Module 4

Junior Secondary Science

Scientific Processes

THE COMMONWEALTH of LEARNING

Science, Technology and Mathematics Modules

for Upper Primary and Junior Secondary School Teachers
of Science, Technology and Mathematics by Distance
in the Southern African Development Community (SADC)

Developed by
The Southern African Development Community (SADC)

Ministries of Education in:

- **Botswana**
- **Malawi**
- **Mozambique**
- **Namibia**
- **South Africa**
- **Tanzania**
- **Zambia**
- **Zimbabwe**

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SCIENCE, TECHNOLOGY AND MATHEMATICS MODULES

This module is one of a series prepared under the auspices of the participating Southern African Development Community (SADC) and The Commonwealth of Learning as part of the Training of Upper Primary and Junior Secondary Science, Technology and Mathematics Teachers in Africa by Distance. These modules enable teachers to enhance their professional skills through distance and open learning. Many individuals and groups have been involved in writing and producing these modules. We trust that they will benefit not only the teachers who use them, but also, ultimately, their students and the communities and nations in which they live.

The twenty-eight Science, Technology and Mathematics modules are as follows:

Upper Primary Science
Module 1: *My Built Environment*
Module 2: *Materials in my Environment*
Module 3: *My Health*
Module 4: *My Natural Environment*

Upper Primary Technology
Module 1: *Teaching Technology in the Primary School*
Module 2: *Making Things Move*
Module 3: *Structures*
Module 4: *Materials*
Module 5: *Processing*

Upper Primary Mathematics
Module 1: *Number and Numeration*
Module 2: *Fractions*
Module 3: *Measures*
Module 4: *Social Arithmetic*
Module 5: *Geometry*

Junior Secondary Science
Module 1: *Energy and Energy Transfer*
Module 2: *Energy Use in Electronic Communication*
Module 3: *Living Organisms' Environment and Resources*
Module 4: *Scientific Processes*

Junior Secondary Technology
Module 1: *Introduction to Teaching Technology*
Module 2: *Systems and Controls*
Module 3: *Tools and Materials*
Module 4: *Structures*

Junior Secondary Mathematics
Module 1: *Number Systems*
Module 2: *Number Operations*
Module 3: *Shapes and Sizes*
Module 4: *Algebraic Processes*
Module 5: *Solving Equations*
Module 6: *Data Handling*

A MESSAGE FROM THE COMMONWEALTH OF LEARNING

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Dato' Professor Gajaraj Dhanarajan
President and Chief Executive Officer

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Introduction

Welcome to the programme in Teaching Junior Secondary Science. This series of four modules is designed to help you to strengthen your knowledge of science topics and to acquire more instructional strategies for teaching science in the classroom.

Each of the four modules in the science series provides an opportunity to apply theory to practice. Learning about science entails the development of practical skills as well as theoretical knowledge. Each science topic includes an explanation of the theory behind the science, examples of how the science is used in practice, and suggestions for classroom activities that allow students to explore the science for themselves.

Each module also explores several instructional strategies that can be used in the science classroom and provides you with an opportunity to apply these strategies in practical classroom activities. Each module examines the reasons for using a particular strategy in the classroom and provides a guide for the best use of each strategy, given the topic, context and goals.

The guiding principles of these modules are to help make the connection between theory and practice, apply instructional theory to practice in the classroom situation and support you, as you in turn help your students to apply science theory to practical classroom work.

Programme Goals

This programme is designed to help you to:

- strengthen your understanding of science topics
- expand the range of instructional strategies that you can use in the science classroom

Programme Objectives

By the time you have completed this programme, you should be able to:

- develop and present lessons on energy and energy transfer; the use of energy in electronic communication; the needs of living organisms and their environmental resources; and the study of scientific processes. The topics on energy and the environment will focus on learning, through the scientific inquiry method, ways to achieve a sustainable environment
- guide students as they work in teams on practical projects in science, and help them to work effectively as a member of a group
- use questioning and explanation strategies to help students learn new concepts related to energy and to support students in their problem solving activities
- guide students in the use of investigative strategies to learn more about particular technologies, and to find out how tools and materials are used in science
- prepare your own portfolio about your teaching activities
- guide students as they prepare their portfolios about their project activities

The relationship between this programme and the science curriculum

The science content presented in these modules includes some of the topics most commonly covered in the science curricula in southern African countries. However, it is not intended to cover all topics in any one country's science curriculum comprehensively. For this, you will need to consult your national or regional curriculum guide. The curriculum content that is presented in these modules is intended to:

- provide an overview of the content in order to support the development of appropriate teaching strategies
- use selected parts of the curriculum as examples for application of specific teaching strategies
- explain those elements of the curriculum that provide essential background knowledge, or that address particularly complex or specialised concepts
- provide directions to additional resources on the curriculum content

How to Work on this Programme

As is indicated in the programme goals and objectives, this programme provides for you to participate actively in each module by applying instructional strategies when exploring science with your students and by reflecting on that experience. There are several different ways of doing this.

Working on your own

You may be the only teacher of science topics in your school, or you may choose to work on your own so you can accommodate this programme within your schedule. If this is the case, these are the recommended strategies for using this module:

1. Establish a schedule for working on the module: choose a date by which you plan to complete the first module, taking into account that each unit will require between six to eight hours of study time and about 2 hours of classroom time for implementing your lesson plan. For example, if you have 2 hours a week available for study, then each unit will take between 3 and 4 weeks to complete. If you have 4 hours a week for study, then each unit will take about 2 weeks to complete.
2. Choose a study space where you can work quietly without interruption, for example, a space in your school where you can work after hours.
3. If possible, identify someone who is interested in science or whose interests are relevant to science (for example, a math or science teacher in your school) with whom you can discuss the module and some of your ideas about teaching science. Even the most independent learner benefits from good dialogue with others: it helps us to formulate our ideas—or as one learner commented, "How do I know what I'm thinking until I hear what I have to say?"

Working with colleagues

If you are in a situation where there are other teachers of science in your school or in your immediate area, then it is possible for you to work together on this module. You may choose to do this informally, perhaps having a discussion group once a week or once every two weeks about a particular topic in one of the units. Or, you may choose to organise more formally, establishing a schedule so that everyone is working on the same units at the same time, and you can work in small groups or pairs on particular projects. If you and several colleagues plan to work together on these modules, these are the recommended steps:

1. Establish and agree on a schedule that allows sufficient time to work on each unit, but also maintains the momentum so that people don't lose interest. If all of you work together in the same location, meeting once a week and allocating two weeks for each unit, this plan should accommodate individual and group study time. If you work in different locations, and have to travel some distance to meet, then you may decide to meet once every two weeks, and agree to complete a unit every two weeks.
2. Develop and agree on group goals, so that everyone is clear about the intended achievements for each unit and for each group session.
3. Develop a plan for each session, outlining what topics will be covered and what activities will be undertaken by the group as a whole, in pairs or in small groups. It may be helpful for each member of the group to take a turn in planning a session.

