NASCA WORKBOOK
NATURAL SCIENCES

Table of Contents

Introduction

The purpose and importance of science

Science is a way of asking and answering questions about the natural world. The natural world means the non-living (physical) world and the living world. Science tries to detect patterns and find explanations for things we observe in the natural world. We use science in many ways in our everyday lives.

Have you used a cellphone today? Watched TV? Used an electrical appliance? Taken prescription medicine? Rubbed cream on your hands or face? Listened to the radio? Traveled in a motor vehicle? Slept under a blanket that you did not make?

All the products listed above are based on science. We accept them as part of modern life.

- Science has helped humans to live longer, healthier lives.
- Modern transport allows us to move around the country easily.
- Electricity provides us with heat to cook food, lights to see at night, and power for a TV set and to charge our cellphones.
- Cosmetics and creams make us look and feel good.
- Science is our best hope to find solutions to global problems such as how to produce enough food for the growing human population, how best to prevent and treat diseases such as malaria and HIV and AIDS, and how to protect the natural environment.

Studying science may start you on a journey to contribute to the future.

The structure of science

Natural Scientists are curious about the natural world. They study the universe by careful observation and experiments. Questions that you might study as a beginning scientist are these:

- What happens to a ball if I kick it up in the air?
- What happens if I mix vinegar and oil together?
- Why does cow's milk go thick if I leave it in a warm place for a few days?

Scientists observe the process or object they are curious about. They may do some experiments. Once they have results, they develop mathematical formulae to describe events, or models to illustrate structures and processes, or they write descriptions of the things they observe. They try to link what they have observed with other research on similar problems.

Scientific knowledge changes over time as scientists improve their knowledge and understanding. However, science is based on thorough investigation, debate and argument until a new idea is accepted by the scientific community.

The approach to the subject that will be taken in this course

Natural Sciences in the NASCA consists of an overarching study of the Nature of Science, followed by three disciplines: Physics, Biology and Chemistry.

- Physics focuses on the physical properties of matter and energy and the interactions and relationships between these. Physicists try to develop mathematical and other models to explain physical phenomena.
- Chemistry focuses on the properties of matter and materials and the ways in which they change from one form to another and react with one another.
- Biology is the scientific study of living organisms from the molecular level to their interactions with one another and their environments.

We recommend that you begin this course by studying the Nature of Science. You should then study Physics, Biology and Chemistry each week so that you do not neglect any of the disciplines.

Prerequisite and co-requisite subjects

NQF Level 4 Mathematics (NOT Quantitative or Mathematical Literacy) and English are co-requisites for Natural Sciences. Physics, Chemistry and Biology need good language and mathematical skills.

Topic 1 THE NATURE OF SCIENCE

Introduction

Science is the study of the natural world and how it works. Scientists try to discover patterns in events in the natural world, and to understand those patterns through careful, systematic study. Through science, we can understand many of the patterns in the universe, such as patterns of matter, energy, forces and motion, chemical reactions as well as patterns in living organisms.

This section introduces you to scientific ways of thinking and scientific methods of inquiry. We introduce the disciplines of Physics, Chemistry and Biology. Study the Nature of Science before you begin to study of each of the disciplines Physics, Chemistry and Biology.

The Nature of Science Content Structure

Topic Heading	Topic (with Approximate Instructional Time)
What is natural science?	2 hours
Scientific inquiry	3 hours
Science in society	1 hour

Subtopic 1. What is Natural Science?

Content:

Unit 1: The nature of science and scientific knowledge

Unit 2: The purpose of science

Unit 3: The value of science

Unit 4: Scientific disciplines

Unit 5: The boundaries of science

Unit 1: The nature of science and scientific knowledge

Learning outcomes:

When you have completed this unit, you should be able to:

- describe the nature of science as a comprehensive and reliable way of understanding patterns observed in the natural world.
- demonstrate understanding that although much scientific knowledge is long-lasting, it is subject to modification as new information becomes available;
- distinguish between the terms *theory*, *hypothesis* and *prediction* as used in science;

Activity 1.1 What do you know about science and scientific knowledge?

This activity establishes what you already understand about science and scientific knowledge.

Highlight words from the list below that relate to science and scientific knowledge.

Experiment; facts; laboratory; apparatus; harmful; untrue; evidence; religion; observation; false; unproven; theory; reasoning; mathematics; truth; unchanging; reliable; faith.

1.1 What is science?

Science is a way of asking and answering questions about the natural world. Scientists look for patterns in the natural world. They investigate the natural world by careful observation and experiments. They try to explain what they are observing. They study similar work conducted by other scientists. Eventually, if most of the evidence agrees, they develop a theory that explains a whole lot of related observations.

For example, Robert Hooke discovered the first cells in 1663. He cut thin slices of cork and examined them with his simple microscope. He saw that cork consisted of little boxes that he called “cells”. Over the next two hundred years, microscopes improved and scientists studied thin slices of many different plants and animals. Eventually, in 1883, a pattern emerged that led to a Law:

All living things are made up of cells.

No living thing has yet been found that is not made up of cells. The theory has proved to be reliable.

[Insert image of cork cells here. Caption: Figure 1.1: Cork cells, first discovered by Robert Hooke.]

Main idea: Science is a systematic way of investigating the laws that govern the natural world.

1.2 Scientific knowledge grows and changes

Perhaps you thought that science consists of a lot of facts that you have to memorise. It is true that science has many facts, but all of them began with observations about the natural world. Facts are established knowledge. The knowledge began with observation and experimenting, leading to reliable facts. Some facts have remained true for centuries. Other facts change as new knowledge is discovered.

> For example, the first cells that Robert Hooke discovered were dead cork cells. They had no cell contents. Later, methods of staining samples of tissue were discovered, and microscopes improved. Scientists noticed that there were objects inside cells. One object was present in all cells, and was called the nucleus. New knowledge had been discovered.

Main idea: Scientific ideas are subject to change.

Activity 1.2: Have you understood your reading?

Say whether each of the following statements is true or false. If false, say why the statement is false.

1. Scientific knowledge was established 200 years ago and has not changed since then.
2. Science is a way of asking and answering questions about the natural world.
3. Scientists produce knowledge that is always true.
4. Scientists try to explain their observations and experimental results.
5. Science can answer every question we may ask.

1.3 Hypothesis, theory, predictions and laws

After a scientist has observed a natural event, and perhaps conducted some experiments, she studies the data she has collected and develops a **hypothesis**. A hypothesis is an educated guess that explains a set of observations. A hypothesis may be very simple.

> For example, every time you kick a ball into the air, it comes back to the ground. You could state a hypothesis as simply as "A ball kicked into the air always falls".

[Insert word box: Hypothesis: A hypothesis is an educated guess that explains a set of observations.]

A hypothesis may be more complicated.

> For example, the hypothesis may be a mathematical equation that describes the rate at which the ball rises and falls.

[Insert equation for the motion of a ball].

A theory is a statement about the world that is supported by evidence from many different sources. Theories apply to many more events than a hypothesis.

[Insert word box: Theory: a statement about the world that is supported by evidence from many different sources]

A boy kicking a football may decide to experiment with all kinds of different objects to see if they all fall back to the Earth if you kick them. After observing and measuring the rate of falling, he could come up with a theory that states:

"All objects fall a distance proportional to the square of the time of the fall".

This theory can be tested by anyone else. It might need to be refined.

For example, another boy may find that wind affects the results. The theory needs to be re-stated:

"Without wind, all objects fall a distance proportional to the square of the time of the fall".

Some theories are based on observations, rather than experiments. Theories based on events that happened a long time ago cannot be tested by experiments. Such theories are a best guess that explain a number of different observations.

