannot be satisfactorily preserved. One form of preservation is heat drying. This may be done by placing the specimen on screen trays or shelves. The screen trays are placed above a source of heat such as a hot-plate or any other heating element at a distance where the heat will not burn or destroy the specimens. The temperature should be regulated between 35 and 37°C. The specimens are prepared for drying by first cleaning away dirt and debris.

Large specimens should be split length wise before spread on the screens to dry. These should be placed in small open boxes and kept in trays within the herbarium cabinet. Large woody and fleshy mushrooms which have been dried should be subjected to fumigation to destroy insects, by placing them in an airtight cabinet for 24 hours along with a dish containing a small amount of carbon bisulphide. (Excessive amount of paradichloro benzene can also be used to fumigate.)

MOSSES

Collecting

The specimens can be handled in large plastic bags or knapsacks. A pocket knife and a trowel for dislodging specimens attached to stone barks should be taken along.

During the collection, care must be taken to dig up specimens so as to obtain the root-like rhizoids. Specimens that are mature or possess reproductive structures should be selected. As much as possible a large amount of specimen should be collected.

When collecting free-floating mosses from ponds actively growing specimens are preferable to dormant or dead ones. The mud and debris are then washed away from the rhizoids. Specimens that grow on barks and rocks may have a little bit of soil on them and these must be washed away.

Preservation

The specimen to be stored in envelopes or on herbarium sheets are carefully washed, blotted partially dry and arranged on several thickness of folded newspaper. The specimens are positioned to display all of the essential body parts to the best advantage. Highly branched forms must be spread out to avoid multiple overlapping at any one point. Then some weight is put on top to press them. This should be light. If the specimens became misshapen they may be dipped in water for a few minutes until they are pliable and then pressed in the dried way.

Bulk-dry Technique

Another technique for preserving large quantities of mosses for classroom study is the Bulk-Dry technique

The mosses are well cleaned in the usual manner and carefully arranged on a piece of cheese cloth along with the sheet containing the field data. The cloth is then wrapped in such a manner as to contain the moss but not to distort its shape. The corners of the cheese cloth are tied with strings and allowed to dry then stored in a paste box containing some paradichloro benzene.

LIVERWORTS AND HORNWORTS

Liverworts prefer moist, shaded areas usually associated with some source of water. Stream and lake banks, moist road banks in forest areas and similar habitats will support terrestrial species. A careful look among grass and other vegetation for liverworts growing in any of these situations may reveal their presence. Where the ground is moist and damp, bushes and over hanging branches should be lifted for the presence of liverworts.

Collecting

A plastic freezer bag may be used for collecting. A knife, trowel or dip net is also used for removing specimens from their subtrate or dipping them from water. The specimens are placed in the plastic bag, inflated then sealed with rubber band. When placed in a carrying box the inflated bag will prevent crushing when other specimens are added. Notes taken should include information on the exact microhabitat, dominant species of the plants associated with the habitat and light and moisture conditions.

During the collection, well-formed, mature specimens showing ripened reproductive bodies whenever possible should be collected. Liverworts are easily kept alive in aquarium or laboratory terrarium and may be cultured until reproductive stages appear and mature. This may be the only suitable way of getting excellent species. If kept cool and provided with some moisture, the specimens will last many days in the plastic bags containers. An aquarium may be provided for the aquatic species; for the terrestrial species, a sloping surface in a terrarium containing small quantity of water may do well to keep them alive for a long period. A mixture of peat moss and loam makes an excellent substrate in which to plant liverworts. A sheet of glass plate is placed over the aquarium or terrarium to maintain the humidity level and keep specimens in somewhat subdued light such as that from a window.

Preservation

Liverworts should be pressed between specimen sheets and dryers with only moderate pressure. Should the specimens tend to stick to the sheets, they should be placed directly on herbarium paper and covered with cloth, as described for marine algae. Either gummed cloth or herbarium paste method should be used for attaching specimens to standard herbarium sheets.

An alternate technique is to store the pressed materials in moss envelopes. In pressing, care must be taken to apply only enough pressure to hold the plant in a two dimensional plane, but not enough to crush it or totally flatten them.

For many purposes, liquid preservation of liverwort is quite suitable. A four per cent formalin solution with or without small quantity of copper sulphate may be used for general preservation.

Club Mossess

The entire plant, including rhizomes and roots should be collected and dried in the manner of true mosses.

Horsetails

Collect all plant parts and if necessary special trips should be made to get immature and mature cones.

Ferns

In collecting ferns, fronds, leaves, the entire stripe, the rhizome and some of the roots should be collected. Also some fronds bearing reproductive bodies. These should be mounted so that the sporangia may be seen on the herbarium sheet. The sexual generation of ferns may be reared on agar, with plant food added or on clean bricks which are kept moist with a solution of plant food and water. These are best preserved in liquid or on permanent microscopic slides.

Conifers

In collecting conifers both 'male' and female cones as well as needles, terminal branches, growth buds and the like from the same plant should be collected. Notes should be taken on the nature of the bark, the height of the tree, the altitude at which it occurs, the nature in which the cone comes off the branch and other things of taxonomic use. Large cones are dried, smaller ones may be preserved in liquid or pressed along with the main plant specimen.

Flowering Plants

Flowering plants, should be carefully collected so that all plant structures including fruits and seeds are obtained.

Many teachers maintain small plant collections of selected material to illustrate such things as different groups of plants, types of leaves, flowers, fruits, seeds, cones or other features that may be of importance in the reaching of plant sciences. Such collections should be made with utmost care to provide all of the taxonomic parts required and to demonstrate the proper technique for herbarium specimens.

In order to collect usable plant specimens it is necessary to know what essential plant parts are needed from each group of plants. Thus a study of plant keys and literature will ensure accurate field collecting. (*See* construction of key)---Identifying and collecting plants.

Small Herbs

When collecting small herbs, pick out plants of medium size which show both mature flowers and if possible mature fruits. Get the complete plant including the roots, stems leaves and floral and fruiting portions. Collect extra flowers and fruits for identification. Carefully dig up the plant and wash the dirt from the roots so that the roots mass may be included on the finished pressed specimen.

Large Plants

When collecting large plants, choose portions with flowers, fruit and a representative of leaf types. Samples of bark and fruits may be put into plastic bag along with a field number. If you are looking for cones, seeds, or fruits of various plants, make sure those specimens picked up from the ground actually come from the plant in question.

In some plants, the flowers, leaves and fruits appear at different times, thus it is advisable to tag a particular tree or plant and collect from the same specimen throughout the year until all of the essential parts are obtained.

The flowers can be preserved by the methods described in Section VI; Techniques for Practical Activities.

The leaves may be preserved by pressing or using the techniques described in Section VI; Techniques for Practical Activities.

(ii) IDENTIFYING AND COLLECTING PLANTS CONSTRUCTION OF KEY

The word key to most students brings to mind a metal device used to unlock doors or padlocks and to provide access to homes, stores, school buildings, etc.

Scientists use key too but not only to open doors to their laboratories. They also use another kind of key to open the door to learning new and exciting things about the world around them. Specifically, they use key for identification purposes. They use key to identify animals, plants, rocks, follis, etc. That is they use the physical characteristics of these objects as stepping stone to the final identification of the object under study. Students in schools and colleges can learn to use a simple key if they understand how one is constructed. The demonstration written and illustrated in the following paragraph, has proven successful in creating an understanding of the use of and construction of a simple key.

Explanation of a Key

A key is divided into steps which ask 'Yes' and 'No' questions. Steps also provide us with directions as to what to do next. Each step has two or more questions which ask us something about the object we are trying to identify. If you answer 'Yes' to a question you will either have identified the object or told what step to go to next. If you answer 'No' to the first question in a step, then you must read the second question under that step. This procedure can be outlined on the board for pupils to see.

One way of putting a key to good use is for the teacher and or students to make a key for identifying the plants which are found on the school grounds. If a simple key is made by the teacher, it could be passed on to the students and a field trip conducted on the school grounds as an immediate follow-up activity. The following might be used as an example for constructing one's own key.

This key is divided into four steps. Each step will ask two questions about a tree. Answer each question with a 'Yes' or 'No'.

If your answer is 'Yes' then you either will have identified the plant or will be directed to the next step which will help you to find out what plant it is.

If your answer is 'No' then read the second question of that step. It will tell you which step to go next.

Step One

Question 1 Are the leaves like needles? They are! Then go to step two.

Question 2 If the leaves are not like needles, then they must be broad and flat.

You may skip step two and go on to step three.

Step 2

Question 1 Do the needle-like leaves grow singly and are they short and difficult to roll between your fingers? You have just found a yew or hemlock tree. Another key will have to be constructed to separate these conifers.

Question 2 Or are the needles long, growing in bundles of two or three together? They are! Then you have identified a pine tree.

Step 3

Question 1 Are the broad leaves of the tree growing opposite each other? This is a tree of the almond family.

Question 2 Or are the leaves of the tree growing alternately? If so then go to step four.

Step Four

Question 1 Are the leaves wide near the middle with small rounded tooth-like edeges?

Question 2 Or are the leaves long and narrow with tiny rounded tooth-like edges?

Students and teachers are reminded that this is just an example of how a key can be constructed to study plants in their evnironment.

Key to some important families of flowering plants

The key below will be found useful if a careful study is made.

Beginning at the large arrow, you will find two alternative paths, requiring for example, a choice between " Ovary Superior " and " Ovary Inferior ". Select the correct one for the specimen you are studying. Follow the path from this selection to the next fork in the path and again choose the route indicated by the characteristics of the specimen. Continue in this way until you reach the end of the route, where you will find the name of a family. Check this answer by comparing your specimen with a description of the family in a text or reference book.

It is hoped that the examination of the flower itself will provide a lot of experience to the pupils by the time they get to the end of key.

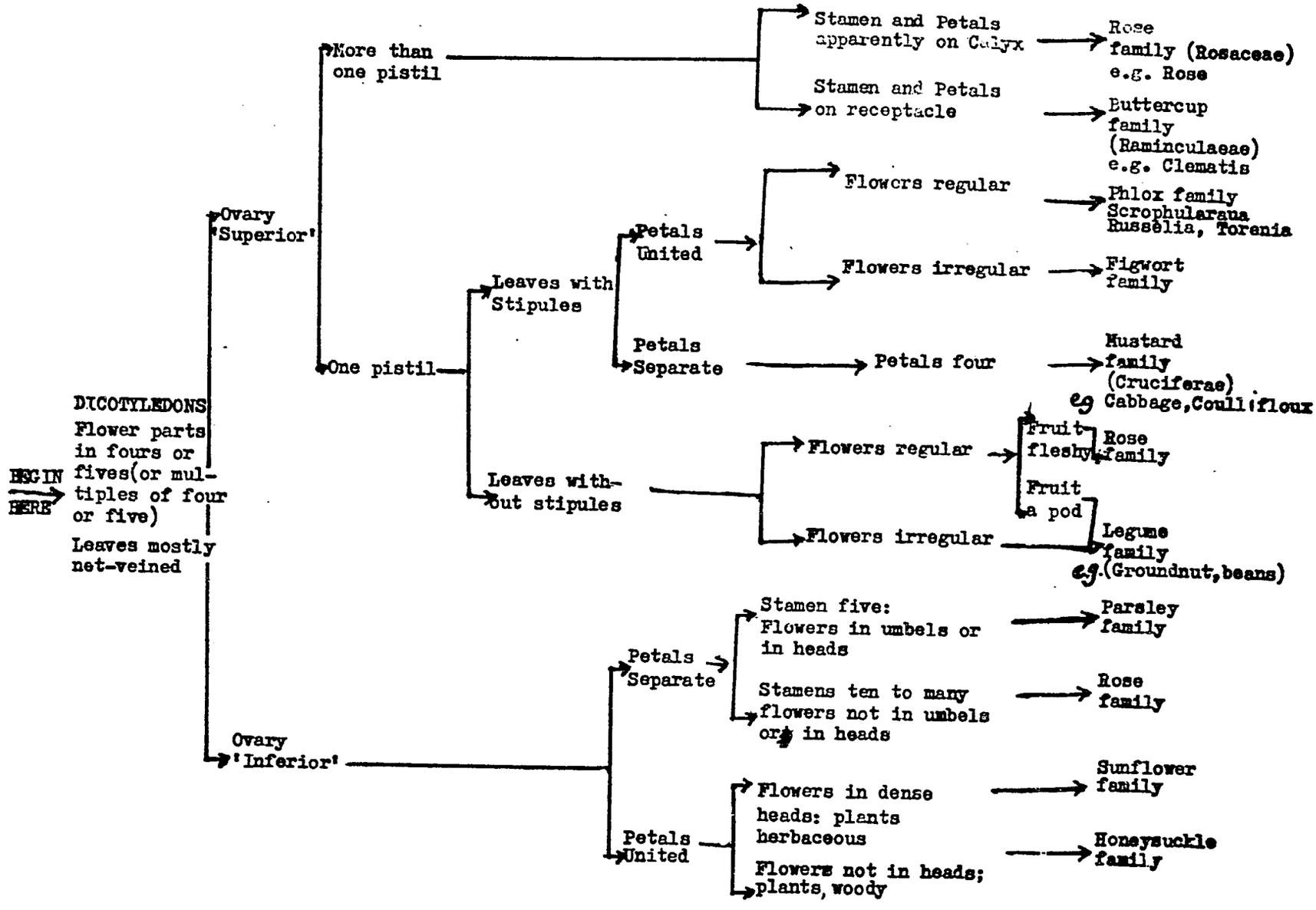
Furthermore, it must be borne in mind that the key can be constructed with names of flowering plants in a locality.