Your group may also choose to call on the expertise of others, perhaps inviting someone with particular knowledge about teaching or about a specific science topic to speak with the group, as long as this is in keeping with the goals of the module and of the group.

Your group may also have the opportunity to consult with a mentor, or with other groups, by teleconference, audioconference, letter mail or e-mail. Check with the local coordinator of your programme about these possibilities so that you can arrange your group schedule to be compatible with these provisions.

Colleagues as feedback/resource persons

Even if your colleagues are not participating directly in this programme, they may be interested in hearing about it and about some of your ideas as a result of taking part. Your head teacher or the local area specialist in science may also be willing to take part in discussions with you about the programme.

Working with a mentor

As mentioned above, you may have the opportunity to work with a mentor, someone with expertise in science education who can provide you with feedback about your work. If you are working on your own, your communication with your mentor may be by letter mail, telephone or e-mail. If you are working as a group, you may have occasional group meetings, teleconferences or audioconferences with your mentor.

Using a learning journal

Whether you are working on your own or with a group, it is strongly recommended that you use a learning journal. The learning journal serves a number of different purposes, and you can divide your journal into compartments to accommodate these purposes. You can think of your journal as a "place" where you can think out loud by writing down your ideas and thoughts, and this "place" has several "rooms".

Ideas/Reflections/Questions
In one part of your journal, you can keep notes and a running commentary about what you are reading in each unit, write down ideas that occur to you about something in the unit, and note questions about the content or anything with which you disagree. You can use this part to record general ideas about how to use some of the content and strategies in the classroom. If you consistently keep these notes as you work through each unit, then they will serve as a resource when you work on the unit activity, since you will have already put together some ideas about applying the material in the classroom. This is also the section of the journal for your notes from other resources, such as books of articles you read or conversations with colleagues.

Plans
This is the section where you work on your activity for each unit. At the start of each unit, you should start considering what activity you will choose to do, and then develop your ideas as you go along. Each activity will also have specific guidelines.

Observations/Reflections
This is the section where you record your observations about classroom experiences, how students seem to tackle various situations and how each instructional strategy works in practice. This is the place to record your notes after you implement the unit activity about what you feel worked well and what could be improved. If you are part of a group, you can keep your notes about good practice and effective group dynamics, based on the group experience, in this section.

Resources available to you

Although these modules can be completed without referring to additional resource materials, your experience and that of your students can be enriched if you use other resources as well. There is a list of some of the resource materials for each module provided at the end of that module.

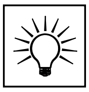
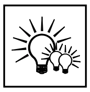
Tips for selecting resources
Working with locally available resources may require selecting those that are most appropriate from among materials that may not be complete or relevant. When reviewing materials to see if they will help you with the module, consider:

- Which module topics does this material address?
- Is it possible the ideas in this material are transferable to the science classroom?
- Is it possible the ideas in this material are transferable to the technologies included in the module?

ICONS

Throughout each module, you will find some or all of the following icons or symbols that alert you to a change in activity within the module.

Read the following explanations to discover what each icon prompts you to do.

	**Introduction**	Rationale or overview for this part of the course.
	**Learning Objectives**	What you should be able to do after completing this module or unit.
	**Text or Reading Material**	Course content for you to study.
	**Important—Take Note!**	Something to study carefully, or a possibly harmful action/substance.
	**Individual Activity**	An exercise or project for you to try by yourself and demonstrate your own grasp of the content.
	**Classroom Activity**	An exercise or project for you to do with or assign to your students.
	**Reflection**	A question or project for yourself— for deeper understanding of this concept, or of your use of it when teaching.
	**Summary**	
	**Unit or Module Assignment**	Exercise to assess your understanding of all the unit or module topics.
	**Suggested Answers to Activities**	
	**Equipment**	List or description of any apparatus or tools that this activity requires

CONTENTS

Module 4: Scientific Processes

Module 4
Scientific Processes

Introduction

This module is not a textbook but rather support material for the teacher. It gives possible strategies a teacher can use to cover the content on scientific processes.

The contents of this module are not prescriptive, therefore, teachers should feel free to use other strategies in addition to or instead of those proposed here. The module gives possible teacher and pupil activities that encourage active learning by the pupils and self-regulation of the teacher's activities.

The objectives and outcomes also indicate what skills the teacher and pupils will develop by going through this module. Teachers should feel free to contact the writers to discuss how they feel about the module and whether it is helping them to improve the teaching and learning of science in their classrooms.

Aims of this Module

By the end of this unit the teacher should be able to:

- define and distinguish four principal scientific processes: classical experiments, simulation, modeling, and inquiry
- guide students through classroom activities that use these four scientific processes
- assess student performance in these scientific processes
- describe the relative strengths and weaknesses of the four processes
- incorporate scientific processes into their regular teaching of science

Unit 1: Experimentation

Unit Objectives

After completing this unit, the teacher should be able to:

- define and explain the classical experiment
- list the basic steps and procedures of organising an experiment
- explain the need for observation, recording, interpreting, and concluding when carrying out an experiment
- impart to pupils the necessary skills and knowledge to carry out classical experiments

Content

- What is a classical experiment?
- Aim and method as initial steps of an experiment
- Observations, results recording, and conclusion in experiments
- Making hypotheses in experiments
- Role of hypotheses of experiments
- Inferences in experiments

Teaching and Learning—Techniques Employed

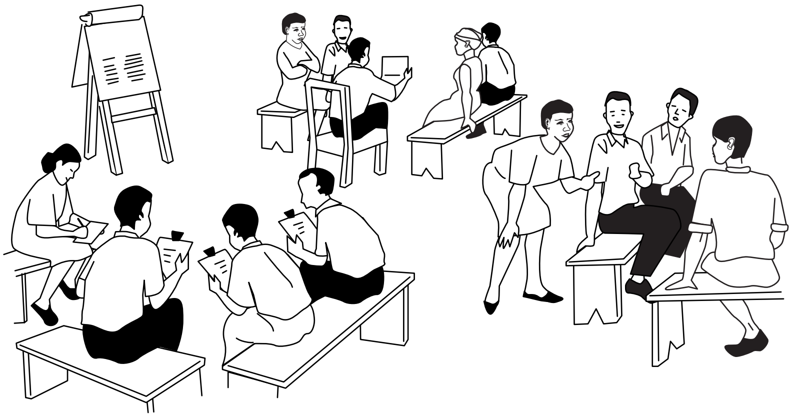
- questioning technique
- observation
- presentation
- reports

Introduction

In science lessons, both teachers and pupils are involved in a number of activities, such as discussing, planning, recording, presenting, applying, classifying, evaluating, experimenting, hypothesising, inferring, interpreting, investigation, observation, and questioning. All these are **scientific processes**. This unit focuses on one of these processes in particular—the classical experiment.