The theory that continents have moved across the Earth's surface explains evidence from the shape of continents, the same fossils found on different continents, and the contours of the ocean floor.

[Insert map of Gondwana here. Insert images of Glossopteris Caption: Africa, South America, Madagascar, India, Australia, New Zealand and Antarctica were once joined into one continent. As Unit 4, p. 98 of SACHED material. Show only *Glossopteris* and *Lystrosaurus*.]

A theory such as the movement of the continents cannot be tested experimentally. It is the best explanation considering all the evidence we have.

Scientists test each hypothesis and theory. They make predictions about what will happen in a particular system if the theory is correct. They then observe nature or conduct experiments to see if the system supports the theory.

[Insert word box: Prediction: A guess about how a particular system will behave if a theory or hypothesis is correct]

Suppose we hypothesize that all objects fall when dropped. We predict that if we drop a feather, a stone, a sheet of paper, and a cup of tea, they will all fall to the earth. Each object we drop is a test of our prediction. If all the objects fall to the earth, our predictions were correct and our hypothesis is supported.

Tests do not necessarily prove or disprove a hypothesis or theory. They often say something about the range of situations under which the theory is valid.

If we tested whether all objects fall when dropped in space, the objects would float away. They would not drop. If we filled a balloon with helium gas, it would float upwards. The theory that all objects fall when dropped is true on earth, and for all types of matter except certain gases.

When a theory has been tested many times, and the evidence seems to always agree, the theory may be raised to the level of a law. A law is an overarching statement that describes how the natural world works.

> In the example about Robert Hooke's discovery of cells, 200 years passed before a law was stated. The law stated that all living things are made of cells.

Physics and Chemistry have many laws. The laws apply in every context that has been tested. Life is less predictable than Physics and Chemistry. Biology (the study of life) has a few laws, but many general principles. Although science tries to describe the natural world in terms of laws, the laws may change if further evidence is discovered.

[New word: Law: An overarching statement that describes how the universe works.]

Main idea: Science works through statements that have increasing levels of certainty: **hypothesis**, **theory**, and **law**. Hypotheses and theories generate **predictions** that can be **tested** to see if the hypothesis or theory is supported.

Activity 1.3: Have you understood your reading?

Match each statement with its correct description.

1. Law	A. An educated guess that explains a set of observations
2. Prediction	B. Careful observations of a natural process.
3. Hypothesis	C. An overarching statement that describes how the universe works.
4. Theory	D. A statement about the world that is supported by evidence from many different sources
	E. A guess about how a particular system will behave if a theory or hypothesis is correct

Assessment 1: The nature of science and scientific knowledge

1. Sort the following statements into scientific statements and non-scientific statements:

1.1 Most of the Sun's energy is in the form of visible light.

1.2. Hip-hop music is nice to listen to.

1.3. Diamond is harder than steel.

1.4. The Earth was created in a miraculous event.

1.5. The Earth formed over 4 billion years ago.

1.6. Elephants are beautiful animals.

1.7 The human brain is made up of interconnected nerve cells.

2. Say whether each of the following statements is TRUE or FALSE. If FALSE, say what is wrong with the statement.

2.1 Scientific laws are true forever.

2.2 Science is a way of asking and answering questions about the natural world.

2.3 Science seeks patterns in nature.

2.4 Science is a body of knowledge that you have to memorize.

2.5 The most basic principle of science is that the universe can be studied by observation and experiment.

Unit 2: The purpose of science

Learning outcomes

When you have completed this unit, you should be able to

- describe the purpose of science as developing generalizable theories that explain events in the natural world through careful, systematic study.

2.1 The ultimate purpose of science

The purpose of science is to develop the natural laws that describe how the universe works. Knowledge is built through careful observation, measurement and experiments. If all the investigations agree over a long period of time, scientists state a theory. If more tests confirm the theory, it may become an overarching law of nature.

The laws of nature are sometimes called the "great ideas of science". Here are some examples of laws of nature that we will explore further in this course:

- Evolution by natural selection explains the diversity of life on earth in the past and the present.

- Newton's laws of motion and gravity predict the behaviour of objects on Earth and in space.
- All matter is made of atoms.
- Electricity and magnetism are two different aspects of the electromagnetic force.

Main idea: The ultimate purpose of science is to develop laws that apply to the natural world.

2.2 Basic research, applied research and technology

Basic research tries to find out more about the universe because it is interesting. Scientists who conduct basic research are curious about the universe. Their findings may be useful to humans in the future, but that is not the primary goal of their research. They are trying to advance scientific knowledge about the universe.

[Insert new word: Basic research: Research that investigates an aspect of the natural world because it is interesting]

Applied researchers have specific goals in mind. They want to use science to create machines or processes that make money and/or benefit humans. Their research may result in a new process, a new machine, or a new treatment for a disease.

[Insert new word: Applied research: Research that uses science to create machines or processes for commercial gain or to benefit humans]

Applied research is closely linked to **technology**. Technology applies the results of science for commercial or industrial goals. Engineers and technicians convert the findings of applied research into factories and industries.

[Insert new word: Technology: the application of scientific research for commercial or industrial goals]

Main idea: Scientific research may be basic or applied, and it is used to develop technology.

Activity 2.1: Have you understood your reading?

Say whether each of the following examples is basic research or applied research. Write “B” next to the statements that are basic research and “A” next to the statements that are applied research.

a. An astronomer discovers a new galaxy.

b. A materials scientist finds a new way to make rubber tyres.

c. An animal breeder breeds a new variety of chickens that are resistant to disease.

d. A biologist studies the diet of crowned eagles in South Africa.

e. A chemist discovers a new element.

Unit 3: The value of science

Learning outcomes

When you have completed this unit, you should be able to

- explain the value of science in developing deeper understanding of natural phenomena and the ability to predict future events.

3.1 Science has value for human society.

We are naturally curious about our world. Science gives us a powerful way of understanding things that happen in our natural world. The laws of nature explain how the world behaves. Science provides a way of learning more and investigating new questions that we ask. By understanding the world, we can predict future events, such as floods, flu epidemics, and eclipses of the Sun.

Science is a way of thinking about the world. It uses reasoning, and evaluates statements in terms of how they are supported by evidence. People who master scientific ways of thinking can solve problems and think critically.

Science is our best hope for curing diseases such as HIV and AIDS, discovering new materials that do not pollute the earth, and developing new technological products such as computers and smartphones.

Science also enables us to marvel at the order in the natural world. The physical world obeys the laws of nature. The living world obeys a smaller set of laws, and it is much more variable than the world of physics and chemistry.

Main idea: Science adds value to our lives in helping us to understand the natural world, and to think logically. Science benefits humans in providing improved health, new materials such as plastics, and new technologies such as mobile phones. It enables us to marvel at the order in the natural world.

3.2 Science provides opportunities for employment

If you are very interested in science, you could become a professional scientist. Professional scientists are employed in universities and research institutes. They have to spend many years studying science in order to practice as a professional scientist. Only a few people are employed as professional scientists.

Many more people become technicians who apply science and technology in their work. Farmers, computer technicians and medical technologists are examples of jobs that are based on science. There are many job opportunities for people who understand science.

Main idea: Science is a gateway subject to many jobs.

3.3 Science encourages critical thinking

In our everyday lives, we have to make decisions about our health and our diet. We have to be able to predict the consequences if we allow rubbish to collect in our neighbourhood. At a national level, we have to contribute to decision-making about the sources of our energy supply, and the importance of providing clean water to all communities.