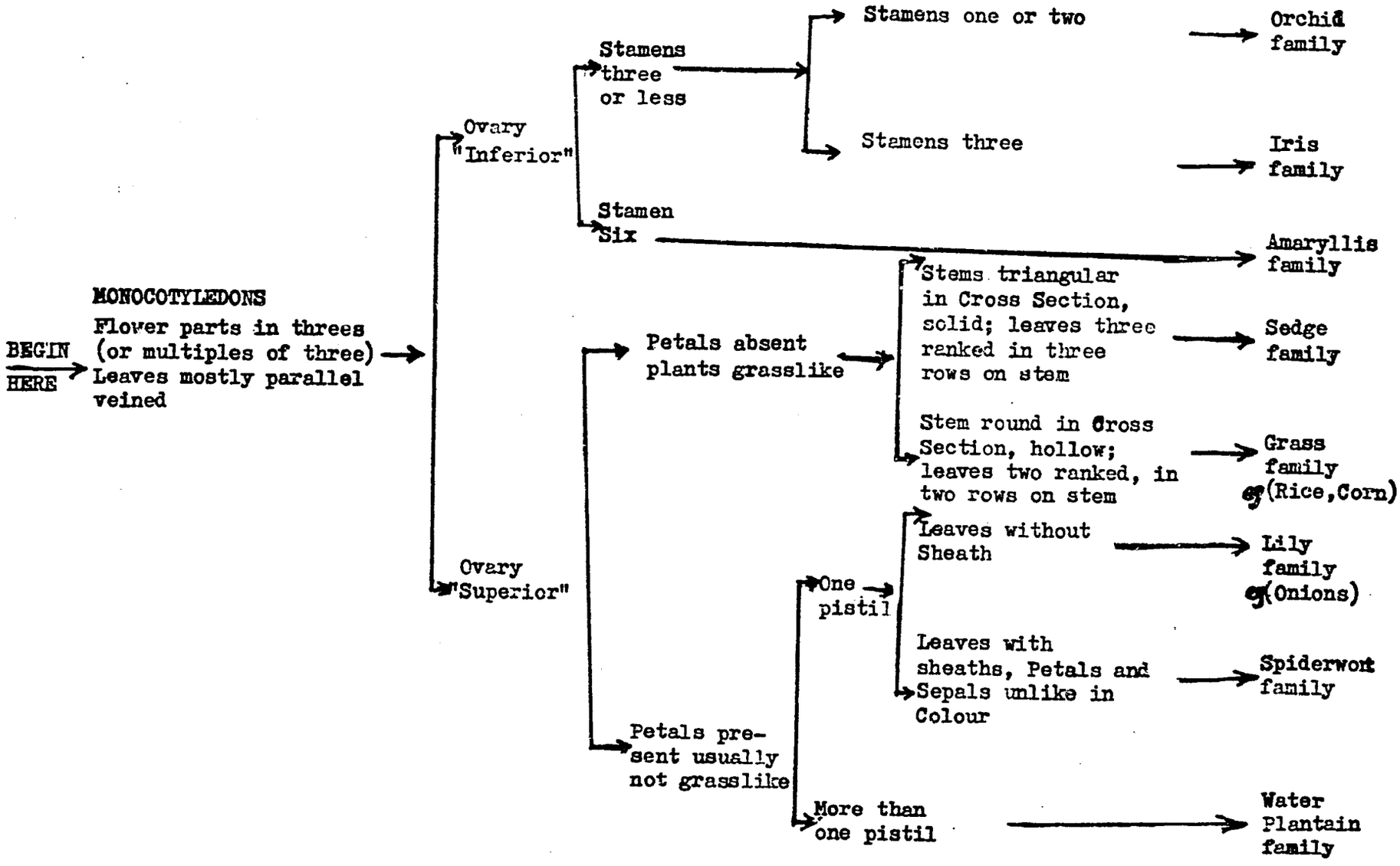
It may be advisable to study the flower before attempting to identify it with the aid of a book.

The following guidelines may be helpful in the preliminary studies:

1. Observe the nature of the perianth and name its parts.
2. Count the parts.
3. Note whether sepals and petals are separate or fused together.
4. Note the number of stamens, their attachments and positioning of the anthers.
5. Count the number of pistils, styles and stigmas.
6. Slice the flower lengthwise through its centre and note the point of attachment of calyx and corolla; (Note also the position of the ovary whether it is superior, inferior or half-inferior.
7. With a sharp blade, slice crosswise through the ovary and identify the carpellary and placental situation.

If these preliminary observations were made on the flower it becomes easier to identify it with the key given. However, it is not sufficient to accept the names determined by the key as final. Further, confirmation need to be sought by comparing the plant in hand with the description of the species whose name was arrived at using the key.


BEGIN HERE
DICOTYLEDONS
Flower parts in fours or fives(or multiples of four or five)
Leaves mostly net-veined
Ovary 'Superior'
More than one pistil
Stamen and Petals apparently on Calyx
Rose family (Rosaceae) e.g. Rose
Stamen and Petals on receptacle
Buttercup family (Raminculaeae) e.g. Clematis
One pistil
Leaves with Stipules
Petals United
Flowers regular
Phlox family Scrophularaua Russèlia, Torenia
Flowers irregular
Figwort family
Petals Separate
Petals four
Mustard family (Cruciferae) eg Cabbage,Coulliflour
Leaves without stipules
Flowers regular
Fruit fleshy
Rose family
Fruit a pod
Flowers irregular
Legume family e.g.(Groundnut,beans)
Ovary 'Inferior'
Petals Separate
Stamen five: Flowers in umbels or in heads
Parsley family
Stamens ten to many flowers not in umbels or in heads
Rose family
Petals United
Flowers in dense heads: plants herbaceous
Sunflower family
Flowers not in heads; plants, woody
Honeysuckle family


BEGIN HERE
MONOCOTYLEDONS
Flower parts in threes (or multiples of three)
Leaves mostly parallel veined
Ovary "Inferior"
Stamens three or less
Stamens one or two
Orchid family
Stamens three
Iris family
Stamen Six
Amaryllis family
Ovary "Superior"
Petals absent plants grasslike
Stems triangular in Cross Section, solid; leaves three ranked in three rows on stem
Sedge family
Stem round in Cross Section, hollow; leaves two ranked, in two rows on stem
Grass family eg (Rice, Corn)
Petals present usually not grasslike
One pistil
Leaves without Sheath
Lily family eg (Onions)
Leaves with sheaths, Petals and Sepals unlike in Colour
Spiderwort family
More than one pistil
Water Plantain family

(iii) CARING FOR EQUIPMENT AND APPARATUS

Introduction

Specific items may have their own requirements which are often clearly stated in manuals or instruction booklets that accompany the items. It is advisable to guard such manuals, to study them carefully and to have them readily accessible for reference by users. It is also useful to have a second copy stored by a person in authority (the senior teacher or chief technician).

Some complex equipment have parts that should only be dismantled by properly trained technicians. Such restrictions are stated in the manuals and should be carefully observed. Miscroscope lenses with many components are one type of equipment which fits into this category.

Usually a piece of equipment will give efficient and long service provided it is installed, used and stored in accordance with the instructions accompanying it.

Some Notes on Specific Items

Lenses should be kept dry and dustfree. One should also avoid touching the glass surfaces. (Our fingers are always moist and greasy and will leave a film of grease that will attract dust and fungi.) Because lenses will easily scratch or break, try not to knock them against hard objects (do not drop them either).

Lenses are usually very delicate therefore care should be taken when they are being fixed into, or removed from an apparatus. One should also turn the screw device on the apparatus gently to avoid damaging the treads

Lastly, lenses should be stored properly. The best method is to store them in a warm cupboard heated with a 15 watt electric bulb. If this is not possible an airtight jar or box (desiccator) with dry silica-gel makes a suitable substitute for storage.

Projectors, cameras and microscopes all have lenses and, if they are removable, should be treated as suggested above.

Projectors are delicate instruments so avoid jarring, especially when the bulb is warm because the filament could easily be broken.

While in use try not to get the microscope lenses wet; if the stage should accidentally get wet, dry it immediately.

As far as storage is concerned, the whole instrument (except for leather cases) should be kept, when it is not in use, in a warm cupboard or a desiccator. The mercury battery of a camera should be removed and stored separately - the terminals should be kept dry.

Tape recorders need to be kept dust-free and dry. Furthermore, it is a good idea to clean the playing head periodically with a dry cloth or cotton wool dabbed in carbon tetrachloride. The batteries should be removed from the tape recorder if it is not going to be used for a considerable period of time. The batteries and the tape recorder need to be stored separately in dry chambers or cupboard.

Related parts of Apparatus and other Small Items

While care of major pieces of apparatus is important and some ideas on their care have been suggested, it is equally important to care for and adequately store related parts for these apparatus. We list some of these and give a short indication of how they should be stored and cared for.

Negatives	avoid dust, moisture; place in desiccator; handle by edge.

Transparencies, Cine Film	avoid dust and moisture. Store in desiccator. Handle by the frame only. It is useful to project these as often as possible.
Microscope slides:	store in boxes, keep dry, free of dust, store in a dehumidified room or in warm cupboard.
Tapes (magnetic tapes)	keep dustfree and dry, and away from strong magnets and currents.
Gramophone records:	keep free of dust. Keep flat or vertically. Avoid heavy weights on those kept flat—keep not more than six in one pile.
Books:	keep free of insects by applying book poison (e.g. mercuric chloride solution) to the inner surface of the covers.
Pins screws, nails:	sort into appropriate cells of divided drawer, keep dry.
Chemicals:	corrosive, inflammable and explosive ones are to be stored separately, and appropriately labelled. Some require special stoppers, containers or submersion in certain liquids, (specific examples—strong acids).
Thermometers:	pad well with cotton-wool or paper when storing, or transporting.

More on Storage

A few general principles should be observed in the storage of various other items. The item should be easy to find again sufficiently quickly: labelling and careful arrangement helps. It is worth finding out what agents may destroy the object or parts of it, and to prevent such agents from acting on it. In so doing, poisonous materials may be applied to the object; this then requires careful instructions on the safe handling of the objects by viewers or users. It is generally useful to inspect stored materials periodically to detect unforseen damage. Below is a list of some of the items usually collected.