The unit will assist you, the teacher, with ideas on how to use the classical experiment in your science teaching. The focus will be on how to organise experiments, record observations as results, and use inferences to draw conclusions. It is hoped this will go a long way toward improving your science teaching methods.

The unit also describes the learning limitations of the classical experiment—limitations that are somewhat overcome by the **scientific inquiry** method in Unit 3 of this module.



To carry out experiments, divide your class into small groups. Small groups provide pupils with an opportunity to talk to each other and discuss the experiment.

Talking and listening are essential components of any learning process in science, and scientists the world over discuss things. In this way, they learn about the ideas and work of their colleagues.

What is an Experiment?

For a science teacher, this word has two strikingly different meanings.

Meaning #1

You might wonder why some things happen the way they do, and yet you are unable to find a satisfactory answer by looking in books or asking experts. You may wish to test your own ideas about why it happens and when you do that, you are **experimenting**. Thus, the first definition of the word **experiment** is:

> "an organised approach to uncovering new knowledge, something not known before, using generally recognised processes of investigation".

This is the kind of experimenting that real scientists do. Such experiments usually start with a **question**, proceed to a **testable hypothesis**, and use other processes that scientists have come to accept as useful. This type of into-the-unknown-experimenting, though normally the domain of trained scientists, can be done in a classroom setting and is the main topic of Unit 3 in this module.

Meaning #2

The more common classroom definition of **experimenting** refers to

> "repeating, or demonstrating, a well-known phenomenon
> by means of a pre-planned activity".

If done properly, this is guaranteed to produce the sought-after phenomenon.

A good way to distinguish this type of activity is to call it a **classical experiment** since it typically involves repeating, or re-enacting, a scientific discovery that has already been made. Another synonym is **demonstration**, since the underlying purpose of this activity is to demonstrate some principle of nature by making it happen in a controlled way.

This unit on experimentation limits itself to this second meaning of the word. It lays out the proper conduct of classroom demonstrations, or classical experiments, in such a way that you can impart the method to your students.

A classical experiment is sometimes called an **investigation** because, to students who have not seen the phenomenon before, it appears to be something new. They investigate by gathering information about a topic in a variety of ways, such as with their senses and with instruments. However some investigations are not experiments. For example, you can find information by reading or talking to other people.

Why should students do Classical Experiments?

This question carries a great deal of philosophical baggage about why and how science should be presented in schools. Generally, when you teach a scientific topic such as the starch component of foods that comes later in this unit, you can teach it several ways:

1. Teach the topic from a book, or have students read about it in a textbook.
2. Demonstrate the topic while the students watch.
3. Have the students carry out the demonstration (undertake a classical experiment) themselves.

All three ways can get the point across. Notice that these three methods are listed in decreasing order of *time-efficiency*. That is, each alternative takes longer than the one before it. You can teach the starch content of foods as a set of facts in five minutes, you can demonstrate it in fifteen, and students will learn the same amount in a hands-on activity after the better part of an hour.

The same list is also arranged in increasing order of *effectiveness*. Your five-minute teaching session will be well remembered until you cease putting the question on tests. After a year, the majority will have forgotten exactly which foods contain starch. However, the majority of students will probably remember their hour of testing foods for years. When the subject of starch comes up in later schooling, they will recall carrying out starch tests. Thus students who did the demonstrations themselves will always carry with them the awareness of which foods are good sources of starch.

Knowing this, good science teachers employ as many demonstrations as they can, using them to teach the concepts and principles they consider most important for their students to remember in the long term.

Planning Experiments

Aim → Apparatus → Method → Results → Conclusion

Classical experiments generally follow the linear plan shown above. Students follow this plan to investigate natural principles and report on them afterwards. Even when a student's classical experiment does not demonstrate what was expected, the teacher can usually point to a missed step and thereby impart a valuable lesson about following directions! Students also use the linear plan to organise and present their reports.

The first step in a demonstration states the idea or concept that is to be demonstrated. This is called the **aim** of the experiment. Every classical experiment will have an aim—a statement of what you are setting out to do or show. In the written report, you may prefer to have students call it the heading of the experiment. The aim of an experiment may also be formulated as a question. Stating the aim in question form will often help students progress smoothly from aim to **method**.

The second part of the experiment is the **apparatus** or experiment section. In this section the student should list all the necessary equipment. In some cases, diagrams can be used to show how the apparatus was set up.

The third part of an experiment is the **method** section, and there are two levels of detail to consider.

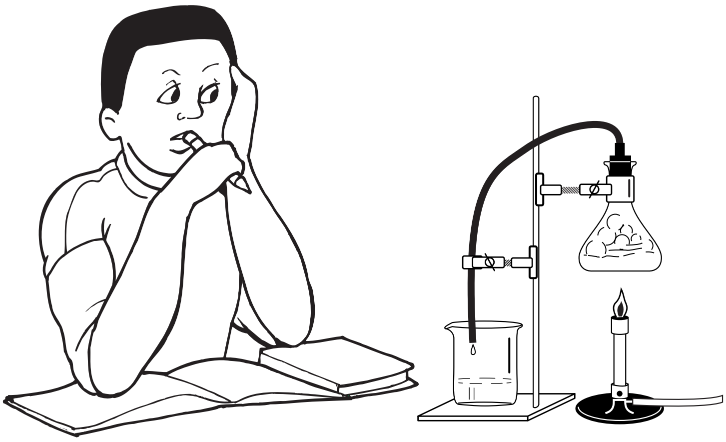
A. When you explain the method to students, you provide a step by step list of how the experiment will be carried out, from start to finish. **Before students begin, you must list all cautions and warnings if there is any hazard associated with some apparatus**. If you are writing such a method for the first time, you may be astonished by how wrong the demonstration can go because your instructions omitted a point that is obvious to you, yet will be overlooked by many students.