Science provides us with the reasons why we need to live a healthy lifestyle, keep the local environment clean, and use renewable energy like solar and wind energy to generate electricity. Science informs us about bacteria in dirty water, and how it causes cholera and diarrhoea. Science helps us understand why it is important to vaccinate our babies. Science enables us to understand that dwarfism is caused by genes, not by evil spirits.

Main idea: Science helps us make informed decisions at home, in our communities and as a nation.

Activity 3.1: Have you understood your reading?

1. Write down FIVE ways in which science is of value to humans.

Unit 4: Scientific disciplines

Learning outcomes

When you have completed this unit, you should be able to:

- give examples of broad scientific disciplines, such as Physics, Chemistry, Biology, Geology, and Environmental Science;
- differentiate the fields of study of Physics, Chemistry and Biology, and indicate overlaps between the disciplines, such as biochemistry (intersection between Chemistry and Biology) and properties of matter (intersection between Physics and Chemistry).

4.1 Science is organised into scientific disciplines.

Science is a collection of different fields of study, which are called disciplines. All the disciplines have the same purpose and philosophy: to develop the natural laws that describe how the universe works through careful observation, measurement and experiments. Some examples of scientific disciplines follow.

- **Physics** is the study of the physical properties of matter and energy, and the interactions and relationships between these. Physics tries to develop mathematical models to explain physical events. It is one of the oldest disciplines.
- **Chemistry** is the study of the properties of matter and materials. It includes the ways in which matter changes from one form to another, and how forms of matter react with one another.
- **Biology** is the study of life and living organisms. It investigates living organisms from the level of molecules and cells to the ways whole organisms interact with each other and their physical environment.
- **Geology** is the study of solid Earth, its rocks, and the processes by which they change.
- **Environmental science** is the study of the physical, chemical and biological conditions of the environment and their effect on living organisms. It is an interdisciplinary science because it draws on Physics, Chemistry, Biology and Geology.

These are just five of the scientific disciplines. Each is subdivided into many sub-disciplines. For example, Biology has about 600 sub-disciplines!

Physics and Chemistry are sometimes called the "hard sciences" because they seek universal laws that apply to the physical world. Physics, particularly, tries to develop mathematical equations that describe events in the physical world. The equations can be used to predict future events, such as the movement of the planets, or what happens to a gas at certain temperatures and pressure.

Biologists study living systems, which are very different from non-living systems. Both living and non-living systems obey the laws of nature, but living systems also obey the instructions from their genes. Genes do not exist in non-living systems. Living systems cannot easily be described by a mathematical equation. It is difficult to develop laws that apply to all living systems everywhere.

Main idea: Science is a collection of disciplines. Physics and Chemistry try to discover the natural laws that describe how the non-living world works. Biology studies the living world, which is much more variable than the non-living world.

4.2 Overlaps between the disciplines

Some scientific disciplines cross two or more of the major disciplines. **Environmental Science** draws on Physics, Chemistry, Biology and Geology. **Biochemistry** is another example. It is the study of the molecules found in living organisms, and how they react with each other. It draws on the laws of Chemistry and how they work in Biology.

The **properties of matter** is an area of study in which Physics and Chemistry overlap. [Sharon / Andre – can you add a bit more explanation?]

Activity 4.1: Have you understood your reading?

Identify the discipline that each of the following statements belong to. Write "P" for Physics, "C" for Chemistry, "B" for Biology, "G" for Geology and "E" for Environmental Science.

a. Blood circulates throughout the body in blood vessels.

b. The elements that make up matter can be arranged in a Periodic Table.

c. Mathematical equations exactly describe the movement of planets around the Sun.

d. The Linnaean classification system is a scheme to classify living organisms.

e. Rocks can be classified as igneous, sedimentary or metamorphic.

f. Joseph Lockyer discovered the element Helium.

g. Gregor Mendel discovered that physical features of an organism can pass on to its offspring.

h. Organisms living along the seashore are affected by waves, tides, and the salinity of the sea.

Unit 5: The boundaries of science

Learning outcomes

When you have completed this unit, you should be able to:

- identify the limitations of science in its inability to investigate phenomena that cannot be proved or disproved, such as beliefs, the purpose of life, issues of good and evil.

5.1 Science and the arts

Science is different from the arts because it starts with observation.

For example, a scientist can study a piece of pottery and identify the type of clay that was used, how the pottery was fired to make it hard, and even how old the piece of pottery is. But a scientist cannot say whether it is beautiful or not, or what it meant to the person who made it.

Scientific statements describe reality, not how humans perceive that reality. Appreciation of art, music and physical beauty lie outside the boundaries of science.

5.2 Science and belief in gods or other supernatural forces.

{Word box: Supernatural: an event that people say is caused by a force beyond scientific understanding or the laws of nature]

Beliefs in supernatural powers such as a god or gods, or ancestral spirits, cannot be proved or disproved, and are therefore outside the boundaries of science. Scientists cannot give answers to questions such as

- What is the purpose of life?
- What is “good” and what is “evil”?
- What is beautiful or enjoyable in music, art or literature?
- What morals should I apply to my life?
- Is there a god or supernatural forces such as ancestral spirits that control my life?
- Do miracles happen?

Main idea: Science only addresses questions that can be proved or disproved. Other questions fall outside the boundaries of science.

Summary of key learning:

- Science is a systematic way of investigating the laws that govern the natural world.
- Scientific ideas are subject to change.
- Science works through statements that have increasing levels of certainty: **hypothesis**, **theory**, and **law**. Hypotheses and theories generate **predictions** that can be **tested** to see if the hypothesis or theory is supported.
- The ultimate purpose of science is to develop laws that apply to the natural world.
- Scientific research may be basic or applied, and it is used to develop technology.
- Science adds value to our lives in helping us to understand the natural world, and to think logically. Science benefits humans in providing improved health, new materials such as plastics, and new technologies such as mobile phones. It enables is to marvel at the order in the natural world.
- Science is a gateway subject to many jobs.
- Science helps us make informed decisions at home, in our communities and as a nation.
- Science is a collection of disciplines. Physics and Chemistry try to discover the natural laws that describe how the non-living world works. Biology studies the living world, which is much more variable than the non-living world.
- Science only addresses questions that can be proved or disproved. Other questions fall outside the boundaries of science.

Assessment 2: The nature, value and boundaries of science.

What I learnt in my Natural Sciences course

The most valuable thing I learned in my Natural Sciences course is that there is an explanation for natural events. It is not magic. This approach to understanding our world has made science more interesting to me.

For instance, last weekend we had a thunderstorm. A house at the top of a hill was struck by lightning. Two children in the house died. Some people said a traditional healer had caused the lightning to strike that house. I could use the knowledge I obtained in this Science course to explain what happened.

On a hot day, warm air containing water vapour rises. As the air rises, water vapour condenses and forms a cloud. The cloud grows as more warm air rises. In the tops of the clouds, it is so cold that the water droplets turn into ice.

The cloud becomes a thundercloud. Small pieces of ice bump into each other as they move around. The collisions cause electrical charges to build up in the cloud.

Eventually, the whole cloud fills up with electrically-charged particles. Lighter, positively-charged particles gather at the top of the cloud. Heavier, negatively-charged particles sink to the bottom of the cloud.

When the positive and negative charges grow large enough, a giant spark - lightning - occurs between the positive and negative charges within the cloud. Most lightning happens inside a cloud.

Sometimes lightning strikes between the cloud and the ground. Positive charge builds up on the ground beneath the cloud. The ground's positive charge concentrates around anything that sticks up - trees, metal rooftops, even people. The positive charge from the ground connects with the negative charge from the clouds and a spark of lightning strikes. It contains so much energy that it can kill a person.