Rocks:	store in divided drawers or display cabinets, label, provide cross references to notebooks.
Shells:	store in divided drawers or display cabinets, provide cross references to notebooks.
Bones:	as for shells, where they are assembled as skeleton of animal, keep in rigid box, padding with cotton wool or sawdust (or other soft material).
Herbarium specimens, and museum specimens (insects etc.):	keep dry prevent destruction by moulds and insects by applying suitable poison (e.g. a few grains of paradichlorobenzene in the box). Warn users of these poisons —users should wash hands with soap after handling the specimens.
Museum jars holding specimen in a fluid:	watch drying up of the fluid; top up the fluid and seal properly.
Dry seeds, fruits, bark:	treat as for herbarium specimens against any insect damage.
Wood (hand specimen):	some may be kept dry in box with paradochlorobenzene; some may be varnished.
Pollen:	store in desiccator.
Photographs:	in album, indexed.

(iv) TOOLS

Many scientists regard their early training in the manual skills as their greatest asset and one of the most important parts of their education. The science teacher who has a knowledge of how to use tools and materials can give originality to his teaching and he can keep his equipment in good working order at all times.

Once a teacher has mastered the basic techniques and seen how easy it is to create and construct apparatus, he can present opportunities for his pupils to construct their own apparatus. The energy of a pupil can be geared to an exciting science programme by a confident and enthusiastic teacher who is familiar with modern methods and equipment. That pupils must do things if they are to learn cannot be over emphasised.

In a science course where the apparatus is constructed by the pupils, it is possible to lay emphasis on first hand experience. A pupil who is able to construct his or her own apparatus can carry on his science education outside as well as inside the classroom. This section outlines some techniques of making, using and caring for tools.

Making of Tools

In addition to the basic tools that could be bought from tool shops the teacher is urged to construct some from local materials. The techniques for making these basic tools can be found in the APSP Unit " Tools in the Classroom ". Below is the list of basic tools which will enable a teacher to make and repair a great deal of apparatus.

Hammer
.3m Tenon-saw
Screwdriver
Pair of pliers
Soldering iron (medium size)
Trimming knife
Steel metal saw
Iron plane
Nail punch
Chisel
File
Brace
Vice
Tinsnip

Using of Tools

Hand Saws

When using the hand saw in sawing wood the following points are worth remembering:

(*a*) Modern saws are designed to cut on the forward stroke and this is where the effort should be made.

(*b*) Use the whole length of the saw. The teeth run the whole length of the saw and there is less effort in using the whole length at each stroke.

(*c*) When starting to saw, guide the blade with the thumb and always start with a back stroke.

(*d*) Always cut on the waste side of the line allowing about 1 mm for planing.

(*e*) The cut-saw is designed to cut across the grain of the wood.

(*f*) The rip-saw is designed to cut along the grain of wood.

The Hammer

The biggest fault with people when using a hammer is to hold it too close to the head. A hammer is designed to have a handle of certain length and if it is held near the end of the handle then it is properly balanced for use.

The Chisel

There are many uses for a chisel but these rules cover all of them.

(*a*) Never have any part of the hand or body in front of the cutting edge.

(*b*) Never use a metal hammer with a chisel; always use a wooden mallet.

(*c*) Whet chisel frequently.

The Screwdriver

In using the screwdriver it must be borne in mind that

(*a*) The tip of the screwdriver should be similar in size to the slob of the screw.

(*b*) In the piece to be fastened, drill a hole slightly wider than the shank of the screw.

(*c*) Friction may be reduced by rubbing soap on the thread of the screw.

The Brace and Bit

When using the brace, it is important to observe the following:

(*a*) Hold the brace perpendicular to the wood and bore a hole until the feed-screw shows on the far side of the wood. Then stop at this point and turn the wood to bore the hole out from this side.

(*b*) The head of the brace is pressed against the body and supported by one hand. The handle is then rotated by the other hand.

The Plane

When using a plane the following techniques may be found useful:

(*a*) Both hands should work together and exert an even pressure.

(*b*) When planing the end of a wood do it just half-way then reverse the wood and start from the other side.

(*c*) Keep the blade well whetted and avoid all nails in the wood.

The Hand Drill

The hand drill is used in drilling hole in metal. In using the following techniques must be adhered to.

(*a*) Mark the centre of the hole using a sharp pointed metal tool.

(*b*) When drilling clamp the metal securely.

(*c*) Use lubricant to prevent over-heating which may destroy the ' temper ' of the tool.

The File

For rough and finished filing the following must be observed.

(*a*) Clamp the work securely in a vice.

(*b*) Keep the file level but held at a slight angle to the work and grip in the hammer.

(*c*) Pressure is applied in the forward stroke only; lifted slightly and withdrawn.

Care

(*a*) Files must be cleaned with a wire brush.

(*b*) Avoid heating a file as it will destroy the " temper '.

(*c*) Never use a file without a handle on the tag.

The Soldering iron

Since the job to be soldered must be cleaned, it follows that the soldering iron must also be cleaned. It must also be properly tinned, i.e. coated with a layer of solder. The following points may be borne in mind.

(*a*) The iron is heated to the proper temperature.

(*b*) The cleaned petal is placed on an asbestos board and flux is applied to the surfaces to be soldered.

(*c*) The solder should be tacked in several places holding the pieces of metal together with a file or screwdriver.

(*d*) The hot, tinned, soldering iron is placed at one end and held there until the metal. gets hot enough to make the solder flow like water. The iron is then drawn slowly along the seam.

Caring for Tools

Caring for tools involves proper usage, proper storage, sharpening and grinding. Most tools are made of steel and they may rust quickly. Hence all tools should be wiped over fairly frequently with an oily rag; moving parts should be kept oiled. It is worth spending time and trouble in the proper storage of tools. All too often the science teachers' tools are thrown into a box or a drawer and suffer considerably. Tools are best stored hanging on racks or on hooks or clips on the wall. The wall should have a large board fixed to it and the racks and hooks should be fitted to the board.

Sharpening

If a tool is properly used it should not require major attention very often. Unfortunately, very few science teachers use tools properly and since most of the tools used for wood-work and for metal work are for cutting, the cutting edges become worn and chipped. Hence they require sharpening.

Saws

Sharpening of saw is a skilled job and an amateur's effort may ruin the saw. It is therefore safe to send to skilled men once in a year.

Chisels, Planes and Knives

These may be sharpened by the following techniques:

(*a*) Some oil-stone dressing is placed on the stone.

(*b*) The blade is placed so that the cutting edge and heel rest flat on the stone.

(*c*) The heel is slightly raised about 5°.

(*d*) The blade is moved back and forth over the oil-stone in a circular or figure-of-eight motion. Keeping the hand parallel with the stone.

(*e*) The blade is then turned over and held flat on the stone, then rubbed for a short time with the same motion as before.

Grinding Tools

If the blade becomes chipped or the proper bevel needs restoring, the edge must bet ground. In grinding the following techniques may be followed.

(*a*) Adjust the tool-rest so that the blade resting on it is at approximately the correct angle (25°–30°) and the stone is rotated towards the blade.

(*b*) The blade is held slightly against the rotating wheel and moved from side to side.

(*c*) The blade must be dipped frequently in water to prevent overheating.

(*d*) It must be checked to see that the cutting-edge is straight and at right angles to the side of the blade.

It is evident that the acquisition of the techniques of making, using and caring for basic tools in the laboratory is to develop confidence on the part of the science teacher in his ability to construct apparatus himself.

Improvisation

Improvisation here may mean using something different in place of the usually acceptable material to serve the same purpose. Similarly, modifying a piece of equipment to serve a purpose different from what is usually known may be regarded as improvisation. The third aspect of improvisation implies designing and constructing a piece of apparatus from materials obtained from local resources.

This section is concerned with the techniques of constructing simple pieces of apparatus from local materials. The emphasis is always on simplicity. Owing to this simplicity the scientific principles that a teacher is trying to emphasise are more easily understood completely than in the case when the apparatus is complex.

If we can encourage teachers and teachers-in-training to produce some apparatus themselves where they have not done so before then this section will have served the purpose for which it is intended.

Making a smokeless burner

In places where there is no coal gas, it is necessary to use other sources of heat. When a high temperature is needed, a stove which burns charcoal is very useful. It is easy to make such a stove from four gallon petrol or paraffin tin.

Materials needed are 4 whole bricks
2-1/3 bricks
Iron sheet
4 gallon paraffin tin

A number of holes are made in the iron sheet with a cold chisel or with very large nail. The tin is also cut so that there is enough to make a turned over edge, so that about a third of a meter height is allowed and turned 1.1 cm inwards. An air-hole 15cm x 15cm is made in it, and the edges used in holding the bricks.

The diagram below explains the technique more

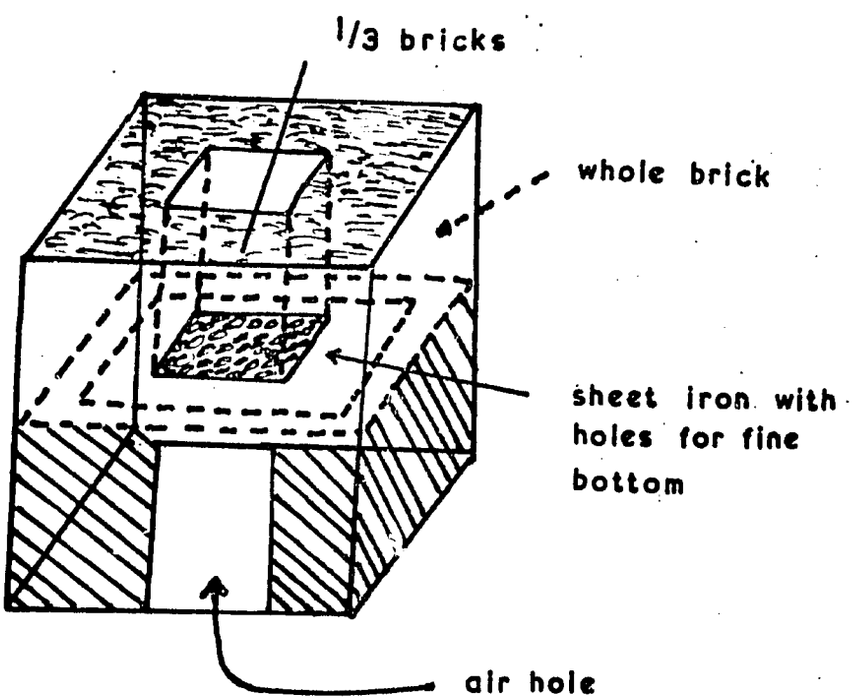


Diagram of Charcoal Stove

Techniques of constructing Spirit Burner

For a gentle heating any metal capped bottle may be used. A hole is punched in the cap. Then a wick is made to fit the hole tightly. This wick may be made from two or three strands of cotton waste or old shoe laces.

References to construction of pieces of improvised equipment can be obtained from:

(1) Unesco Sourcebook for Science Teaching

(2) Techniques and Apparatus for the Science Teacher, Beleson & Creaser, O.U.P.

(3) Making Elementary Science Apparatus

Safety in the Laboratory

It is impossible to list all the safety rules, that must be observed in the laboratory, but here are a few rules or suggestions that should guide the teacher when dealing with tools, machines, chemicals, general science apparatus, glass tubings, other glassware and high voltage electricity, etc. It is the duty of the teacher to make each student safety conscious and also to be safety conscious himself in and outside the laboratory. This list of rules is simply to remind the teacher so that he can in turn remind his class.