   When students describe the teacher's method in their report, they should summarise it in just a few sentences. They should write just enough of the method so that you, in your assessment role, can judge whether or not they understood what they were doing.

B. You may provide the aim and apparatus for a classical experiment but not the detailed method. At this level, you are informally assigning the design of the experiment to students. The activity that follows employs a student-designed method for an investigation of starch in food.

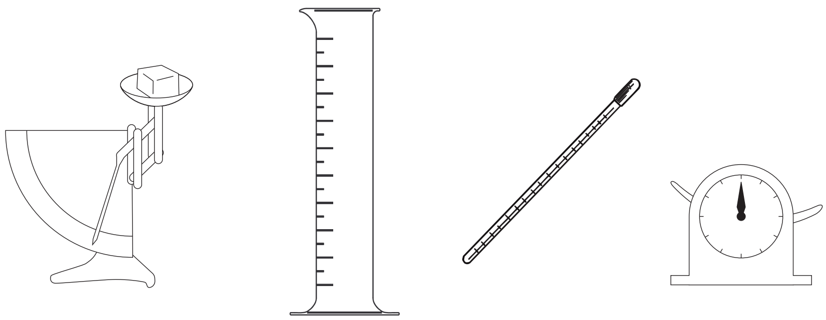
   When students report on an investigation for which they designed the method, their description of the method should be more detailed—as if they were teaching a sibling or a younger student how to repeat the demonstration.

The fourth part of the classical experiment is the **results** section. Everything that has happened during the experiment must be recorded. Where feasible, have students record their results in tables or in the form of graphs.



This results section is sometimes called the **observation** section. When you observe in science, you use four senses—sight, touch, hearing, and smell—to note what happened during the experiment. Can you guess why students should not use their sense of taste?

Results or observations using just our senses are not good science, because they are **subjective**—dependent upon the observer's opinions and personal reactions—and are therefore open to challenge. More reliable information can be obtained using **measurements** such as height, length, width, time, distance, or temperature. Equipment is required for taking measurements, but the result is more **objective**, regardless of who measures.



Observation can take the form of **changes**. In this case, observations need to be recorded before, during, and after the changes take place.

The final part of an experiment is called the **conclusion** section. When one draws up conclusions about an experiment, one makes statements that are final about what one set out to learn. Thus, the conclusion should relate to the aim in a logical way. It is also called the **interpretation** section, because that is the type of thinking employed, or the inference section, because that is the type of conclusion being drawn. To infer means to work out what happened from the evidence or results observed.

Classroom Activity

Using what has been described about experimenting or investigating, plan for small groups of pupils to carry out an experiment to find out which food substances contain starch. You provide the aim of the experiment and all the necessary materials and equipment to carry out the experiment successfully. When they have completed the investigation, let them generate a report by answering the questions below.

Activity

1. What is the aim of the experiment?
2. What apparatus did you use? What diagrams did you include for the apparatus?
3. What was the method for this experiment? Describe step by step how the experiment was carried out.
4. What results/observations did you find in this experiment? Use tables to present your results/observations.
5. What were your interpretations, conclusions, or inferences for this experiment?

From Doing to Reporting

While your pupils carry out the experiment, you should move from group to group to assist and answer questions. During the first lessons, you will need to give your pupils more assistance until they become accustomed to doing things themselves. At the end of the activity, a class discussion should follow. During the class discussion, go over the entire experiment and find what observations were made. In effect, the students first give their report orally, then in writing.

The following are possible observations your pupils should provide as answers to the questions on the main activity. If they do not answer to your satisfaction, use good questioning techniques to elicit more accurate responses.

1. Aim: To investigate/test for starch in a variety of food substances.
2. Apparatus: A variety of food substances, iodine solution, test tubes, etc.
3. Procedure:
   (a) Make solutions/pastes of the various food substances in water.
   (b) Add one or two drops of iodine solution to the paste.
   (c) Observe colour changes.

4. Observation: Where there is starch in the food substance, the colour changes to blue/black.
5. Conclusion: Some food contains starch whereas other foods do not.

Reflection

1. When you went round the groups:
   (a) Did everyone participate in the discussions?
   (b) Did everyone get a turn to give their opinions and ideas?
   (c) Did everyone listen to each other's point of view?
   (d) Did everyone have something to do?
   (e) Did everyone agree with the observations and conclusions the group made?
   (f) What could be done to improve the activity?
2. Were you able to successfully plan this experiment for your pupils?
3. Were your pupils able to describe the different sections of the experiment?
4. What problems did you encounter?
5. What problems did your pupils encounter?
6. What suggestions can you make to overcome the identified problems?
7. Were you happy with the example of the experiment suggested?
8. What other alternatives could you have used?

Summary

The focus of this unit was planning a classical experiment and having pupils carry it out in the classroom. The components of a classical experiment were presented, with alternate terms also described. An example of an experiment on food tests was used as the main activity.

Unit Test

1. Give examples of science processes.
2. What is a classical experiment? How does it differ from experiments performed by real scientists?
3. Name the five main components of a classical experiment.
4. What senses can you use to make observations during an experiment?
5. One human sense is not used for testing results in an experiment. Which sense is this, and why isn't it used?
6. What measurements can you make when carrying out tests. What special equipment would you require for each measurement?

Unit 2: Simulations and Modeling

Unit Objectives

By the end of this unit, the teacher should be able to:

- define simulations and models from the point of view of a science educator
- explain the uses of simulations and models during the teaching and learning process
- list advantages and disadvantages of their use
- use a model, a simulation, or a role model to enhance learning in the classroom

Content

- simulations and their uses
- scientific models
- role models in science teaching

Teaching and Learning Techniques

- questioning
- observations
- presentation of reports

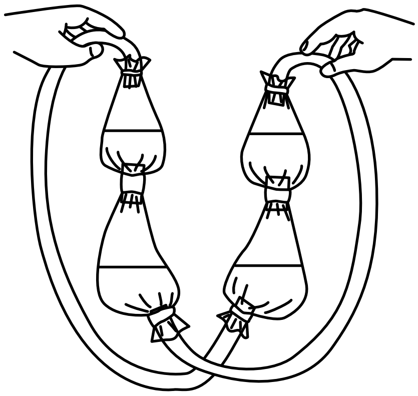
Introduction

Unit 1 of this module focused on classical experiments as a method of teaching and learning science. The focus of this unit is on using **simulations** and **models** to teach science. Simulations can be regarded as one of the scientific processes that were given in Unit 1.