Lightning can strike anywhere. No-one can control where the lightning will strike. Houses with metal rooftops on top of a hill attract lightning. This explains why the house on the hill was struck by lightning and the two children died.

I learnt about this from studying static electricity in my science course. I can help people in my community understand things that happen in the natural environment.

Read the passage above and answer the questions that follow. The passage is a student's essay on what she learnt by studying a Natural Sciences course like this course.

a) What belief does the writer address in the essay?

b) What is the value of science to the writer? Answer in one or two sentences.

c) In what way does the writer show critical thinking? Answer in one or two sentences.

d) Does the writer's explanation for lightning fit into basic research, applied research or technology? Give a reason for your answer.

e) Put the following sentences into the correct order to describe how a thunderstorm develops and lightning strikes a building.

A building gathers positive charges.
Water vapour condenses into water droplets.
Lightning strikes a building when the negative charges in the cloud connect the positive charges on the building.
Warm air containing water vapour rises.
The ground beneath the cloud becomes positively charged.
Pieces of ice colliding with each other cause the particles to become charged.
Heavy, negatively-charged particles collect in the bottom of the cloud.
Water freezes at low temperatures.

Summary Assessment

1. Choose the correct answer for each question below.

1.1 Which statement defines a scientific theory?

A. An educated guess that explains a set of observations.

B. An overarching statement that describes how the natural world works.

C. A statement about the world that is supported by evidence from many different sources.

D. A guess about how a particular system will behave if a theory or hypothesis is correct.

1.2 Which statement defines a scientific Law?

A. An educated guess that explains a set of observations.

B. An overarching statement that describes how the natural world works.

C. A statement about the world that is supported by evidence from many different sources.

D. A guess about how a particular system will behave if a theory or hypothesis is correct.

1.3 Which statement defines a prediction?

A. An educated guess that explains a set of observations.

B. An overarching statement that describes how the natural world works.

C. A statement about the world that is supported by evidence from many different sources.

D. A guess about how a particular system will behave if a theory or hypothesis is correct.

1.4 The study of plants is an example of which scientific discipline?

A Chemistry.

B Biology.

C. Physics.

D. Environmental Science.

1.5 The study of the properties of matter is an example of which scientific discipline?

A. Chemistry

B Physics

C. Biology.

D Both A and B.

1.6 Which of the following cannot be investigated by science?

A. What morals should I apply in my life?

B. How do stars form?

C. What causes ocean waves?

D. Why does vinegar fizz when it is mixed with bicarb?

Subtopic 2: Scientific enquiry

Content:

Unit 1. The process of scientific enquiry.

Unit 2. Presenting scientific reports.

Unit 3. Scientific reasoning.

Unit 1: The process of scientific enquiry.

When you have completed this unit, you should be able to

- explain that scientific knowledge is based on systematically-collected (rigorous) evidence, with no fixed sequence of steps followed by every scientist;
- describe observation as the essence of science, specifically observation using the senses, instruments that enhance the senses (e.g. microscopes, telescopes), and instruments that detect stimuli that humans cannot detect (e.g., magnetic fields, electrical fields, electromagnetic waves);
- explain the importance of recording accurate data in the form of measurements, verbal descriptions, photographs or diagrams;
- explain how analysis of data enables inferences to be made;
- describe the use of controlled experiments as one way of collecting rigorous evidence in science, specifically experiment and control, dependent, independent and controlled variables, accurate data recording, replication of experiments;
- explain the importance of avoiding bias by striving for objectivity in collecting and interpreting data, for example, by having many different investigators or groups of investigators working on a problem;

1.1 Scientific enquiry

We have stated previously that science is based on observation and experimentation. Science and scientists use many different types of investigation and reasoning when they investigate the universe. There is no fixed series of steps that all scientists follow. There are only a few basic steps that can be called the **scientific method** of enquiry.

1.2 Observation

[Note to Sharon and Andre: I realise that most of the examples here are biological. Please add or replace from your discipline]

Observation is gathering information about nature as it exists. We talk about observing "with a scientific eye". It means noticing every detail, using all our senses, and using instruments that enhance our senses. For example,

- microscopes allow us to see objects that are too small for the eye to see.
- telescopes enable us to see objects that are very far away.
- very sensitive listening equipment allows us to hear sounds that we are too high for the human ear to hear, such as the squeaks of bats.

- Instruments can be used to detect odours of chemical substances.

Some details about nature come from sources that humans cannot detect. For example,

- we cannot detect magnetic fields, but birds use the Earth's magnetic field when they migrate. We use instruments to detect magnetic fields.

[New word: Magnetic field: A magnetic field is the force that a magnet emits].

- We do not have a sense that can detect electrical fields, but some fish use electrical fields to detect their prey. We use instruments to detect electrical fields.

[New word: Electrical field: An electric field describes the area near any electrically-charged object]

- We can detect certain electromagnetic waves as sound and visible light. We use instruments to detect other electromagnetic waves.

[New word: Electromagnetic wave is a form of radiant energy that reacts with matter by being transmitted, absorbed or scattered]

Commented [ERD1]: This doesn't really make sense. Sharon – can you re-phrase it?

Main idea: Observing natural events "with a scientific eye" is the essence of science.

1.3 Carrying out experiments

In an experiment, the scientist changes some aspect of the natural world and observes the effects of the change.

For example, a chemist might mix two substances, such as vinegar and bicarbonate of soda, and observe what happens.

Experiment and control

Experiments must be carefully designed so that the effect the scientist observes is the result of the change he has made and nothing else. Some experiments are designed around an experiment and a control.

- The experiment is set up to test the effect of the change he is making.
- The control is set up to make sure that only the change he has made causes the effect.

For example, a scientist wants to test whether bean seeds need light to germinate. [The next part of text could be replaced by diagrams illustrating the experiment and control]

He plants 10 bean seeds in one tray of soil, and 10 bean seeds in a second tray of soil. He waters each tray with exactly 100 ml of water every second day. He puts one tray inside a closed cardboard box. This is the **experiment**. The change he has made is to cut out light. He puts the second tray next to a window. This is the **control**. The control receives light.

By setting up an experiment and a control, the scientist can be sure that the results are due to the presence or absence of light, and not any other factor.

[New words: **Experiment**: the setup that tests the effect of a change in the environment.

Control: the setup that makes sure that the results are due only to the change in the environment**]**

Dependent, independent and controlled variables

Variables are factors that cause or influence the outcome of an experiment.

- The independent variable is the variable that the scientist controls. He decides the values of this variable.
- The dependent variable changes as a result of the scientist changing the independent variable. It is the effect of the independent variable on the event.
- Controlled variables are variables that could influence the outcome of an experiment. The scientist tries to make sure that these variables are kept under control. They must not affect his measurement of the effect of the independent variable on the dependent variable.

For example, bicarbonate of soda fizzes when you mix it with vinegar. You can try this at home. Put about quarter of a teaspoon of bicarb into a large measuring jug, and add 50 ml of vinegar. Measure how high the fizzy mixture rises in the measuring jug.

[This should be illustrated in a labelled diagram].

Wash and dry the measuring jug. Now test the effect of increasing the quantity of bicarb on the reaction. Try half a teaspoon, one teaspoon and two teaspoons. Always add 50 ml vinegar each time.

- The independent variable is the amount of bicarb you use.
- The dependent variable is how high the fizzy mixture rises.
- The controlled variables are the amount and type of vinegar you add, the type of container (glass, metal, or china), and the temperature at which you do the experiment.

[New words: Variable: factors that cause or influence the outcome of an experiment.