1. Deposit all oily rags into a metal container.
2. Never bring any unknown liquid near an open flame.
3. Never clean off a work-bench or laboratory table with your bare hands. Always use a brush or wooden scraper.
4. Place all scraps of wood, metal and glass into the rubbish bin immediately.
5. Store kerosene, petrol, benzene and all other inflammable liquids in approved fire-proof containers. A fire extinguisher or a bucket of sand should be available.
6. Always wear goggles or an eye shield when using a grinder.
7. When gas stoves and bunsen burners are to be used, instruct the students as to the proper method of lighting them.
8. Check all gas-hose connections regularly for leaks.
9. Do not plug in any device or project that you have made until you have checked the circuit thoroughly.
10. When inserting a glass tubing into rubber stoppers lubricate the tube and the rubber stopper with soap and water or petroleum jelly. Grasp the tubing close to the end entering the stopper and force the tube into the hole using a rotary motion.
11. Handle all corrosive substances with care. Always add acid to water.
12. Store containers of dangerous chemicals like acids and alkalis on the floor or on a low shelf. Be sure to label all bottles. Discard the contents of unlabelled bottles.
    Note:—Many safety posters are available from insurance companies or industrial plants.

Accidents however do happen inspite of strict observations of these rules therefore the science teacher must be prepared to deal with them. The laboratory rule, " Report all accidents immediately " should be known and understood by all students. The teacher must know how to deal with them immediately. The immediate aid box and fire fighting apparatus must be in good order at all times.

Immediate Aids

The aim of the immediate aid is to stop the sick man from dying at once. The teacher's role in this case is to give immediate aid and send for help.

The DO's and DON'Ts are;

1. Do stop bleeding
2. Do prevent shock
3. Do send for help.
4. Don't move the sick man unnecessarily.

How to Stop Bleeding

The dangerous kind of bleeding comes from the arteries and cause death in a matter of seconds. The signs of bleeding from the arteries are:—

Blood is red

Blood comes out in spurts

Blood comes from the heart side of the wound

The action to be taken therefore is:

1. Squeeze the main artery of the limb.
2. Put a pad and very firm bandage on the wound.
3. Raise the limb.

In all cases it is necessary to put a pad on the wound bandage and tie the bandage over the wound. If it is found that one bandage does not stop the wound, another one may be put on top of the first.

How to Prevent Shock:

There are two kinds of shocks, first shock and second shock. All wounded suffer from first shock. It looks like a faint. There is pale, cold skin, a weak or absent beat of the heart in the arteries and shallow breathing.

The action to be taken in this case is to keep the wounded man quite warm with blanket or any heavy clothing.

The causes of second shock are tearing of flesh, loss of heat, loss of liquid and pain due to wrong handling immediately after an accident.

The action to take is to leave the wounded person lying in the position in which he is found, and keep him warm with blanket. The only reason for moving a wounded man is to prevent him getting hurt more. It is necessary to move him from fire or from an electric wire or falling house. (Remember to switch off the electricity before removing a man or electric wires).

Following are a few specific accidents and how to deal with them immediately.

Acid in the eye	Wash with plenty of water and then Sodium bicarbonate 1%
Alkali in the eye	Wash with plenty of water and then 1% of boric acid
Poison with sufferer conscious and burns in the mouth	Wash mouth with much water, egg white, or milk
Poison with sufferer conscious with no burns in the mouth	Give salt and water to make him sick, then castor oil or milk or egg-white.

Burns

Put out the flames by putting the man on the ground and beating out the flames. Then treat for shock.

It must be borne in mind that even though accidents are few in a good laboratory, it is necessary for the teacher to have some training in immediate aid. It tells the teacher what to do and what orders to give to in case of accident.

Safety outside the Laboratory

Accidents do not only happen in the laboratory. They may happen in the field, in the garden, etc. The most common accidents that happen in these places are falls, bites from poisonous animals, cuts from tools and breaking of skin by wooden splinters, etc.

Bites from Poisonous Animals

As soon as it is realised that some one had had a poisonous bite, the action to be taken is to stop blood flowing towards the heart by pressing the vein a few centimetres away from the point of bite between the heart and the bite. A slight incision of the affected place using a blade dipped in milton or dettol will help the poison to flow out with the blood. Then send for help immediately or take patient to hospital for treatment.

Falls

The victim may be treated for shock as described earlier in this section.

Cuts and Breaking of Skins

These may be treated with antiseptic and plastered. It is however necessary for the patient to have tetanus injection in a hospital.

CHAPTER 20 PART II—METHODS

OBSERVING ORGANISMS IN THE WILD

(*Observing Outdoors*)

(*Outdoor Observations*)

Introduction

We refer to observations made outdoors in the natural setting as field observations. Thus if we observe a weaver bird weaving its nest in a tree, or if we observe the opening of the flowers of a forest plant in the forest itself, or if we observe a cloud forming, these are field observations.

It is difficult to draw a sharp line of demarcation between field and laboratory observations. However, it is useful, as far as possible to check what we find in the laboratory against what happens in the field, if we are to be sure that the laboratory observations reflect correctly what happens in nature. One set of observations may illustrate the other. Some animals may behave differently in captivity: some may not feed or may not breed. It is thus necessary to complement our laboratory findings or experiments with field studies.

Some of the remarks we make apply equally to laboratory and field observations.

One advantage of laboratory observations is that we can control the various factors, for example, period of light, temperature, food and diseases to which the organism under study is subjected. Also we can make observations in the laboratory or indoors late in the night or at awkward times. This is useful up to a point. In the field, however, we usually have much less control over such environmental factors. Thus we can more readily explain laboratory findings scientifically (if only our experiments have been properly conducted) than we can field observations. On the other hand certain phenomena may just be impossible to observe in the laboratory, as we have indicated above.

Nature is one vast limitless resource for our scientific studies. With some patience we can derive much pleasure and knowledge reading the open book of nature. At the least we can start various investigations, some of which we will have to continue indoors or in the laboratory.

Our immediate tools are our senses and our brain. Of course, we extend these with various aids such as the thermometers, telescopes, microscopes, calculating machines, etc. We consider some of these tools later.

Importance of the Notebook

The notebook is an important extension of and an aid to our memory. We may have so many observations to consider that we may easily forget them unless we note them down in an orderly manner in our notebooks. (We sometimes condense such information in suitable graphs, statistics or equations). Besides some observations may be slow in accumulating; if we do not note down the first observation, we may have forgotten it by the time we make the second one. These considerations apply equally to quantitative data. Furthermore we may be interested in derived quantities based on our original observations; an example is the rate of growth of an organism or a population, between successive observations. Such derived quantities can be calculated from the data assembled in our notebooks.

It is not only verbal descriptions and quantitative data that we enter in our notebooks. We can also include labelled sketches, plans or outlines of our investigation, questions that occur to us, tentative conclusions, calculations—whatever we would later like to remind ourselves about. A good illustration of children's notes is found in Section IV of Handbook for Teachers (S.E.P.A., 1974). For adults the notes may be sophisticated, but we should not expect elaborate notes from children or adult beginners.

How can we judge the adequacy of notes? The following questions may be useful in this regard.

Is the statement clear, even if not a complete sentence, so that I myself or another person can readily understand what is meant?

Is the sketch large enough and clear enough, so that others can recognise the object?

Do the notes, drawings, measurements, indicate the aspects, etc. that I set out to show?

Have I included the appropriate units (e.g. measurement of length of insect in mm)?

Generally, it is useful to ask before collecting notes: " What would I like to show? " It is then easier to check later to find out if we have achieved our intentions.

Extensions to the notebook are various other records that we can make: examples are photographs, cine films, tape recordings, traces made by special recording instruments, specimens of the object studied, (e.g. rocks, feathers, leaves, stuffed birds). It is generally helpful to add a written note that remind us about, or draws another person's attention to, the point of interest in the record or display.

To see our scientific efforts growing and developing, we should *date our records and notes*.

When we find ourlseves at a loss what notes to put down, we can resort to the five basic questions: What? Where? When? How? Why? They will often help us generate questions on the phenomena or object under study and lead us to interesting discoveries that we may note down.

Many beginners in science are tempted to preserve the fine copies of their notes, and to discard the original brief notes and possibly simple and scruffy sketches and rough calculations. The original notes are valuable, and show our thinking much better, in many ways, than the polished account that we later construct out of them. It is generally advisable to preserve our original notes. Sometimes they reveal interesting information the significance or importance of which did not at first occur to us, until we later made some other observations.

Use of Sketches in the Field

Sketches made directly in the field can be a full record of findings or may supplement other records. It is essential the sketch should be made in the presence of the object, rather than later, out of one's memory, if it is to be a reliable record.

In a study of the rocks exposed in a road cutting, the relative extents of various layers of interest or directions of folds or layers may be shown at a glance in a labelled sketch.

Similar remarks apply to many other phenomena we may study in the field.

An interesting record of a naturalist's impressions is Cott's Uganda in Black and White (H.B. Cott, 1962, Macmillan, London).

Useful Tools

With practice you will find what tools you find most useful for field observations, depending on your own interests, on the particular locality you investigate, and how much you or your team can comfortably carry into the field.

A number of the following are of general use, but they are not exhaustive by any means: pencil, pen, notebook, pocket-knife, binoculars, collecting tubes, bags and envelopes, or vasculum, wrist watch, tape measure, compass, handlens, pocket microscopes, camera, tape recorder, geologist hammer, cutlass, hand shovel, pickaxe.

Decide and revise your own selection of useful tools.

It is worth keeping a list of your tools and checking you have collected all of them before leaving any one collecting spot. It is very easy to forget a tool in the field. Alternatively a tool kit in which each tool has its own marked place serves as a good reminder when you are packing your tools-- any gap immediately warns you of a missing tool.

Safety Precautions

In unfamiliar areas, such as the deep forest, or where there are dangerous wild animals, you need an experienced and properly armed guide, who will provide the necessary instructions It is important to follow such instructions.

It may be possible, on an expedition, to carry a medicine or first-aid box with suitable ointments, etc., for insect bites or bruises.

It is generally advisable not to ingest unfamiliar fruits or seeds, as these may turn out to be poisonous. An experienced guide familiar with the wild plants species of an area will be able to offer useful guidance on this.

Special precautions are necessary near cliff edges or edges of quarries, muddy areas, on rivers, and during rainstorms in the forest.

Useful Field Guides

Each area may have its own specific field guides. Where these do not exist, some general ones may be used this itself is an opportunity for you to compile a specific guide to your area.

There may be guides to the geography of a particular locality, maps, guides to the rocks of an area, the stars visible from an area, or such other things as soils, vegetation, plants, animals generally, birds, mammals, insects, to be found in that area.

In some cases, the various living things to be found in one habitat may be in one guide, e.g. plants and animals of the rock pools of East Africa, organisms in ponds.

Inquiry from experienced school, college or university teachers, librarians, or other amateur scientists, may enable you find the most useful guides for your area and interest.

The guide will help you identify an object you come across, and may tell you a little about it. You can verify this from your own observations and add to it. You must not forget to make your own records in your notebook. In some cases you may wish to build up your own collection of a particular group of objects or to send specimens to the school, university or national museum to be added to the existing collections. Such gifts are always welcome, but should carry adequate notes and, where necessary, should be suitably preserved. Where you expect to make such gifts, it is a double investment to make your intention known, and to learn the appropriate methods of collecting and preserving the particular specimens from the Curator in charge of the laboratory or museum before you go collecting.

What are adequate notes? Generally these should include the name or local names, if known, the place where the object was found, notes on the habitat, time and date of collection, the state of the object, the name of the collector, any other information you think may be useful to others.

It is worth noting that your own observations in nature may throw new light even on a well known object or species. Remember that the naming of the object or species is only a small part of its scientific study. A useful rule is to regard the name as the beginning of the scientific investigation of the object. Also, do not worry if you do not remember scientific names of various species you encounter. The more often you meet them, the more likely you will be to remember these.

Books such as the following may be of some use to you in your field work:

Rocks:

McCallien, W. J., 1952: *The Rocks of Accra, Ghana*, University of Ghana. (A Guide to the Coast Along High Street.)