Definition and role of simulations

The Oxford Learner's Dictionary defines a simulation, as "an operation in which a real situation is represented in another form". Simulation can be described as a reproduction of a situation or action for study or training purposes. The emphasis in simulation is on reproducing the *action* of something else, not its appearance.

A simulation is a useful teaching and learning tool. It represents a real structure for the purpose of explaining how something works. As you can see in the four-bag simulation of the four-chambered human heart, physical resemblance can be sacrificed as long as the working principle is clear.



Simulation: how the heart works

How can simulations be used?

Simulations work best when it is not possible or desirable to see the action in real life. The more realistic the simulation, the less explanation will be required, but as long as the intended action is clearly reproduced, the simulation should impart the desired learning.

Commonly, the teacher demonstrates or carries out a simulation for the pupils, who gather around to watch. You can explain what is being simulated, either through the questioning technique (the preferred method) or by explaining.

Less commonly, students in small groups carry out an assigned simulation as part of a classical experiment. As a project, a group of students could construct its own simulation. Considerable creativity may be required, but the action portrayed by the simulation will likely never be forgotten.

Be prepared with background knowledge about the simulation, especially if it is dramatic. Students are likely to be curious about what is really happening, and "teaching moments" abound for the teacher who can answer unusual questions. Creative simulations can make the learning of science unlike anything else your students learn in school. You should develop a range of simulations and use them to guide the teaching of science in your classroom.

What are the advantages of simulations?

Reece and Walker (1998) give the following advantages of simulation:

- Can be used where the real situation is dangerous, costly, difficult, or too time consuming.
- Can be repeated until the desired level of learning is achieved.
- Can be stopped at any stage in order to inject concepts, principles, etc.
- Students are active and, if they conduct their own simulations, can take responsibility for their own learning.
- Can be used as an introduction to the actual topic.
- Can be fun because pupils learn as they play.
- Are good at developing skills.

Disadvantages of simulations:

- Can be time consuming.
- May be difficult to supervise if all pupils use simulations at the same time.
- If rough or inaccurate, simulations can create false impressions about the real action they attempt to portray. The teacher intuitively sees past the limitations in these cases, but students' intuition may be insufficiently developed to do that.

The Future of Simulations—the World Wide Web

If your classroom has a computer with access to the World Wide Web, you have another source of science simulations. Many Web sites simulate scientific principles right on the screen. Here are two examples:

- For an alternative to the four-bag simulation of a human heart, consider this Web page from the US Public Television Network's science program *NOVA*. It shows a constantly beating heart in the form of a cutaway diagram—a representation that is scarcely possible in any other medium. The Web address, or URL, is http://www.pbs.org/wgbh/nova/heart/heartmap.html

- Perhaps the best-known Web simulation is "Virtual Frog", an on-screen simulation of the dissection of a frog to view its anatomical features. Students use the computer mouse as if it were their dissecting instrument. The URL is http://curry.edschool.virginia.edu/go/frog/

  This simulation has been on the Web since 1994, and in that time has saved the lives of thousands of frogs.

Models and Modeling

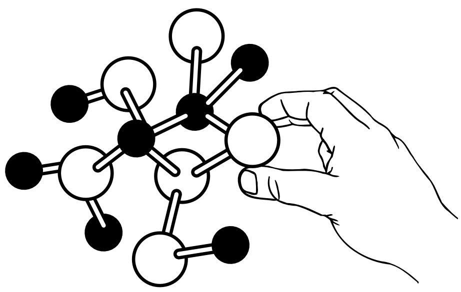
Scientists use the word **model** a great deal. Unfortunately, society has its own uses for the word—in phrases like "fashion model" and "late model car". Here, we want to deal with the scientific definitions.

The *Oxford Advanced Learner's Dictionary* defines modeling as:

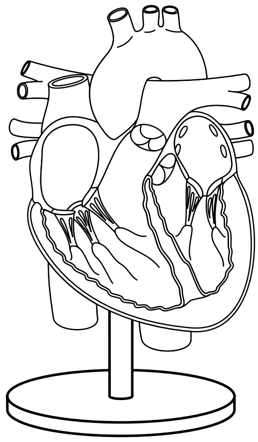
> "a process of copying or imitating the way a person speaks, dresses or behaves".

From this definition comes the idea of **role model**. While role modeling is not a scientific process, we briefly discuss it at the end of this unit. For our purposes in science, a model represents an otherwise invisible or **unviewable** object, for the purpose of teaching and learning the science about that object.

One of the best-known of scientific models is the ball-and-stick model that shows how atoms combine to form molecules. As another example, consider the model of a human heart shown below.



Atomic model



Model of a human heart

Models Compared to Simulations

In science, what differentiates a simulation from a model? Compare the above model heart to the four-bag simulation of a heart in the previous section. The simulation demonstrated the *action and function* of the heart. The above model portrays its *shape and form*. You probably know the fundamental principle in the natural world that **form follows function**. This suggests that there is a place in your science teaching for both models and simulations. Models teach form; simulations teach function.

In practice, the boundary between simulation and model can blur. Consider the abstract thinking that scientists often use to understand something, and which they usually call a model. The **wave model** and **particle model** of light are examples. These are not models that students can build well—they are meant to be mental models, or models of thought. Although these are true models in the scientific sense, their vague form suggests that you might not want to include them in a junior secondary discussion or project on scientific modeling.

Consider next a globe—a *model* of the planet Earth. Its oceans and continents obviously represent the earth's form, likely even its colour. But now, spin the globe in front of your students, and shine a light from one side. Now the globe is *simulating* the processes of sunrise, sunset, summer, winter, and planetary rotation. A model that also provides a simulation is called a **working model**. It embodies both the form and the function of the original object.

Working models are more effective teaching/learning tools than the separate static models and simulations. Unfortunately, working models tend to be difficult to make and are therefore expensive.

A useful approximation to a working model is a student-built static model. Students can construct a model fish from paper and glue. This model is definitely not a working model or simulation because it cannot swim or float properly in water. Yet to make it, students have to consider both the form and function of the various parts of a fish. So in a way, making a static model can be as effective for learners as watching while someone else demonstrates a working model. The hands-on experience of building the model will help them understand the function of the parts they are modeling.

In general, models are easier to build than simulations, and student-built models tend to teach many of the concepts of a simulation. Wise is the science teacher who teaches with models, and also has students building models.