Independent variable: the variable that the scientist changes during the experiment.

Dependent variable: the variable that indicates the effect of changing the independent variable.

Controlled variables: Variables that must be kept constant in an experiment.]

Main idea: Experiments involve changing some aspect of a natural event and observing the effects of the change.

Activity 1.1: Have you understood your reading?

Match the correct definition with each term listed below.

Term	Definition
1. Dependent variable	A. A variable that must be kept exactly the same for the experimental setup and the control setup.
2. Experiment	B. The variable that the scientist controls.
3. Controlled variable	C. The variable that changes as a result of changes in the independent variable.
4. Control	D. The setup that tests the effect of the change a scientist is making.
5. Independent variable	E. A setup that ensures that only the change the scientist has made is responsible for the effect.

1.4 Recording data

Data means the observations and measurements a scientist makes. Data must be accurately recorded. "Accurately" means data must be exactly what the scientist observes. Here are some ways that scientists record data:

- Drawings or photographs.
- Measurements;
- Descriptions.

Here is an example of how data about an animal may be recorded:

Cheetah

[Insert drawing of a cheetah. Caption: An adult cheetah]

Measurements of a cheetah (average for 7 male and 7 female cheetah)		
Body part measured	**Males**	**Females**
Nose to tip of tail	2,06 m	1,9 m
Ear	75 mm	75 mm
Shoulder height	881 mm	847 mm
Mass	48,4 kg	35,8 kg

Form

Cheetahs are tall and slender, with long, thin legs. They have spotted coats. The background is slightly brownish, and is covered with many oval or round black spots. They have a black stripe from the corner of each eye to the corner of the mouth.

{New word: Data: the observations and measurements that a scientist records about a natural event.]

Replicability

Any observation or experiment must be able to be repeated by another scientist. This is called **replicability**. We say a scientist **replicates** another experiment.

[New word: replicability means that another scientist can repeat an experiment and get similar results]

For example, I tried the experiment with vinegar and bicarbonate of soda, and got the following results:

Volume of fizzing when different amounts of bicarb are mixed with 50 ml vinegar.				
Amount of bicarb	¼ teaspoon	½ teaspoon	1 teaspoon	2 teaspoons
Amount of fizzing	110 ml	120 ml	135 ml	135 ml

My friend repeated the experiment, and she got the following results:

Volume of fizzing when different amounts of bicarb are mixed with 50 ml vinegar.				
Amount of bicarb	¼ teaspoon	½ teaspoon	1 teaspoon	2 teaspoons
Amount of fizzing	100 ml	115 ml	130 ml	135 ml

Her measurements were not exactly the same as mine, but the same trend was visible: the more bicarb you mix with the vinegar, the more fizzing took place, up to about 1 teaspoon.

Main idea: Scientists must record data as accurately as possible. Observations and experiments must be replicable.

Activity 1.2: Have you understood your reading?

Read the description of the cheetah and answer the questions that follow:

a) Name the part of the data that shows measurements.

b) Name the part of the data that is a description.

c) What type of data is shown in the Figure?

d) The figures shown in the table are the averages for seven adult male and seven adult female cheetahs. What pattern can you see in the data?

e) I used a kitchen measuring jug to measure the fizzing of vinegar and bicarb. It has markings in 25 ml units. My friend and I estimated (guessed) the height of the fizzing if it was between the 25 ml markers. Write a sentence about the accuracy of data collection in this experiment.

1.5 Identifying patterns

When a scientist has collected similar data many times over, she may start to recognize a pattern. The patterns may begin to appear in tables and graphs. Then she can make a general statement about her observations. The general statement is called an **inference**.

[New word: Inference: a conclusion based on evidence and reasoning]

> After measuring 50 male and female cheetahs, researchers have found that, apart from the ear size, the average measurements for females are smaller than those of males. They can make an inference: Female cheetahs are smaller and lighter than males.

In Physics and Chemistry, an inference can be written in words or in the form of a mathematical equation.

> For example, a scientist drops a football from a tall building. He measures how far the ball has fallen after 1 second, 2 seconds, 3 seconds, 4 seconds and 5 seconds. He finds that the ball that falls for 2 seconds falls four times further than the ball that falls for 1 second. The ball that falls for 3 seconds falls nine times further than the ball that falls for 1 second. After many tests, the scientist makes a general inference, which can be stated in three different ways:

- **In words**: The distance travelled is proportional to the square of the time of travel;
- **In equation form**: Distance = constant x $(\text{time})^2$
- **In symbols**: $d = k \times t^2$

Main idea: If data collected from many experiments and observations agrees, a scientist can make a general statement called an inference.

1.6 Avoiding bias

Scientists' observations should not be influenced by what they expect to happen. Their interpretations of their results must also be impartial. We say their observations and interpretations must be **unbiased**.

If several researchers investigate an event, the chances of collecting unbiased data increase. The researchers may work separately or as a group. They must discuss their results and agree on the interpretation of results. Their conclusions are then unbiased.

[New word: Unbiased: impartial, not influenced by expectations]

Main idea: Scientists try to be as unbiased as possible in their investigations and interpretation of their findings.

Assessment 2: Scientific enquiry

1. Distinguish between the following sets of terms:

1.1 Experiment and control.

1.2 Independent variable, dependent variable and controlled variable.

1.3 Accuracy and replicability.

1.4 Observation and experimentation.

2. Have you noticed that as a ball rolls down a hill, it rolls faster and faster? The Italian physicist Galileo Galilei (1564-1642) carried out some experiments to investigate the relationship between time and distance an object falls. Galileo made a board out of brass and hard wood. He fixed the board to a base so that it sloped downwards. He rolled a large ball from the top of the slope. He stopped the ball after it had rolled for 1 sec, and measured the distance it had moved. Then he replaced the ball at the top of the slope and allowed it to roll for 2 seconds. He measured the distance it moved. He repeated the measurements for 3, 4, 5 and 6 seconds.

[Insert diagram as in Trefil & Hazen, p. 36]

Distance a ball has rolled after each successive second.							
Time elapsed (s)	0	1	2	3	4	5	6
Distance moved (cm)	0	1	4	9	16	25	36

2.1 What problem was Galileo investigating?

2.2 What was the independent variable in his investigation?

2.3 What was the dependent variable in his investigation?

2.4 What should Galileo do to improve his investigation?

2.5 What conclusion can Galileo draw from his investigation?

Unit 2: Presenting scientific reports

When you have completed this unit, you should be able to

- identify the structure and style of a scientific report.

2.1 Scientific reports

A scientific report is the way a scientist reports her investigation and findings.

A scientific report describes exactly why an investigation was done, how it was done, and what the findings were. The report must enable other scientists to repeat the study to test whether their findings agree with the first investigation. Eventually, if enough scientists achieve similar findings, a general principle can be stated.

There are many different types of scientific reports. One that is commonly used reports on an investigation. It has four main sections:

Introduction: Here the author states what problem was investigated, and what other scientists have found out about similar problems. The author states why it was important to investigate the problem.

Methods: The author describes the methods in detail. This is important for other scientists to replicate the investigation.

Results: The author presents the results in the form of measurements, descriptions, diagrams and/or photographs. Measurements are often presented in the form of tables and graphs.

Discussion: The author interprets the results. She shows how the results answer the problem she stated in the introduction. She also shows how her findings relate to the findings of other scientists.

Main idea: A scientific report makes a scientists' investigations available to the scientific community. It enables other scientists to replicate the study.

Activity 2.1: Writing a scientific report

Here is a scientific report on a student's replication of Galileo's experiment with rolling balls.