Shepherd, W., 1962: *Rocks, Minerals and Fossils*, Weidenfeld & Nicolson, London (For the beginner).

Hamilton, W. R., Woolley, A. R., and Bishop A. C., 1974: *The Hamlyn Guide to Minerals, Rocks and Fossils*. Hamlyn, London (Advanced).

Soils

Russell, E. W. 1961 *Soil Conditions and Plant Growth* 9th Edition Longmans, London.

Richards, B. N. 1974: *Introduction to the Soil Ecosystem* Longmans, London.

Clouds:

Ludlam, F. A., and Scorer, R. S., (1957): *Cloud Study*, Murray, London.

Stars:

Sidgwics, J. B., (1957): *Introducing Astronomy*. Faber and Faber, London.

Menzel, D., (1964): *A Field Guide to the Stars and Planets*, Collins, London (Advanced).

Worvill, R., (1973): *The Stars and their Legends*

Animals:

Elgood, J. H., (1957): *Birds of the West African Town and Garden*.

Booth, A. H., (1960): *Small Mammals of West Africa*, Longmans, London.

Street, P., (1961): *Shell Life on the Seashore*, Faber & Faber, London.

Campbell, B., (1959): *Bird Watching for Beginners*, Penguin, Hammondsworth.

African Primary Science Programme. (1969): *Small Animals* (Teachers' Guide, Trial Edition).

E. Dance, S. P., (1972): *Seashells*, Hamlyn, London.

Plants:

Gledhill, D., 1972: *West African Trees*, Longmans, London

General:

Shell East African Nature Handbooks

Observers Books (East African?)

Harris, R., 1969: *Natural History Collecting*. Hamlyn, London.

Guide to National Parks of East Africa.

Younge, C. M., 1963: *The Sea Shore*, Collins, London.

UNESCO, 1975: *Teachers' Study Guide on the Biology of Human Populations*. Africa. The UNESCO Press, Paris.

MICROSCOPY

A microscope is a device for making very small things look larger than they really are and to show us objects that are too small to be seen at all with the unaided eye. With the help of the microscope a vast world of tiny plants and animals, all very small has been discovered. The microscope has enabled man to find answers to questions like how hairs grow, how substances like bone and wood are constructed.

A microscope in unskillful hands may not seem to come up to expectations but the same instrument in the hands of an expert can provide endless wonderful results. It is therefore necessary for teachers to know how to get the best out of this instrument. To be able to use them effectively one must have at least a rough idea of how it works. However, this section is mainly concerned with some specific techniques of microscopy.

Microscopic work involves a complete knowledge of techniques of the preparation of specimens; plus mounting and operating the microscope. Thus the various techniques employed on these operations have been outlined to enable tutors to be familiar with proper handling of things in microscopy.

Preparation of Specimens

Every branch of microscope work has its own techniques and special apparatus. Some of the processes employed are extremely elaborate and involve the use of a great number of chemicals and physical reagents, but there are several quite simple operations that one can learn to perform.

The apparatus needed may be a small pair of scissors, a pair of pointed tweezers, a packet of one edged razor blades, a few needles fitted with handles.

One or two jars, one or two saucers, a few pieces of glass tubing, a little rag for wiping purposes. Instead of saucers it is more convenient to use small glass or china dishes if they are available because we shall be dealing with very small quantities of liquids.

Occasionally a spirit lamp may be needed. For cleaning slides and cover slip it is generally sufficient to use warm water with detergent or soap if they are greasy, but they must be thoroughly rinsed.

An eye dropper may also be of help in taking small quantities of liquid, but a piece of plain glass tubing may also be used. To take a specimen from jar of water, the tube is held with one finger over the top to seal it. It is then dipped into the water so that its lower end comes over the specimen. The finger at the top of the tube is raised and put back immediately. Then the tube taken out of the liquid and transferred into the other container by gently lifting the finger at the top to allow air to enter the tube gradually and this would make the liquid flow slowly from the tube.

Many a time it becomes difficult to observe moving organisms under the microscope The observer would require to slow down the movement of the organism or stop it entirely in order to observe well. There are several ways of slowing down the motions of small animal so that they can be studied. With creatures as large as water fleas, one way is to draw out some of the water, leaving them just sufficient to swim in. Another way is to put a little pressure on the cover slip so as to hold them still, but not enough to squash them. Gentle pressure may be put on the cover slip with the two points of an open pair of tweezers, usually the weight of the tweezer is sufficient.

An easier way altogether is to thicken the water with jelly or gum. Some people use 'guince mucilage' for this purpose. Quite good result can be obtained with one of the Cellulose pastes sold for paper hanging, such as "Polycell". A few grains with a dessert spoonful of water will make a thick slime if allowed to stand for say ten minutes.

Still another way is to 'stun' the animal or put them to sleep. This can be done by bubbling carbon dioxide through the water in which they are found.

Plant Sections

Some of the most beautiful and interesting specimens for low power examination are obtained by cutting sections across plant stems. These must however be very thin and should be cut in the following way.

Depending whether one is right handed or left handed, the piece of plant stem is held in one hand and a new razor blade is held in the other hand. With both elbows resting on the table. Thick pieces are first cut off the top of the stem to leave a flat surface for the next cut. Cutting should be done by drawing the blade side ways, so as to slice it, never pushing it against the stem to crush the cells. Always the cutting should be be done with the blade moving towards the person.

Now for the next cut; this must be as thin as possible, for it is to be the object of study. It takes a lot of practice to make good thin sections, but it is a good idea to make several cuts in succession while the hands are in position. The sections will stay on the blade in a row, and when it is full the best ones can be selected for subsequent treatment.

Very Delicate Stems:

Various methods have been devised for dealing with stems that cannot be held properly without squashing them. One is to grip such stem between two pieces of cassava pith, which can be obtained from inside a cassava twig. A piece of raw carrot or soft cork can be used in place of pith.

In using a raw carrot or cork it is necessary to slice it down the middle and in each half groove a suitable size to hold the stem firmly when they are put together again. In cutting the section the pith, carrot or cork as well as the stem are cut through.

Fixing and Staining:

Having cut a few sections, the next task is to fix them. All tissues from living things require fixing, which means killing them or preventing decay without destroying their structure. To fix your plant sections, allow them to float off the razor-blade into a small dish containing milton fluid. At first each section is seen to be covered with tiny bubles, but these will soon clear and the sections will sink to the bottom. Very thin sections may be needed to soak for only a few hours, but it is well to leave them in over night by which time they should be thoroughly blenched and all the contents of their cells disappeared.

They must then be washed; which simply means transferring them with a needle to a vessel of clean water leaving them for about ten minutes and transferring them again to more clean water for half an hour. The less easily seen parts of a plant section can be made clearly visible by staining them. The various processes of staining can be very elaborate, but only the simplest method will be described here. The specimens are thoroughly washed in distilled or at least well-boiled water and placed in a solution of Delafield's haematoxylin diluted with equal quantity of water.

The specimens will stain a violet colour in about ten minutes, when it can be taken out and soaked in tap water until the colour turns blue.

A more perfect result is obtained if the haematoxylin is diluted to a pale violet colour at the start and the specimens are left in it for several hours, and afterwards in tap-water for twenty four hours.

Clearing and Mounting

Specimens which have been carefully prepared whether plant sections (stained or unstained) or any other type of object, are often worth mounting permanently on a slide. For objects which are easily soaked in water the simplest way of doing this is to lay the wet object in the centre of the slide, covered with a drop of water glass and lay a cover slip on top. This would take several days to dry or set.

After setting it is finished off by "ringing" with black bitumen cement before being ringed the slide is carefully wiped clean all round the cover slip and dried. Then the juction at the edge of the cover slip is sealed with cement to prevent moisture from getting in. The cement is applied with a small paint brush. Sufficient bulk being made by adding layer upon layer.

Another technique of mounting objects is that the object must be thoroughly dried which means not only removing the visible water but also the water which may have absorbed. This is most conviently done by immersing them for an hour or more in alcohol. For objects that are not obviously wet such as the head of a gnat or the leg of a fly should be treated in the same way to remove the moisture that may be inside them,.

When the specimens are taken out of the spirit they may be cloudy or insufficiently transparent, so the next process is to clear them.

This clearing may be done with oil of cloves. They should be left in the oil until they sink to the bottom and appear transparent which may take half an hour or more. They are then put into turpentine for ten minutes to remove surplus oil. They are now ready for mounting in Canada balsam.

The mounting may be done by putting small drops of warmed balsam in the middle of the smear, then drop a clean cover slip over it and gently press down. If the cover slip does not easily go the slide is held above a spirit lamp flame to warm slightly. It is necessary that the balsam should reach right to the edge of the cover slip and ooze out a little over the slide.

If there is a lot of surplus balsam or the slide it can be wiped off with a rag dipped in xylol, but attempt should not be made to clean it properly and the rag should be kept clear of the cover slip. The slide is then set aside to harden, which may take several days.

To mount a fly's wing or a plant section (stained or unstained) or any other such object, the specimen is immersed in xylol for two to three hours. Then a clean slide is obtained and a drop of warmed balsam is put in the centre. The specimen is put on the balsam and arranged nicely using two needles dipped in xylol. After that a cover slip is dropped over the top and finished as before.

In case air bubbles appear under the cover slip they can be removed by warming the slide.

Both balsam and xylol are inflammable therefore keep them away from naked flame as much as possible.

Mounting Thick Specimens:

If a specimen like insects head or some object that is thick enough to make the cover slip rock or which would squash if the cover slip is pressed down then the cover slip may be supported by inserting small fragments of from a broken cover slip at three or four different points round the edge. These are best put roughly into position at the same time as the specimen. When the cover slip has been put on, any projecting pieces may be pushed flush with its edge with a niddle.

Another way is to cement a thin ring of the size of the cover slip to the slide first rings can be cut out of sheet of alluminum with scissors or from card. The neatest way to stick the ring is to dip it in balsam. Let the balsam drip off and then lay it in the centre of the slide. It must be allowed to set before proceeding further. When the slide is ready the object can be mounted in the same way as before. The space between the rings must be filled with balsam until it begins to overflow. The cover slip should rest exactly on the rings, but it is better for the rings to project slightly than for the cover slip to overlap it.

Mounting Opaque Objects:

To mount objects intended for top lighting, such as a piece of butterfly wing, a small beetle or sporangium of a fern a slide cut out of black cardboard may be used. The sticking medium may be any kind of gum, but transparent cellulose adhesive are better.

The first step is to guage the thickness of the object and cut a ring of thin cards which can be placed on top of another to obtain a thick ring. Then the cell is stuck neatly in the centre of the ring. The object is to be attached with gum also but before that is done, it must be perfectly dry. In the case of a large object, a single small drop of adhesive should be placed in the very centre of the ring. When the object is put in it, it will completely hide its attachment When the object has been mounted the slide is put in a warm place to dry. Then the cover slip is put on it while it is still bone dry.

Insect Subjects:

To examine insect subjects at a higher magnification, it is necessary to make them flat and transparent. The following techniques may be used. Assuming the insect has been caught and killed without any damage to any of its parts, it can be kept in a small bottle of methylated spirit for any length of time until ready to be worked on.

The insect is soaked in water for four hours and transferred to a small vessel of caustic potash solution or caustic soda solution. The insect can remain in the solution for one or two weeks depending on its size and nature. It is then transferred to pure water which must be changed several times until all the potash or soda solution is washed off. After that the water is poured off and the insect is covered with acetic acid for two or three days until one is ready to work on.

The next thing to do is to transfer the insect to a shallow dish of water and spread out its wings, legs and other parts which may cling together by means of small paint brush and setting needle. The insects body can now be emptied by using a small cork or a short length of round pencil. The cork is placed on the head end of the body and gently rolled towards the tail applying slightly pressure to squeeze out all the internal juice.

When the insect appear to be a hollow skin it is transferred to glass microscope slide and the water is drained off. The parts are then arranged for a good display then another slide is placed on top and pressed flat. The insect is left in this position for a day or two.