Advantages of using models in teaching and learning

- Models are not difficult to organise.
- Pupils become active participants and tend to take more responsibility for their own learning.
- Models motivate students to ask more questions.
- Models give the teacher (and students!) a break from ordinary teaching. When students are fully engaged in using or building a model, the teacher has more time to observe the learners.
- Models can be fun for pupils to build.

Possible disadvantages:

- The model/simulation can be difficult to see if it is too small.
- If the model does not resemble the real item it is supposed to portray, it can be difficult to understand the purpose of the model or simulation.
- Unless the teacher has a worksheet or set of written questions prepared, students may have no written record of seeing the model.
- If poorly organised, simulations can be boring or frustrating for students. Many adults retain a memory of the classroom demonstration that did not work!
- Pupils can be passive watchers for too long.
- Can be costly in terms of teacher preparation time, materials, or space.
- Pupils may perceive the exercise as mere entertainment.

Role Models in Science Teaching

We return now to the *Advanced Learner's Dictionary* definition of a role model. According to Cohen and Marion (1977), pupils can learn many things in the classroom without the deliberate and planned action of the teacher or deliberate effort and practice by the pupils themselves. The learners only need to see particular behaviours being demonstrated by someone. The learners will be able to imitate the behaviour on their own. The person who demonstrates the behaviour is the **model** and his or her actions are called **modeling**.

One hopes that you, the teacher, are a suitable model! But you can do more than that. Teachers can bring role models into their science classes by inviting guest scientists to visit the classroom. The scientist role model may be filled by a scientist, an engineer from a nearby industry, a trained technician in a scientific field, or a medical doctor.

Hints for Using a Role Model in Science Teaching

Not all scientists can impart their professional passions to a younger audience. There are three actors in this modeling scenario who need to be prepared for successful modeling: you the teacher, the visiting scientist, and the student audience.

Your responsibility is to determine if the visiting scientist will be a suitable role model. Ask what the scientist would like to bring to the class. If there is a large choice of subjects, look for the closest matches to topics that your class is or will soon be studying.

How accustomed is this scientist to capturing an audience through the use of questions? Have they engaged schoolchildren of this age before? Can they bring models or simulations? Industrial and academic chemists can often bring spectacular demonstrations, but they must be safe for a large group of pupils. In effect, you are interviewing a job candidate for a short-term job as a role model. Satisfy yourself that the candidate meets your criteria.

The visiting scientist needs to know the science topics being studied in your classroom, and it will help if the visitor is aware of the particular passions of some of your students. The scientist's contribution as a role model may only be to motivate one student to turn a personal passion into a science career—but if that student goes on to rid Africa of malaria, the classroom hour will be well invested!

Ask the visiting scientist if there are questions that should be asked, but which the students might not think of. For example, someone should ask at what age the visitor's interest in science began and how he or she studied science outside of school. The scientists can help you prepare a list of such questions so if the pupils don't ask them, you can.

Your pupils need preparation as well. Give them an overview of the scientist who will be coming and the work he or she does. It may be appropriate to have the students plan some pertinent questions ahead of time—perhaps even designate who will ask certain questions, especially if the answer will be of direct interest to a certain student. It may also help if students (or some students) investigate the scientist's speciality ahead of time.

One good "meeting of minds" between an inquiring class and an enthusiastic scientist can alter the whole tenor of a science classroom for weeks.

Classroom Activity—Simulations and Models

Your Unit Assignment is to teach a lesson using a model or simulation. Either present a lesson by using a model in class, or have your students create a model as a learning exercise—perhaps both. This is a broadly defined project and you will need to plan the specifics of this activity in some detail before you give it to your students.

When the lesson has been completed and discussed in class, ask yourself the following questions:

1. Were you able to plan and execute the project successfully?
2. If your learners made the models, were they able to follow the instructions?
3. Were your learners able to have a meaningful discussion afterward?
4. What problems did you encounter?
5. What problems did your learners encounter?
6. What suggestions can you make to overcome the identified problems?
7. Were you happy with:
    (a) the way the main activity was presented?
    (b) the way the entire unit was presented?
8. What changes could you make to improve:
    (a) the project?
    (b) your use of models and simulations in general?

Summary

The focus of this unit was on modeling as a strategy for teaching science at the junior secondary school level. Models and simulations are used to make science seem real when it is not possible or desirable to teach and learn using reality. Models are especially helpful when real situations are dangerous, costly, difficult, or too time consuming. Models, simulations, and role-modeling were defined and explained, including their similarities and differences.

Unit Test

1. What is:
   (a) a model?
   (b) a simulation?
2. What are:
   (a) the advantages of using models and simulations for teaching and learning science?
   (b) the disadvantages of using models and simulations for teaching and learning science?
3. How does the teaching with models differ from teaching with simulations?
4. What problems are associated with teaching and learning with models?
5. What planning steps are associated with bringing a scientist role model to class?

Unit 3: Inquiry

Unit Objectives

By the end of this unit, you should be able to:

- define scientific inquiry, both generally and as it applies to the teaching and learning of science
- differentiate between inquiry and traditional classroom experiments
- list obstacles to the use of inquiry in the classroom

Introduction

Unit 1 of this module dealt with classical experiments and demonstrations, and drew the distinction between that type of experiment—normally undertaken in science classes—and *real* experiments that scientists conduct.

This unit is about **scientific inquiry**, and it deals with real experiments. In its purest form, scientific inquiry for a science teacher means “the conduct in the classroom of actual scientific research on unknown topics of local importance”.

One can see right away that such inquiry is a truly scientific process. For the purist, scientific inquiry is the *only* truly scientific process in this module! (The other units deal with processes of teaching and learning.)

In recent years, science education has undergone a paradigm shift, from fact-based to inquiry-based learning. The trend is to make students think and act the way scientists do when confronted by something unknown. This shift is more prominent in the upper primary and junior secondary grades, while the senior secondary grades are still used to lay the theoretical and factual groundwork for post-secondary study.

Scientific inquiry is only starting to enter the formal school curriculum or syllabus, and it will likely never form the entire syllabus. For one thing, teaching through inquiry can be difficult to carry out because it is subtle and complex. Classroom management and logistics become more of an issue, so beginning teachers are advised not to try inquiry until their other classroom skills are developed. The apparent sparseness of a syllabus based on inquiry also means that student assessment is a challenge, especially demonstrating objectively to administrators that deep learning has taken place.