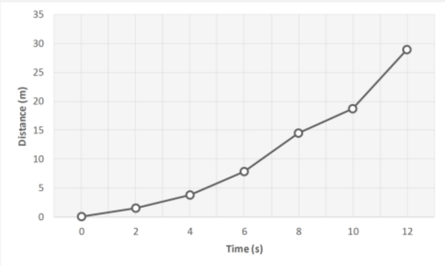
Investigation into the relationship between distance travelled and time as a ball rolls down a slope.

Introduction: As an object falls from a height to the earth, its speed seems to increase. This investigation tried to find out whether there is a relationship between time and distance covered as an object falls. We predict that distance covered increases with the time over which an object falls.

Method: A straight, steep section of road, a football, a tape measure and a stopwatch were used for the experiment. The researcher released the football at the top of the slope. After two seconds, a helper stopped the ball. The researcher measured the distance the ball had rolled. He started the ball at the top of the slope again, and let it roll for four seconds. The helper stopped the ball, and the researcher measured the distance the ball had travelled. The researcher repeated this method for 6, 8, 10 and 12 seconds.

The researcher repeated the whole experiment 10 times, and calculated the average distance that the ball travelled in each 2-second interval that it rolled.

Results: Table 1 shows the average distance travelled by the ball after it was released. Figure 1 shows the same information in the form of a graph. It is clear that as time increases, the ball travels greater distances.



ll	
10	**12**
18.8	**29**

Figure 1: Average distance versus time of a falling ball

Discussion: If speed = distance ÷ time, this investigation shows that speed increases from 0,8 m/s in the first two seconds to 2,4 m/s between the 10th and 12th seconds. The prediction is correct. A ball travels a greater distance the longer the time that it falls.

Answer the questions that follow.

1. What is the title of the scientific report?

2. Which section of the report:

a) Presents the findings of the study.

b) Describes how the investigation was conducted.

c) Draws a conclusion based on the evidence.

d) Describes why the investigation was carried out.

3. How did the researcher make sure the data were accurate?

Unit 3: Scientific reasoning

When you have finished this unit, you should be able to

- explain how science uses logical reasoning, specifically inductive and deductive reasoning, in advancing our understanding of the natural world;
- distinguish between science and pseudoscience, applying the reasoning and methods of scientific inquiry to detect pseudoscience.

3.1 Inductive and deductive reasoning

Reasoning is the process of connecting evidence with conclusions. Reasoning plays an important role in science. Two types of reasoning are commonly used in science. They are inductive and deductive reasoning.

[New word: Reasoning: the process of connecting evidence with conclusions]

- Inductive reasoning is used to make a general statement when a number of observations agree.

  For example, Robert Hooke discovered in 1663 that cork consisted of cells. Over the next two hundred years, many scientists discovered that hundreds of different organisms consisted of cells. In 1839, a general statement, called the Cell Theory, was stated. It says that <u>all living things consist of cells</u>.

  Inductive reasoning goes from specific observations to a general statement. If a pattern emerges from many separate observations, scientists can make a general statement. The general statement is often called a theory. The theory must be testable to qualify as science.

[New word: Inductive reasoning: making a general statement that describes a number of specific observations]

- Deductive reasoning starts with a general statement or theory and predicts what should happen if the theory is correct. It goes from the general (the theory) to the specific (the tests).

  For example, suppose a scientist discovers a new type of mould that has not been studied before. She is not sure whether it is a living organism or not. According to the cell theory, if it is living, it must consist of cells. She must study the mould using a microscope to see whether it consists of cells. The cell theory (the general) allows her to test a specific observation (the mould).

[New word: Deductive reasoning: predicting what observations will result if a theory is correct]

Main idea: Scientists use different forms of reasoning to build knowledge. Inductive reasoning moves from specific observations to a general theory. Deductive reasoning tests the general theory by making specific observations.

Activity 3.1: Have you understood your reading?

Read each statement below, and state whether it describes reasoning (R), inductive reasoning (IR) or deductive reasoning (DR)

Statement	
A general statement or theory that describes a pattern found in a number of specific observations.	
A prediction about what will happen in a specific instance if a theory is true.	
The process of connecting evidence with conclusions.	
A process that moves from a general statement to a specific observation.	

3.2 Pseudoscience

Some "disciplines" call themselves science, but they are not. They fail the tests of science, and fall under "belief", which is outside the boundary of science. Four tests separate science from belief:

1. Are the "facts" true as stated?

Scientific facts are supported by evidence. They are true in every context in which they have been tested.

If the "facts" are not supported by evidence, they do not belong in science.

> For example, astrology (your stars foretell, or your horoscope) claims that each of us has a birth-sign, depending on the position of the Sun, moon and a cluster of stars on the date of your birth. The birth-sign determines what kind of personality you have and what the future holds for you.
>
> There is no evidence that the position of the Sun, moon and stars at the time of your birth do influence your life. Astrology falls outside the boundaries of science.

2. Is there an alternative explanation?

Although scientific knowledge does not claim to always be true, it is based on tested hypotheses. It considers all alternative explanations, and accepts the explanation that fits the evidence best.

> Many people around the world claim to see objects in the sky that have come from outer space. Such sightings are called "unidentified flying objects", or UFOs. In almost all cases, it is a satellite, or an aeroplane, or the planet Venus.

Science requires that anyone making a claim that does not fit with accepted science must prove their claim.

3. Can the claim be tested?

In order to qualify as science, a claim must be testable by experiments or observations. If you cannot test the claim by experiments or observations, it does not belong in science.

> For example, traditional medicine cannot be tested scientifically, because treatment varies depending on the patient. A scientist can identify the chemicals present in traditional herbs, but the effect of traditional herbs on a patient cannot be tested.

Only knowledge statements that can be tested fall within the boundaries of science.

4. Do the claims contradict accepted knowledge?

Although scientific knowledge changes as new discoveries are made, there is a large body of knowledge that has been tested and accepted as true. Claims that contradict accepted knowledge must be rigorously tested before they are accepted as scientific knowledge.

> Many people believe that albino people do not die, they disappear. Thinking that albino people just disappear is an example of a belief that contradicts accepted knowledge. It falls outside the boundaries of science.

Sometimes, non-science claims seem to explain a small set of observations, but ignore a large number of related observations.

> For example, people called "dowsers" look for underground water by using a forked stick. They say the forked stick pulls downwards where there is underground water. If you drill a borehole at the spot where the stick pulls down, you may find water, but sometimes you don't.
>
> Accepted knowledge is that underground water does not exert a force that pulls a forked stick towards it. In fact, about 90% of the earth's surface has underground water. If you drill a borehole anywhere on land, the chances of finding water are quite high. Dowsing is pseudoscience.

Main idea: Some kinds of "knowledge" claim to be scientific but they do not meet the requirements of science. They are pseudoscience.

Activity 3.2: Have you understood your reading?

Someone handed you a flyer that says:

"Dr XXXX can help you solve these problems:

- Bring back lost lover
- Get a good job
- Help you win at gambling"

How would you test whether these claims are science or pseudoscience?

Summary of key learning:

- Observing natural events "with a scientific eye" is the essence of science.
- Experiments involve changing some aspect of a natural event and observing the effects of the change.
- Scientists must record data as accurately as possible. Observations and experiments must be replicable.
- If data collected from many experiments and observations agrees, a scientist can make a general statement called an <u>inference</u>.
- Scientists try to be as unbiased as possible in their investigations and interpretation of their findings.
- A scientific report makes a scientists' investigations available to the scientific community. It enables other scientists to replicate the study.
- Scientists use different forms of reasoning to build knowledge. Inductive reasoning moves from specific observations to a general theory. Deductive reasoning tests the general theory by making specific observations.
- Some kinds of "knowledge" claim to be scientific but they do not meet the requirements of science. They are "pseudoscience".