The next step is to separate the slides carefully and wash the specimen into a dish of alcohol. After half an hour it may be removed by means of a brush and put in a dish of oil of cloves to clear it.

The final stage is to immerse the specimen in turpentine or xylol for a few minutes to remove the oil. Then it is placed in the centre of a final slide. The turpentine is drained off as much as possible, then the parts are arranged nicely and a small drop of canada balsam put on it. The cover slip is placed on the balsam and pressed gently down and finished off. This is then ready for use.

Using the Microscope

Although many teachers are quite familiar with the use of microscope there are basic techniques which will ensure the safety of the instrument and mounted slide and also its proper performance. Very often these techniques have been overlooked for one reason or the other resulting in the poor performance of the instrument. This section assumes complete knowledge of the parts of the microscope and how to use it.

Focusing:

One of the most important operations in the use of microscope is adjustment of the instrument to bring the object into focus. The technique in doing this is to lower the objective by means of the coarse adjustment until its bottom is about a height of two mm above the specimen. This must always be done without trying to look through the microscope for unless one watches what is being done one is likely to jam the objective down on to the specimen and this may quite easily crack the slide and the front lens as well. The idea is to have the lens definitely lower that it will have to be when it is in focus. This means the first movement, while actually looking through the microscope, is to raise the objective.

Care of the Microscope:

The microscope is a precision instrument and needs treating with respect. Always it must be put away in its box, or under a cover when not in use. It must not be left at places where it is likely to be exposed to steam and smoke or kept near chemicals, vinegar and any substances liable to give off fumes.

The brass parts are usually lacquered and should never be cleaned with metal polish. A dry duster or chamois leather should be used to remove dust from the metal parts, but not from the lenses. If by accident a stain appears on the microscope tube, it may be wiped off with damp cloth or a little benzine, but on no account should methylated spirit or alcohol be used as these will immediately remove the lacquer and spoil the appearance of the microscope It may even damage a moving part by carrying a sticky solution of lacquer into them.

When lifting the microscope it is always necessary to hold it by the limb with the hands well clear of the knobs, stage and lenses. The microscope has been set to work smoothly and any undue strain on the wheels might do damage to it. For the same reason no attempt should be made to undo screws or take the microscope to pieces.

Lenses:

The lenses of course, require special care. The eye pieces and the objectives are supplied without any dust inside and none can get in unless they are tampered with. The inside surface of the lens should never want cleaning. If they appear misty it can only be due to condensation, but it is difficult to imagine how this could happen unless they are unscrewed often.

Anyway, condensed water may be wiped off with a soft rag. The first rule for lenses is to clean them as little as possible. The second rule is that before wiping blow on then first to get rid of any loose dust.

The mirrow and the condenser lenses may be cleaned with a soft rag, but these are less liable to suffer important damage. Never allow liquids to dry on a lens.

Fine Adjustment Screws:

If the microscope has a fine adjustment it will be found that this has a very short range of movement: To guard against the wheel reaching the end of movement when in fact it need to be moved, it must always be turned to a midway position before focusing begins. All large movements should be made with the coarse adjustment screws before using the fine adjustment.

References in Microscopy

1. *The Microscope made easy by* A LAURENCE WELLS. Fredric Warne & Company Limited London (For more Techniques and more about collecting specimens especially from ponds and the Sea)

2. *The Microscope and how to use it: by* GEORGE STEHLI, Oak Tree Press Limited, London.

   (For more advanced techniques and especially for work with Biological material)

3. *Microscopic Objects: by* JEAN C. THOMPSON, The English University Press Limited London.

   (For advanced methods of preparing and mounting objects)

4. *Practical Microscopy: by* L. C. MARTIN & B. R. JOHNSON, Blackie & Sons Limited, London.

   (For a Summary of information about all kinds of microscopes including the electron microscope)

CULTURE METHODS (GENERAL)

Artificial Sea-Water

450g sodium chloride
35g magnesium sulphate
50g magnesium chloride
20g potassium sulphate
Dissolve in 20 litres distilled water.

Culture Medium (liquid, for yeasts—modified Pasteur)

1.0g potassium dihydrogen phosphate
0.1g calcium monohydrogen phosphate
0.1g magnesium sulphate
5.0g ammonium tartrate
75g glucose
Dissolve in 1 litre distilled water.

Culture Medium (Liquid, for algae— Benecke)

0.5g calcium nitrate
0.1g magnesium sulphate
0.2g potassium dihydrogen phosphate
Dissolve in 1 litre distilled water, and add a trace of ferric chloride.

Culture Medium (liquid, for bacteria - Bouillon)

Mince 500g lean meat
Mix thoroughly with 1 litre water.
Keep in a cool place for 12 hours, stirring occasionally.
Filter the mixture through fine muslin.
Make up to 1 litre with water.
Add 10g peptone and 5g sodium chloride.
Autoclave for 1/4 hour or heat in a steam oven for 1/2 hour, to sterilize.
Decant the liquid, and muetralize with sodium hydroxide to pH 7.4

Cage for small animals

Generally the following principles must be observed:

Adequate space must be provided to allow movement of the animals and to prevent overcrowding.

Perforation of cover or wall of cage to allow adequate aeration (without allowing the animals to escape).

Glass front to cage to allow observation.

Renewal of food (or keeping twig in water to keep fresh).

Removal of excreta to keep cage clean.

Precaution against other animals entering to disturb or kill those in the cage (e.g. ants, cats).

Placing of the cage, with an eye on lighting and ventilation, so that conditions are suitable for the animals, (e.g. it would not do to place the cage where it would be heated by the mid-day sun).

Pond Water

May be used as medium for the animals taken from that same pond, and renewed at frequent intervals. It is necessary to watch the animals closely to detect deaths. If it is not really necessary to keep the animals isolated in a jar then they may be fetched from the pond for observation in the laboratory only when it is necessary to do so.

(*Application to Hydra, Amoeba*)

(It is necessary to avoid dipping your bare hands in pond water in case it is infected; further, wash your hands thoroughly after work with pond water)

Aquarium See Unit: Tilapia

CHAPTER 21 AIDS

Apart from the regular discussions and activities in class and laboratory sessions there is a great variety of agents capable of facilitating the development of interest and motivation in students. All these are aids to learning and we can consider them under three categories thus:

Literature

Audio-visual materials

Organizational and institutional (set-ups) mechanisms

The advantages of these aids vary with the needs and circumstances. Sometimes purely factual information may be needed in order to make progress in a given investigation. Here literature comes in. At other times, direction may be needed when maps or charts are more useful than literature. At still other times it may be necessary for one to see the actual working of a model before grasping fully the scientific principles behind the design and operation of a machine. Neither literature, nor drawings would really suffice.

It is therefore important that our science classes have access to some of these various aid to learning. It is important because they will provide opportunities for learners to develop interest, motivation, and insight. This latter faculty comes often in circumstances of change in location or environment, as well as during reflection following interesting or new experiences.

Field trips, film shows, visits to interesting locations generally provide ready opportunities for development of insight. All these then should be part and parcel of our science studies. Here, then, are some suggestions of sources and utilization of such aids.

Literature:

Apart from textbooks, encyclopedias, journals, magazines, newspapers and atlases, other literature which can form supplementary reference reading are handbills and travel guides put out by travel agents, airlines and tourist offices; bulletins, information posters and brochures published by various information agencies and government and private sector departments; extension pamphlets from departments of agriculture, forestry, fisheries, survey and explorations, mining, public works, as well as their reports (annual or otherwise) and year books.

Generally all these may be obtained free upon request in writing to the appropriate bodies. Examples of use of such literature: multiple uses can be made of such literature, e.g. to provide topics for writing a unit: or information for discussion or seminar; or subjects and materials for projects; or just a lead to developing other ideas in science at the appropriate level. The value is greatly diminished if use is made of them for lecture or " private study " purposes.

Audio-visual materials:

These are always around as

maps, useful not only for the cartographic skills to be developed, but also for planning field studies away from base;

charts of various kinds, from the navy showing depths, sandbanks, etc., or from the merchant marine or oil companies, chemical or pharmaceutical firms, showing various aspects of biological, geographical or geological features not found easily as such in books or journals. They may be charts showing in colour the major marine organisms in particular areas or in oceans generally; or they may be coloured representations of life histories of particular pests or parasites of economic importance;

pictures from UN, government (local and embassy) information services showing interesting features of the earth, space, ocean exploration, e.g. satellite pictures of the earth, of cloud formation, of drought areas, etc.,

models of various kinds, depicting landscapes, animal and plant anatomy and morphology or form; dams, bridges, settlements; machines, and even ecological systems. These may be made by various bodies, departments or even local woodwork and metal work classes, or art classes working in clay. They form valuable illustrations the importance of which would justify establishing close co-operation between the instructors in the various departments: special models, take the form of educational toys of various kinds; some of which provide motors and clock work mechanisms for other uses;

gramophone and records; tape recorders; are valuable aids in dealing particularly with animal sounds, class discussions, music classes or lessons on sounds;

radio (national, foreign) also provide suitable programmes in science at various times;

Television stations where they exist generally also provide special science telecasts which could be programmed into formal science studies;

films and filmstrips are generally made for specific purposes and scientific films would usually be intended for educational purposes. But other, even commercial, films may show aspects of the environment or natural phenomena which could be useful for extra-curricula learning or even part of a science study. Sources of films are scientific firms, science associations, foreign embassies or information agencies.

Use of Audio-visual materials; must be as aids not the lessons pure and simple. Their use should be preceded by relevant reading and introductory discussion; and followed by suitable discussion and report writing that would relate the materials to other activities of the students.

Organizational Aids:

These are generally mechanisms for the provision largely of group activities outside the regular occupational situations. They take the form usually of varied associations of people with similar or related interests, that are pursued in spare time, rather in the manner of hobbies. However, the primary aim is not relaxation or recreation, as with hobbies. It is rather enrichment and motivation.

Examples of such associations are

Young farmers or gardening clubs catering for the interests of those interested in gardening, farming, agricultural science, ecology, plant and animal pests and parasites, etc.;

Young fishermen's clubs catering to the interests of those keen on seashore, fishing and fishery, marine sciences, boating and marine technology, etc.;
Science clubs or societies (at School or college) catering for the interests of students and teachers of science as well as others interested in science. This takes the form of special talks, seminars, field trips;

Science associations of various kinds as for instance:

subject associations
science teacher associations
national science associations

Science Fairs which may be exhibitions or competitions based on novel or original work done by scientists and technologists or by students of science and engineering. The aim is to stimulate in the young an active interest in science and engineering, provide an educational experience and give public recognition to talented individuals for work they have done.

Organizing a science fair: The completed projects of the club's members can be exhibited in competition for awards at a small science fair; or they can be selected for entry to a larger fair involving several institutions; agencies; etc. If the exhibition is at a small local fair, then it would need to be organized by the club members, particularly its sub-committee or activity group responsible for science fairs. The chairman of the group might become the Fair Director and the group would proceed to set out rules governing the competition; draw up a programme for the fair and seek out sponsors for the fair and judges for the exhibits.

Sponsors could be Ministry of Education, Commercial Firms, University faculties, or science research laboratories, or any other group of interested adults. This is essential because a lot of fund raising job will have to be done and students, by themselves, may find it too big a task to handle alone.

When preparations are well under way a compilation of summaries or abstracts of the project reports would need to be made and published. This will give viewers or visitors a rapid over-all idea of the scope and quality of the exhibits and they can select which ones interest them most. Fuller individual reports could be produced and placed at each stand if need be. But usually the candidates would be available at each stand to explain orally what the project is all about; and to answer questions raised by the viewers — a valuable learning experience in itself.

Organizing science clubs (or societies): this is often a first step in the move to formalize extra-curricula science studies in schools and colleges. A start is made with discussions by the students of the form and structure of the club, the pattern of its organization and the scope of its activities. It is advisable for an experienced instructor to help guide the discussions, but the responsibility for actually forming and running the club should be that of the students.