This unit cannot fully equip you to teach via inquiry. Unless they were practising scientists before going into education, schoolteachers find that teaching this way takes years to master and requires support from experts in hands-on workshops. This unit’s more modest goal is to make you aware of the technique, and we hope your ability to use it will improve with experience.

Components of Scientific Inquiry

The conduct of a pure or total classroom inquiry session can be contrasted with the demonstration of a classical experiment, as shown in this table:

Classical Experiment Steps (from Unit 1)		**Scientific Inquiry Steps**
1. Aim (given to students)	...	1. State Original Question (usually given, could be a student question).
2. Apparatus (list is given to students)	...	2. Students form and state a testable hypothesis.
3. Method (steps are given to students)	...	3. Students design an experiment to test the hypothesis.
4. Results (recorded by students)	...	4. Students conduct experiment, compare results to hypothesis.
5. Conclusion (recorded by students)	...	5. Students answer the question—or else restate the hypothesis and suggest another experiment.

The distinction should be immediately apparent. Compared to the predetermined steps of a classical demonstration, a pure scientific inquiry is a "blank slate" with nothing more presented to the students than the question to be answered and some general rules to follow.

In practice, most classroom inquiry is less dramatic than the blank slate. Notice that the table is drawn with several intermediate columns missing. That's because the table shows only the two extreme positions of pure demonstration and pure inquiry. Most inquiry-based classroom work lies between the two extremes, particularly when students are new to inquiry. Also, teachers who use inquiry tend to move in stages from left to right across the table, gradually gaining comfort and expertise with the inquiry process.

Another point that this table does not convey is that even in a pure or right-column inquiry, the teacher is constantly in motion around the classroom, using questioning techniques to help each group of students refine their hypothesis, devise testing or measuring strategies for it, overcome obstacles, and so on. The "state the original question" step is often done in a whole-class discussion and student teams frequently help each other. You could say that inquiry boils down to a classroom-based, teacher-assisted scientific investigation. It is genuine scientific inquiry, but is appropriately packaged for the age group.

Examples of Classroom Inquiries

These examples are not presented as a Main Activity or Unit Test for you to complete as part of this course. While you are free to try the examples, you may prefer to set them aside until you have more experience. As presented, these examples tend toward the "pure" form of scientific inquiry. We have already stated that most teachers adopt inquiry teaching gradually, rather than begin with a detailed project like the examples that follow.

1. The Flowers in the Headmaster's Garden

"The flowers in the Headmaster's garden are dying. Why are the flowers in the Headmaster's garden dying?" That question—if true!—is sufficient for a rich inquiry. It is sufficient because:

- The problem poses an authentic inquiry and is not contrived.
- The problem is stated as a question.
- The problem is of local importance, not an abstract principle to investigate.
- There is a practical need to solve the problem—to prevent the plants from dying.
- Students have access to the problem. It does not require expensive equipment, only local tools and good scientific thinking.
- Students stand to gain a great deal of prestige if they solve the problem for the headmaster.

If the flowers in your headmaster's garden are not in fact dying, then use this question as a model for a similarly relevant inquiry in your locale. Do elders remember when the nearby stream used to have more fish, for example? If so, formulate a classroom inquiry on that topic.

2. The Mpemba Effect

"Does hot water freeze faster than cold water?"

In 1963, a Tanzanian school student named Mpemba tried freezing similar-sized containers of hot and cold milk. The container with the hot milk formed ice first. When in high school in 1969, he asked his teacher why this was so. Of course the teacher did not believe him, even after Mpemba demonstrated it right there in the school. Only when he asked a real scientist, one Dr. Osborne who had visited their class, was Mpemba vindicated. Like any good scientist, Dr. Osborne repeated the experiment and obtained the same result. They published their findings (Mpemba and Osborne, 1969) and it generated a considerable stir in the physics community that continues to this day. Though known from other sources, the phenomenon now bears Mpemba's name.

The refusal of Mpemba's high school teacher to trust the experiment lies at the core of why science education is moving towards inquiry. Educators have noticed that the general population, even if taught in science all through school, is completely incapable of recognising the simplest scientific inquiry. Tending to think that science is located in books, people automatically dismiss a new phenomenon happening before their eyes as wrong. The long-range intent of inquiry-based teaching is to rescue future Mpembas from the ridicule this student endured from people who thought they understood science.

You can turn Mpemba's discovery into an inquiry by asking your students: "Was Mpemba correct?" and having student teams figure out how to prove it. However, proving the Mpemba effect is not as good an inquiry as the dying flowers in the headmaster's garden, because:

- The question is not of immediate local import.
- The answer is already known. Repeating someone's experiment is part of the scientific process, but this experiment has already been repeated and verified many times. It is now a demonstration or classical experiment.
- The students will not gain prestige by solving it.

It is possible to present the Mpemba effect to your class so it sounds like a real inquiry—but then it is no longer an authentic question, but a contrived one.

The question "Was Mpemba correct?" is better viewed as a vehicle for teaching your students *certain parts* of the inquiry process. In the table that shows the extremes between demonstration and inquiry, consider this question as lying somewhere to the right of centre. The Mpemba question teaches students how to turn a broad yes/no question into a testable hypothesis (inquiry step 2) and a workable experiment (inquiry step 3). Even you, the teacher, will be eager to see which groups of students can design an experiment that "proves Mpemba".

However, there is room for true inquiry. Even to this day, scientists are not sure *why* hot water freezes faster than cold. Jeng (1998) reviews the explanations that have been put forward but says the final verdict is not in.

Now that is fodder for a real inquiry: "*Why* does hot water freeze faster than cold?" Besides being an authentic question, this inquiry into cause provides several other ingredients for genuine inquiry:

- Students must review the science literature on the various proposed causes.
- When reporting their findings, students must abandon the traditional laboratory report and instead produce a genuine scientific paper—one that reviews the literature and then describes their own contribution to science.

The downside is that your students are unlikely to find the cause. We close this introductory discussion of classroom-based inquiry by stating that **failed experiments are an expected outcome of true inquiry**, and can be handled to advantage. After failing in 700 experiments, Thomas Edison is said to have remarked, “Well, now we know of 700 things that don’t work”. As long as the students analyse their failure, and suggest a better hypothesis or experiment for next time, they should **receive full marks for failing**. As a teacher, you have crossed the line from demonstration to inquiry when your student assessments align with that principle.

And yet... after reading about the Mpemba effect, this author thinks that experiments using a **parallel plate classifier** might uncover the cause. Apparently no one has tried this approach yet. Ask a mining engineer to sketch a parallel plate classifier for you, then put your students to work on discovering, one hopes, the true cause of the Mpemba effect.