Summary Assessment

1. A student carried out an experiment to investigate the effect of exercise on pulse rate. He measured his pulse rate by counting the number of beats per minute at his wrist.

1.1 Write a hypothesis for the experiment.

1.2 What would you predict if the hypothesis is true?

He wrote up the experiment like this:

"*I stood still and took my pulse. It was 76. I skipped for three minutes and took my pulse again. It was 120. After one minute, it was 96; after two minutes it was 84; after three minutes it was 80, and after four minutes it was 76. Exercise makes your heart rate go up."*

1.3 Write an introduction for the experiment.

1.4 Write the method the student followed.

1.5 Present the results in the form of a Table.

1.6 Write a brief discussion of the results.

2. Use the following terms to complete the sentences that follow.

Observation; experiment; inference; accuracy; bias; replicable; inductive reasoning; deductive reasoning; pseudoscience.

2.1 Drawing out a general theory from a number of specific observations is an example of ……………..

2.2 Astrology is an example of …………..

2.3 A scientist who changes her results to suit her hypothesis is guilty of ………

2.4 Scientific knowledge is based on ………….. and ……………..

2.5 A scientist's observations must be ……………… by other scientists.

2.6 Testing a general theory with specific experiments or observations is using …………

2.7 An …………….. is a general statement that scientists make if data from many observations and experiments agree.

2.8 A scientist must ensure ……………….. when he collects data.

Subtopic 3: Science in society

Content:

Unit 1. The ethics of science.

Unit 2: Social responsibilities of scientists.

Unit 3: The benefits and disadvantages of scientific discoveries.

Unit 1: The ethics of science

When you have finished this unit, you should be able to

- identify the ethical norms of science, such as accurate recordkeeping, openness, replication, critical review of each other's work, honesty in reporting results;
- describe the importance of ethics in research, such as avoiding unnecessary pain and suffering, taking care of animals in captivity, and obtaining informed consent from human participants in research;
- explain how research should be evaluated in terms of possible harmful effects of applying the results of the research.

1.1 Honesty in science

Growth of scientific knowledge depends on honesty in the scientific profession. Scientists are expected to keep accurate records. Anyone can check the records. Another scientist should be able to replicate the experiment and get similar results. Before a scientific paper is published, it is reviewed by other scientists.

These are all safeguards that make sure scientists are honest in their claims. Occasionally, a scientist is caught out for making up data, or holding back information. A dishonest scientist can lose their job, and lose the funding for their research. They may be barred from the scientific profession.

Main idea: Honesty is very important in the growth of scientific knowledge.

1.2 Ethics in research

Ethics are moral principles that govern a person's behaviour or the way we conduct an activity. Scientists have moral principles. They make sure that experiments do not harm the environment, including all living organisms and humans. Living organisms that are used in experiments are properly cared for. If research involves humans, they must be fully informed about the purpose of the research. They must agree to participate, and allowed to withdraw if they wish to.

[New word: Ethics are moral principles that govern a person's behaviour.]

Scientists should not conduct research that could endanger the lives of others or the environment without their consent. This kind of research is not ethical.

Main idea: Scientists must ensure that their research does not harm other humans, living organisms or the environment.

1.3 Evaluating harm that may come from applying the results of research.

Scientists working in certain fields may not know what harm their research may cause in the future. Medical research, for example, may harm people or society in the future. Some types of research may lead to weapons used in war.

Sometimes scientists work on a particular problem without knowing that their findings may have harmful effects. If the funder asks the scientist to sign a confidentiality agreement, it may mean that the research could have harmful effects. The scientist can then apply her own moral principles to decide whether to take part in the research.

Main idea: Scientists should be aware of what harm could come from applying the results of their research. They use their own moral principles to decide whether to conduct the research.

Unit 2: Social responsibilities of scientists

When you have finished this unit, you should be able to

- discuss the social responsibilities of scientists in how their findings are applied in society, as well as advising government and the general public about the benefits and risks of applying scientific discoveries, for example, genetically modified food, or the risk of climate change.

2.1 Scientists are specialists and citizens

Scientists can provide specialist advice to the general public when they have to make important decisions. Some issues that scientists can address are:

- Should all schoolgirls be given pills that protect them from getting HIV? The treatment is called Pre-Exposure Prophylaxis (PrEP).
- Are genetically modified organisms (GMOs) dangerous to humans and the environment?
- Is climate change really happening?
- Should South Africa build nuclear power plants, or invest more money in solar and wind power generation?
- Is conservation more important than farming?

Scientists can advise government on these issues. However, they must base their advice on evidence, not opinions. They must be expert in the issue being investigated.

Main idea: Scientists have a social responsibility to advise government and the public about issues within their area of expertise.

Unit 3: The benefits and disadvantages of scientific discoveries

When you have finished this unit, you should be able to

- evaluate the benefits of applying scientific discoveries for humans, and the risks of their application to the natural environment, for example, the benefits and disadvantages of the Green Revolution.

3.1 Benefits and disadvantages of scientific discoveries

Humans have benefitted in many ways from scientific discoveries. We live longer, healthier lives. The number of babies surviving beyond five years has increased. We can produce enough food for the 8 billion people living on Earth. Our lives have improved because of mobile phones, motor cars, radio, clothing, and sanitation.

Although humans have benefitted from science, the natural environment suffers because of the growing human population. Thus scientific discoveries that enable more people to live on Earth now threaten the survival of nature. Wars break out, and terrible weapons of mass destruction kill thousands of people. Science brings benefits and disadvantages to the Earth.

Main idea: Scientific discoveries benefit humans, but they can bring disadvantages to humans and the environment.

Case study: The Green Revolution

An example of a scientific discovery that brings benefits to humanity but disadvantages to the natural environment is the Green Revolution. It started in 1961, when India had too little food for its growing population. New varieties of rice were grown. One was a dwarf rice, that produced more grains of rice per plant. It had shorter stalks, which we cannot eat, than the old varieties. Under the best conditions (for example, using fertiliser and pesticides), the new rice could produce 10 tons per hectare, compared with 2 tons per hectare before the Green Revolution. Soon, India was able to feed its own people and export its excess.

The Green Revolution spread to other countries and other crops. Fertilisers, weed killers and insect poison have also helped to increase agricultural production around the world. The average person in the developing world now eats 25% more food per day than before the Green Revolution.

The Green Revolution has had negative effects on the natural environment.

- It allowed crops to grow in places that were unsuitable for farming, such as tropical rain forests. Farmers clear tropical rain forests in order to grow crops.
- The Green Revolution relies on fossil fuels such as oil. The oil is used to provide diesel for the farm machinery, and to manufacture the fertilisers and pesticides. If fossil fuels run out, agricultural production will collapse.
- Excess fertilisers are washed out of the soil and enter rivers and lakes. They cause the water to turn green with the growth of microscopic water plants. Decaying plants use up the oxygen in the water, causing animals in the water to die.

Without the Green Revolution, millions of people would have died of starvation. The Green Revolution allowed the world's population to continue increasing to its present level.

Assessment 3: Science and society

1. Read the Case study about the Green Revolution and answer the questions that follow.

1.1 What are the benefits of the Green Revolution?

1.2 What are the disadvantages of the Green Revolution?

1.3 What is a pesticide?

2. What is your opinion about whether schoolgirls should be given PrEP? Support your opinion with evidence.

3. What ethical principles do you have to observe if you do research on humans?

4. A researcher wanted to "prove" a particular hypothesis. Her observations and measurements did not support the hypothesis. She changed the figures so that they did support her hypothesis. What was ethically wrong with her actions?