The preliminary discussion would lead to the convening of a meeting to elect an organizing committee that would draw up a draft of the structure of the club and also of its constitution. This committee would need to meet early and expedite its work so that the initial interest of the rest of the possible membership does not wane before they can have concrete proposals to consider.

The next step is for the organizing committee to convene another general meeting at which the draft structure and constitution can be considered. If the structure is accepted then the constitution can be either also accepted or amended and a general election of officers be held. This would give the club a properly constituted status.

The next step would be to draw up a calendar of the club's activities for the years and appoint activity groups or sub-committees to take responsibility for organizing those activities. Such activity groups could easily take the responsibility for planning for example:

Special talks and seminars
Field trips
Visits to industrial, Public works, centres
Projects and exhibitions

This has the advantage of spreading the work among the membership and giving as many members as possible a chance to participate actively in the running of the club.

The constitution of the club should state the general aims and objectives of the club.

That is, it should set out clearly what the club is expected to do for its members, the school or colleges and the public in general. It should also state who are eligible to become members of the club and what responsibilities such a membership entails. It should state clearly how the club is to be organized, what categories of officers are to be created and how and when such officers are to be elected. The constitution should also state whether there may be special categories of membership e.g. for staff or other scientists and what these should be. It should also state clearly whether the members should pay any membership fee or any special fees; and show how funds for meeting the expenses of the club are to be raised.

Science clubs can help greatly in raising the level of science teaching and learning in a school or college. They relate the learning not only to the interest of the student but also to various aspects of his environment and his daily life, to an extent that the science curriculum cannot quite achieve. This makes them a must for any serious activity-based science teaching programme.

Some ideas for science club activities: Continuity is highly essential. The club should rather start and progress gradually than bloom forth in a rush and then fade out after a brief while.

Its activity group on projects has a great deal of scope for catering for the interests of students in photography, motor engines or cars, model building, paper folding, electronic gadgets, gardening, as well as for open day exhibitions.

Its activity group on field trips could take the members on well-prepared visits to nature reserves, forest, bird sanctuaries, lagoons, seashore, mining sites and so on. The advance preparation should include arrangements for special permits to be obtained where necessary transportation, provision of useful recording tools, e.g. cameras, tape recorders, notebooks

The activity group for special talks and seminars could also take on responsibility for, occasional film shows. Possible sources of scientific films being scientific films associations and national and foreign information services.

The group responsible for visits could list down for possible visits, textile and other factories, distilleries, breweries, mines, ships, research laboratories, crafts workshops, and so on. Again the preparations should be made well in advance for meals, permits and transport to be adequately provided.

Similarly the group responsible for science fairs could take into consideration the club's relationships with local science associations from which to obtain assistance in displaying its members' exhibits, or even with special supervision of projects.

6--Sources of Information and Materials

CHAPTER 22: INTRODUCTION

In addition to adequate basic preparation, innovative teaching in science, or even learning on one's own, requires considerable resourcefulness. But, resourcefulness alone is not enough. It requires dedication to the approach, self-confidence in both teacher and learner, as well as the confidence of the teacher in the learner and vice versa. However, neither dedication, nor confidence, is enough.

This approach to teaching and learning science also requires a favourable environment that provides logistical support. This support can be crucial in the context of anyone trying faithfully to teach by the approach advocated here in this Sourcebook.

Often times the teacher may need time to chew over some of the concepts to be illustrated as well as some particular approaches in methodology which may be applicable to the particular situation. If he should become concerned with items of apparatus or equipment, it should be a rare instance when he must construct the items from scratch.

Similary, if he should become concerned over pieces of information for one or a set of lectures, it should be rarely that he must research the topic(s) freshly for this purpose. Each instructor starting out on a teaching venture such as this should have ready access to sources of information and materials.

A ready source means just what it says one that is right there just when you need it. The material that it contains should already be "packaged" and all you need to do is to open it up and find it in good condition useful, valuable, relevant, apt, exact and reliable.

All this underlines the need that the innovative teacher has for the type of support that facilitates innovative teaching an approach in which all his students can participate actively and creatively. In a sense, this need is also freedom from anxiety over the sources of information and materials. Moreover, this is also applicable to those learning science primarily through independent study.

But this should not be taken to mean that the science teacher should not be allowed the opportunity to make apparatus and equipment, or to glean information of a special nature for his teaching. Having been freed from the burden of 'sole responsibility' for the logistics of science teaching, there is much that he can do.

For example, he might need to improve his lesson notes, start a discussion in class or even liven up a discussion that is tending to flag. He might also need to help students initiate an independent project, whether it is an individual or group effort.

Alternately, the students might wish to have additional information to aid them in writing reports, interpreting their data or findings or as a supplement to the general information found in their textbooks. Furthermore, both the students and the instructor may need ready sources of particular information for purposes of public debates, discussions, talks, as well as for other means of popularizing science.

However, the information needed sometimes may not be found in any textbook or encyclopedia. It may be either new, specialized or available only through discussions with people working outside science teaching. For instance, such people as field workers in agriculture, geology, fishing and fishery, construction, water engineering, villagers and so on can render invaluable information.

Similarly, the materials needed sometimes are not assembled as science equipment or apparatus nor even intended for such use. They have to be adapted by improvisation through someone's ingenuity.

Then there are the quasi-institutional bodies that aid effective science teaching and learning. To illustrate this point, consider the science clubs, fairs and exhibitions referred to in Section V Chapter 21. While the science teacher should be expected to exploit all of the aforementioned resources, he cannot be left entirely responsible for organizing and running them all.

Nevertheless, the best time to have physical aid sources and information is when one needs it. It is advisable to ensure that one will have it when it is needed by trying to make some provision for it beforehand in hopes that "it might just be useful sometimes."

Thus, it would be wise to start a tit-bits file or folder, or even keep a box of reference cards. Initially these could be kept in the classroom. But perhaps after extension and organization of the material it could be given space in the school's science library or be a special part of the general library.

The same may be done with physical aid sources. A collection of items can be made from a variety of sources as outlined in Chapter 24 of this section. As stated earlier, however, the object of the exercise is merely to stimulate creativity—not to provide the basic items of equipment and apparatus needed for the teaching of science.

In other words, this means that there should be an organized attempt to provide support for teachers of science-- at all levels—and to make it readily available to them. The need for such ready sources as facilitators cannot be overstated for innovative instruction and learning in science.

CHAPTER 23 SOURCES OF INFORMATION

Introduction

If a science education programme is to be alive, interesting and relevant to the teacher and learners, it must utilize the contemporary people of today's science as well as institutions that are in operation at the present time. Nature itself provides an unending source of materials and information. We need to develop a keen sense of awareness.

Once we start noticing things in our environment, more and more things come to our attention. Soon we begin to see how some things and phenomena are connected and interwoven. It is a good attitude to say to oneself " I know there is something new out there that I have not noticed before ". We should go out each day to find out something new or at least learn more about something we have seen before. It would be a good idea to keep a daily notebook entitled " things I have noticed and learned today ".

People as a source

It is, of course, impossible to gain first hand knowledge about everything. Therefore, we need to tap other people so that we may share their knowledge and experiences. Most people are very willing to discuss their work, interest and hobbies. We come in contact with people from all walks of life. A great deal could be learned if we programme ourselves to make the best of these opportunities.

In any school the teachers are a ready and willing source. We need to get into the habit of asking. " Why does that work ". " How does that work ". " What is the essence of this particular subject ". " What other areas of study does it lead to ". " How does the particular subject of an individual teacher affect me as a person ". " What other things interest the teacher and why ".

The other people in and around the school are also sources of information. For example, it is interesting to observe the dexterity of the fingers of a secretary. Just what is going on within the brain and nervous system that allows a person to perform such a task as typing. There are questions of how long a person can sit and type. At what point does fatigue set in. Some of

this information can be obtained by observation, but talking with the person will provide further information and help guide the observation. Similar kinds of ideas can be explored as far as the gardeners, the custodians, the cooks, and the stewards are concerned. All of these people can give information on the job they are doing, plus they may have interesting hobbies that are scientific in nature.

In order to get information from Research Scientists, the tutor should try to arrange visits to companies and institutions where people like these are employed. These people are also willing to visit and give talks to students and teachers if they are invited. There are many types of people that the tutor may be interested in making contact with: geologists, surveyors, foresters, meteorologists, engineers, game and wild life scientists, and a host of others. It would even be a good idea to arrange visits to universities and also invite university scientists and instructors to visit the school for both lectures and informal talks.

Visits should also be arranged to breweries, mines, textile mills, sawmills, hospitals, medical laboratories, etc. The people to talk to in these places are many and of great variety: managers, brew masters, researchers, laboratory technicians and assistants, labourers, janitors, drivers, mechanics, maintenance men, clerks, secretaries, doctors, nurses, midwives, matrons, and so on.

One could also visit and interview hotels and caterers, as well as the police station--particularly the crime investigation department. The techniques used to solve crime are very much scientific and interesting. A visit to an armed forces camp could also provide a great deal of information. These places have mechanical engineers, road builders, electronics engineers, meteorologists, automechanics, carpenters, drivers, cooks and teachers.

There are of course many local craftsmen who are quite willing to describe the procedure of their craft, and do not, for the most part, object to persons observing them at work. Some of these people are: blacksmiths, gold and silver-smiths, leather workers, potters, masons, carvers, carpenters, bakers, watch repairers, fishermen (net making), etc.

Places as sources

Generally speaking, any factory would be an excellent place to visit and obtain information. Some that have not already been mentioned are: food processing factories, (i.e. fish, cereals, preserves, etc.), leather, electronic equipment (TV, radios, stereos, ...), plastic, glass and many more factories.

An interesting and informative place is the museum. There are several types of museums and in some cases, one museum will have virtually all types under one roof. The usual types are: cultural, natural historical, herbarium, zoological, war, art, and geological museums. In most cases there are people working in these places that will give information about the things in the museum. There are also lecture series given at some. These lectures are usually free or have a very low entrance fee.

It is also possible to obtain specimens and slides from museums. This, however, is quite limited. The museum will only do this in cases where they have an abundance of a particular thing. The museum usually provides written material about the objects on display. This is usually presented right along side of the object. They will also have inexpensive, or sometimes free, handouts on selected items.

Any farm, large or small, is an infinite source of information. Crop plantations with cocoa, tobacco, rubber, coffee, oil palm, maize or vegetables are usually quite large. Sometimes two or three of these major crops will be found on the same plantation. Animal farms with various combinations of poultry, cattle, sheep, goats, fish, etc., provide a good source for studying animal behaviour, eating habits (diet), mating, reproduction and co-existence.

Zoos and parks, whilst somewhat artificial, still provide a wealth of information about selected species of plants and there are all sorts of animals that we may not otherwise have the opportunity to observe. For example: snakes, lions, large cats, gorillas, birds, hedgehogs, porcupines and various types of monkeys are on hand.

Besides all of the places mentioned, there is of course nature herself. We have the beaches, the mountains, waterfalls, lakes, lagoons, springs, streams, trees, rocks as well as the sky with all of its magnificent cloud formation to observe.

Things to observe

With something like rocks, there are many specific things to observe: the exposed rocks near the sea or even where the road has been cut through can provide information about erosion, formation and composition of rocks. It would be a good idea for the school (if it does not have one) to build a collection of rocks. This could also be done on an individual basis by the tutor or the student. One is then forced to explore methods of identifying the rock in a given collection. In fact, museums will help in the identification if they are approached. Lastly, if we are observant, we will see many types of rocks exposed on and in buildings, for example, a marble floor.

Other Sources

Films: The teacher should, if film equipment is available, keep up-to-date catalogues and lists of sources of films from both local sources and those at large. There are always collections of films at universities, science association, industrial firms, educational supply houses, as well as embassies.