Another suggestion—students who can follow the cooling process with temperature probes are also more likely to discover the cause.

Summary

This unit has introduced classroom inquiry by contrasting it with the classical experiments of Unit 1. While not providing sufficient instruction for teachers to start using inquiry methods, it has aimed to spark teachers’ interest by means of examples and to point to further teacher learning.

To learn more about inquiry methods in teaching, consult Jarrett (1997) for suggestions to inject “a little inquiry” into your regular teaching, as well as a comprehensive bibliography of other resources.

Unit 4: Improvisation

Unit Objectives

The learners should be able to:

- demonstrate a variety of skills and knowledge on the use of improvisation as a teaching and learning strategy
- define and explain improvisation in the teaching and learning of science
- list the basic conditions and procedures when using improvisation in the science classroom

Content:

- What is improvisation?
- The role of improvisation in the teaching and learning process
- Conditions and procedures when using improvisation
- Disadvantages of improvisation

Teaching and Learning Techniques

- questioning techniques
- observations
- group discussions
- class presentations
- teacher demonstrations

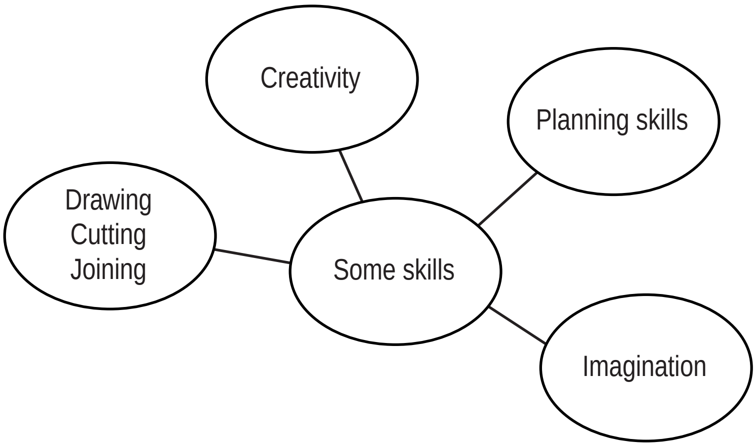
Introduction

In Unit 2 of this module, the focus was on modeling as one of the scientific processes. You discovered that pupils can learn many things by observing models.

In this unit, the focus is on improvisation and its role in the teaching and learning of science. Under what conditions and procedures can you use improvisation when teaching science to your pupils?

What is Improvisation?

As a teacher, you would wish to have ample time to conduct lessons and have access to unlimited supplies of science equipment to use in your classroom. However, in most cases this is not possible and you might become frustrated.



Most schools do not have enough science equipment. There are many reasons for this: some equipment might have been lost, some might have been broken, and in some cases there might not be funds available to purchase the equipment.

Under these circumstances, you might be forced to teach science lessons without adequate equipment and materials. What you might have to do is improvise. This means making use of alternate materials to produce usable science equipment. According to Mutasa and Wills (1994), to improvise means to make something from whatever is available, without advanced planning.

What are the conditions and procedures for successful Improvisation?

If you plan to organise practical work for your pupils but science equipment is not available, you need to have the skills and knowledge to improvise. Consider the following points:

- When you become aware of the non-availability of adequate science equipment in your school, there is a need to improvise.
- If you have large classes, you may not have enough equipment to go around.
- You might have to improvise if there are inadequacies in your school's science equipment.
- Do you have the necessary tools or equipment to improvise? This is an important area to consider.

The need to improvise is a necessity in science teaching. Ask your pupils to help you collect materials and bring them to the classroom. Do this regularly, so materials are replaced as soon as they are used.

Advantages of Improvisation

Consider the following advantages of improvisation:

- Low cost—materials are collected from the local environment
- Simple and easy to use
- Easy to transport
- Readily available
- Reliable

Disadvantages of Improvisation

- Equipment is difficult to store.
- Too cheap to be seriously considered as science equipment.
- Students view improvised equipment as not valid.

Main Activity

Plan to have your pupils in their respective groups carry out this activity. Ask them to go out of the classroom and make collections of whatever materials they can find and that could make useful science equipment. They should come back to class, make a list of things they have collected, and suggest possible uses for the items they collected.

Activity

1. Make a list of the items you found.
2. For each item, state its possible uses in your science lessons.

Answers to the Main Activity

You should go around to each group, assisting the pupils. At the end of the activity, hold a class discussion. During the class discussion, go over the questions as directed in the main activity.

The following are possible items your learners might provide:

1. (a) Plastic containers of all sizes (yogurt cups, ice cream boxes, etc.)
   (b) Wood off-cuts and boxes (straight and clean pieces)
   (c) Tin cans of different sizes (clean and with lids)
   (d) Plastic tubing (different sizes and different lengths)
   (e) Strings and cords of different sizes and materials
   (f) Coffee and jam jars (with or without lids)
   (g) Galvanized nails and screws (straight and different sizes)
   (h) Pieces of cloth (of different colours and sizes)
   (i) Large glass bottles (with or without lids)
   (j) Fruits of different types and sizes
   (k) Seeds (of different types and sizes)

2. (a) Yogurt cups for measuring volume
   (b) Wood off cuts for measuring mass and calculating volume by measuring width, length, and depth
   (c) Tins cans for boiling water, etc.

With your assistance, your pupils should be able to give possible uses for all the items they collected.

Reflection

1. When you went around the groups, did you find everyone participating in the discussions?
2. Did everyone listen to each other's point of view?
3. Did everyone have something to do?
4. Did everyone get a turn to say what he or she thought?
5. Did everyone agree with the decisions the group made?
6. What could be done to improve this activity?

Self Assessment Test

1. Were you able to successfully plan and execute the main activity?
2. Were your learners able to collect adequate items?
3. What problems did you encounter?
4. What problems did your pupils encounter?
5. What suggestions can you make to overcome the identified problems?
6. Were you happy with the way Unit 4 was presented?
7. What improvements can you suggest to improve this unit?

Summary

The focus of this unit was on improvisation as a strategy for the teaching of science. Explanations for why teachers have to improvise were given, along with the conditions and procedures for successful improvisations, and the advantages and disadvantages of improvisation. A main activity for the class was suggested.

Unit Test

1. What is improvisation?
2. Why should teachers want to improvise?
3. List some of the items you have to improvise for your science lessons.
4. What are the:
   (a) advantages of improvisation?
   (b) disadvantages of improvisation?

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