Charts: The best thing for teachers to do is make charts of their own. A collection of these should be compiled. The teacher should be able to get assistance from audio-visual aid centres, science education centres in universities as well as the ministry of education. There are also ready-made charts available from educational supply houses.

Tapes: Again the best idea (assuming the teacher or some of the students have a recorder) is to make your own tapes. There are even instructional sources, such as the American Association for the Advancement of Science, which will give guide-lines for making tapes as well as supply ready-made tapes. To ensure the safe-keeping of tapes, they should be stored away from strong electrical currents and magnets in a dry, dust-free place.

Tapes are particularly good for studying bird songs, mating calls, and other animal sounds. A recorder can also be used on field trips to record observations which can be transcribed after returning to the classroom or laboratory.

Slides (transparencies): These can also be home-made and catalogued. It is also important to build up a large and varied library of these for ready access. They will aid and enhance the teaching of many areas of science. The slides should be indexed under subject and scientific phenomenon. They can also be used as special teaching sets. This will help with remedial work, as well as be a source for people that wish to forge ahead. Of course, slides can aid with review work as well.

One can obtain slides from libraries, universities (probably on loan), and educational supply houses. There is also a chance of viewing slides at some museums.

Reference books

Reference books on scientific topics can be found in libraries of schools, universities, towns, research institutes, factories, hospitals and in some cases, private stocks of books. A teacher should keep addresses and numbers of libraries in the vicinity for correspondence, visits and as a place to send students. Some specific reference books are:

Encyclopedia Brittanica
Van Nostraud Dictionary of Science and Technology
Nelson's Encyclopedia
Oxford Children's Encyclopedia
Rears Cyclopedia
Spector's Biological Data, and
Origins of Greek Science.

Classics of Field Observation

To give you an idea of the fruits of patient field observations, you may need one or more of the following works by famous scientists:

DARWIN, C. R. 1881: *The formation of vegetable mould through the action of worms, with observations on their habits* London.

FABRE, J. H. 1949: *Scenes de la vie des insectes* (*Scenes of insect life*) Nelson, Paris.

LEAKEY, L. S. B. 1959: *A new Fossil from Olduvai.* Nature 184, 491-493

LEAKEY, L. S. B. 1960: *The Origin of the genus Homo.* In S. Tax: *Evolution after Darwin,* Vol. 2. Chicago University Press Chicago, Illinois.

Frisch, K. von 1961 — *Bees: Their Vision, Chemical Senses, and Language.* Cornell, University Press, New York

Lorenz, K. Z. 1952 — *King Solomon's Ring.* Crowell, New York

Tinbergen, N. 1953 — *Social Behaviour in Animals* Metheun, London.

Suggestions for Field Studies on Organisms

1. Organisms that may easily be studied in the field:

Worms:	Making casts
Ants	on march, building nests, collecting nectar or pollen, attacking or capturing prey, tending aphids.
Bees	at nest, foraging
Butterflies:	(adult and larval stages): feeding
Birds:	building nest, feeding young, courting, fighting, moving on ground and in flight, catching insects, protective behaviour, visiting flowers.
Lizards:	feeding, fighting, courting
Various Plants:	flowering, vegetative reproduction, fruit or seed dispersal, habitat preference, associated animals, exudation from bark or branch or leaves, form of plant (variation in form—climber, tuber), succession on freshly exposed substratum

2. Processes that may best be studied in the field:

pollination
plant dispersal
colonization of new areas (rubbish heap, exposed soil surface, dam or pond, walls, building)
animal movement (mode of movement, speed of motion)
sounds made by animals (how is sound made?, kinds; when are the particular sounds made; do they communicate with the sounds?)
Nest building: materials used, how the materials are collected, how they are treated, how they are used; are there any interesting patterns in the behaviour of the animals or in the architecture (construction) of the nest?
Animal feeding: how do they feed? how often? when? on what? are there food preferences?
do they store any food?
Care of young;
grooming of other animals;
fighting, aggression;
courting, under what conditions do they court—any particular season?
animal migration

3. Phenomena that may be investigated in the field:

animal behaviour
Cryptic colouration
Warning colouration
Mimicry
Symbiosis
Animal movement
Plant dispersal
Animal anigration
Flower pollination by animals
Daily cycle of activity or events in nature
Cloud formation and rain
Spread of plant disease in farms
Erosion
Tides
Seasonal changes in pond, river, estuary
Seasonal changes of agricultural products sold in markets.

CHAPTER 24 SOURCES OF MATERIALS

A sound programme that is inquiry-based must utilize an abundance of materials, objects and activities. If the teacher is creative and resourceful, he can find many useful materials all around, inside and outside of the classroom. Almost any object new or old, or from nature herself, is worthy of scientific investigation. If it is old it makes sense to study the object to see from whence it came and what changes it has undergone through ageing. If it is new, it is interesting to study and predict the possible changes it will go through as it grows older. Listed below are some possible sources of materials: places where one may obtain materials and which material may be obtained from each place.

1. *A Fitter's Shop (an automotive repair shop)* will always have a number of old parts lying around. The tutor or the students could probably pick up things like old carburetors, generators, batteries, ties, mirrors, radios, windows, clutch plates, gears, transmissions, wheel rims, ball bearings, springs from seats, magnets from speedometers, metal tubing and even an old engine block. One could eventually construct a working motor, a small car or a cart. An electric hand generator to create static electricity could also be made.

2. *From a Blacksmith's Shop* one could obtain things like funnels, tin, springs, hinges, wire, old pipes, iron weights, solder, pans and pots quite cheaply. Using things such as these one could construct all sorts of apparatus like balances, pendulums and the like.

3. *From Electric Appliance Shops* that sell and repair appliances one can obtain wire (insulated and non-insulated), tubes, condensers, resistors, batteries, transistors, insulation tape, irons, recorders, radios, switches, speakers, plugs, outlets, cables, etc. If these things are old and used, they can be procured for little or nothing. Most shops clean out their repair rooms periodically. If one were around at these times many useful objects, could be picked up. With enough bits and pieces one could make his own radio (wireless). Even a simple computer or calculator could be constructed from these materials.

4. *From Provision Shops (Foulah Shops) and Grocery Stores* many materials can be found such as card board boxes, paper, bottle and bottle tops, cans, large barrels, wooden crates, cigarette cartons, etc. Of course, one could buy things like matches, candles, wicks, kerosene, thread, needles, ammonia, baking powder, baking soda, vinegar, oil, starch, salt, seeds gelatine, and a variety of other things which could be used in experiments, biological and/or chemical. Containers of any type that are obtained are quite necessary for they give us the facility to store and preserve specimens and materials. This aids in organizing our entire process of classification.

5. *At African Markets* there are all sorts of materials which are useful for scientific study. For instance, charcoal, baskets, benches, clay pots, herbs, roots, beads, shells, seeds, wood, straw, newspaper, wire, nails, rope, bags made from rope and raffia, nets, glass, leather, cloth bones, blades, knives, cups, wooden spoons, etc., can be got for little or no money. Things like dishes, metal spoons, calabashes, sieves, dried fish, old clothes, mirrors, powder, soap, palm oil, ground nut oil, coconut oil, combs, and various foodstuffs can also be purchased rather inexpensively from the market areas. The use of these items are varied and fairly self-evident: one could (*a*) study the various bone structures of fish; (*b*) perform experiments on potatoes, cassava root, rice, etc. to discover their starch content or how well they ferment; (*c*) use items such as string, calabashes, sieves, mirrors, oil, and so on, in performing experiments or in constructing apparatus.

6. *From the Carpentry Shop* there are, again, many useful things that are free and considered waste by the carpenters. Some of these things are: sawdust, scrap wood, old nails, hinges, leather scraps, sponge scraps, springs, broken glass, used sandpaper, old saws and saw horses (benches, to saw on) formica pieces, glue, varnish, paint, turpentine, and the like, One could even borrow tools like hammers, screwdrivers, saws, chisels, spanners and vices. Further, one could have the carpenter to make tables, benches, cabinets, shelves, chairs, boxes and cutting boards for classroom use.

7. *The Shoemaker* (*cobbler*) will leave nails, polish, used containers, cleaning fluid, knives, blades, shoe strings, thread, pins, needles, hard rubber scraps, as well as leather scraps, lying around. He may also lend or give the tutor foot molds made of wood or iron. One could study the general shape of a foot. It might be interesting to try to actually make a shoe from scraps.

8. *At Hospitals* one can obtain chemicals, drugs, and various medicines. If a tutor approaches a laboratory technician and indicates that he wants these materials for classroom purposes, he will most likely get them. There are also materials that are discarded like cartons, boxes, benches, hypodermic needles, pans, used film, tubes, spook, gauze, tips (sticks tipped with cotton wool), table, and stethoscopes. Note, however, some of these items may need to be sterilized.

9. *In Research Laboratories* such as the ones at industrial companies, many of the same materials can be obtained as in hospitals. If the laboratory does mineral research, one could most likely stick up rock and mineral samples, as well as some chemicals. If a rapport develops between the tutor and the researchers, it is very likely that many different kinds of chemicals and other apparatus can be obtained for little or no cost

10. *At the Dock or a Quay* one could obtain lumber, cartons, rope, cable, string, iron rods, scrap metal and fishing net. On the *seashore* itself we could, of course, get all the sand one could want, plus plants, sea weeds, shells, drift wood, rocks, coconuts, sea water, fish, etc.

11. *In the Bush or Forest* there are all sorts of materials for scientific inquiry. One can get all sorts of plants, trees, bushes, flowers, fungi, etc. There are also food plants like beans, cassava leaf, potato leaf, okra, pepper, etc. to be found in abandoned farms.

There are also the insect and other animal groups. One can collect samples of things like worms, insects, rodents (e.g. rats, grasscutters), monkeys, baboons, snakes, antelopes etc. Even if we do not or cannot collect some of the above animals, they can be observed in their natural habitat.

Students can be encouraged to raise plants of their own or even set up small gardens. They will learn through experience which types of plants will root when a piece of the plant is put into water and those that will not, i.e. those that must be planted by its roots in order to grow.

Large or small collections of animals and insects can be built by gathering specimens from the bush. One must find ways to keep the specimens alive or at least determine the causes for their inability to survive outside of their natural surroundings. Butterfly and other insects may be collected, classified, and preserved in a glass-covered case for future classes to study or use as an example when building their own collections.

12. While it is possible to obtain thread, spools, pins, needles, and scrap cloth from *Textile factories and Tailor shops*, we can obtain many things from *local workers in cloth design*. The people that do tie-dying (gara, wax print, Adinkra print, batik, and weaving) can supply students or the tutor with small scraps, as well as loan (or give) them some of the dyes or tools of their trade. It would be an interesting exercise to make one's own thread and then produce cloth or fabric from the thread.

13. Again, from the local environ. materials can be obtained from *Craftsmen*, such as stone workers, wood carvers, jewelers, bench and cabinet makers, etc. From the stone and rock samples obtained for study, it would be interesting to note which types of stones or rocks are best suited for cutting and sculpture. This is also true of wood--some types are more suitable for carving than others. It would be a good activity to have the students actually try to carve figures from stone and wood. With these efforts, it will become apparent which types of tool and implements are necessary for the work. Perhaps the tutor or the students will invent even better tools.

The jewelry maker will employ all sorts of small stones, seeds, beads, etc. Pebbles or beads could be used to make some kind of filter. These things, particularly beads, along with sticks or toothpicks could be used to make models of chemical compounds.

14. Miscellaneous items can be obtained from home, school and other places not mentioned above To name a few: ink, chalk, rubber, erasers, blackboard erasers, rulers, maps globes, rubber. bands, labels, paper, old electric light bulbs, florescence lights, shoes, toothbrushes, flower pots, jars, bottles, pots, pans and basins of varying size, old clocks or watches and an abundance of other, items can be utilized in scientific investigations.

With all these a lot of activity is possible to make science learning a very interesting and absorbing experience.

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