Summary of key learning:

- Honesty is very important in the growth of scientific knowledge.
- Scientists must ensure that their research does not harm other humans, living organisms or the environment.
- Scientists should be aware of what harm could come from applying the results of their research. They use their own moral principles to decide whether to conduct the research.
- Scientists have a social responsibility to advise government and the public about issues within their area of expertise.
- Scientific discoveries benefit humans, but they can bring disadvantages to humans and the environment.

Summary Assessment

1. Read the text below and answer the questions that follow.

In 2016, a 16-year-old South African girl, Kiara Nirghin, won the Grand Prize at the Google Science Fair in California, USA. Her project was inspired by the serious drought and its effect on food production in South Africa in 2016. She investigated the problem of how to make soil hold more water. You can add water-holding materials to the soil, and it will stay damp for longer than normal soil.

Commercially available water-holding materials are synthetic. They are not biodegradable and they cost too much for local farmers. Kiara's project turned orange and avocado peels into a material that holds water in the soil. It worked better than commercial products. Kiara's water-holding material uses waste products (orange and avocado peels) and is biodegradable. It is cheap to produce. It could help farmers produce food in drought conditions.

1.1 What agricultural problem was Kiara investigating?

1.2 How can you make soil hold water for a longer time than normal?

1.3 What happens to crop plants if the soil dries out?

1.4 List the benefits of Kiara's discovery.

1.5 List the disadvantages of using synthetic water-holding materials.

1.6 What is the effect of a serious drought on food production in South Africa?

Suggested sources of additional information

1. Search the Internet for more information about Science in society. *https://www.youtube.com/watch?v=Lg9-HTtgFOk* is about the founder of the Green Revolution, Norman Borlaug.

Use Search terms such as "Green Revolution" and "Green Revolution in Africa".

2. Search the Internet for "The Nature of Science" videos. *https://www.youtube.com/watch?v=TkvjDZseD4k* is very good, but quite long.

https://www.youtube.com/watch?v=fpeLuU6hxkA is intended for children, but it is a very concise description of the nature of science.

https://www.youtube.com/watch?v=77TFiYWPxoQ is another good description of the nature of science.

My Notes

Use this space to write your own questions, comments or key points.

SOLUTIONS

Subtopic 1 What is Natural Science?

Unit 1: The nature of science and scientific knowledge

Activity 1.1

Experiment; facts; laboratory; apparatus; evidence; observation; theory; reasoning; mathematics; reliable.

Activity 1.2

1. False. Scientific knowledge began thousands of years ago and has changed significantly over time.

2. True.

3. False. Scientific knowledge changes as new evidence is discovered.

4. True.

5. False. Science can only investigate questions that are testable.

Activity 1.3

1. Law	C. An overarching statement that describes how the universe works.
2. Prediction	E. A guess about how a particular system will behave if a theory or hypothesis is correct
3. Hypothesis	A. An educated guess that explains a set of observations
4. Theory	D. A statement about the world that is supported by evidence from many different sources
	B. Careful observations of a natural process.

Assessment 1

1.

Scientific statements	1.1; 1.3; 1.5; 1.7
Non-scientific statements	1.2; 1.4; 1.6

2.

2.1 False. Scientific laws can be abandoned or changed if new evidence shows that they are wrong.

2.2 True.

2.3 True.

2.4 False. Science is a way of understanding the natural world.

2.5 True.

Unit 2: The purpose of science.

Activity 2.1

a. B

b. A

c. A

d. B

e. B

Unit 3: The value of science

Activity 3.1

1. Select any five from the following:

Science gives us a powerful way of understanding things that happen in the natural world.

Science enables us to predict future events such as floods, flu epidemics and eclipses of the sun.

People who master scientific ways of thinking can solve problems and think critically.

Science enables us to cure diseases.

Science enables us to develop new materials and technologies that make our lives easier.

Science provides opportunities for employment.

Science provides evidence that helps us make decisions at a personal, community and national level.

Science enables us to marvel at the order in the natural world.

Unit 4: Scientific disciplines

Activity 4.1

a. B

b. C

c. P

d. B

e. G

f. C

g. B

h. E

Unit 5: The boundaries of science

Assessment 2

a) The belief that a traditional healer can cause lightning to strike a particular house.

b) Science enables the writer to explain natural events scientifically to his or her own community.

c) The writer thinks critically about a traditional belief. He considers the scientific explanation for lightning. He uses his knowledge to challenge an incorrect belief.

d) Basic research. It is about explaining a natural phenomenon, not using it to make lives easier.

e) Warm air containing water vapour rises. Water vapour condenses into water droplets. Water freezes at low temperatures. Pieces of ice colliding with each other cause the particles to become charged. Heavy, negatively-charged particles collect in the bottom of the cloud. The ground beneath the cloud becomes positively charged. A building gathers positive charges. Lightning strikes a building when the negative charges in the cloud connect the positive charges on the building.

Summary assessment

1.1 C

1.2 B

1.3 D

1.4 B

1.5 D

1.6 A

Subtopic 2: Scientific enquiry

Unit 1: The process of scientific enquiry

Activity 1.1

Term	**Definition**
1. Dependent variable	C. The variable that changes as a result of changes in the independent variable.
2. Experiment	D. The setup that tests the effect of the change a scientist is making.
3. Controlled variable	A. A variable that must be kept exactly the same for the experimental setup and the control setup.
4. Control	E. A setup that ensures that only the change the scientist has made is responsible for the effect.
5. Independent variable	B. The variable that the scientist controls.

Activity 1.2

a) The table titled “Measurements of a cheetah” shows meaurements.

b) The part with the heading “Form” is a description.

c) The figure records data visually by means of a drawing.

d) The ear size is the same in males and females. In all other measurements, males are larger than females.

e) The data is not very accurate, because the measuring instrument (a kitchen measuring jug) did not have enough markings. The researchers had to estimate measurements.

Assessment 2: Scientific enquiry

1.1 The experiment is the setup that tests the effect of the change a scientist is making. The control is the setup that only the change the scientist has made is responsible for the effect.

1.2 The independent variable is varied by the researcher. The dependent variable changes as a result of changes in the independent variable. The controlled variables are kept exactly the same in the experimental and control setups.

1.3 Accuracy refers to how carefully you collect data by measurements, recording descriptions, and diagrams. Replicability refers to whether the investigation can be carried out by other scientists and produce similar results.

1.4 Observation refers to using all our senses to study something. Sometimes we use instruments to enhance our senses. In experimentation, the scientist changes some aspect of the natural world and observes the effects of the change.

2.1 Galileo as investigating whether an object really moves further the longer the time that it falls.

2.2 Time (seconds).

2.3 Distance moved (cm)

2.4 He should repeat the measurements many times and calculate an average distance moved after each second.

2.5 Galileo can conclude that the distance moved does increase with each successive second that the ball rolls.

Unit 2: Presenting scientific reports

Activity 2.1: Writing a scientific report

1. Investigation into the relationship between distance travelled and time as a ball rolls down a slope.

2. a) Results.
   b) Methods.
   c) Discussion.
   d) Introduction

3. The researcher repeated the investigation 10 times and calculated averages.

Unit 3: Scientific reasoning

Activity 3.1

Statement	

A general statement or theory that describes a pattern found in a number of specific observations.	IR
A prediction about what will happen in a specific instance if a theory is true.	DR
The process of connecting evidence with conclusions.	R
A process that moves from a general statement to a specific observation.	DR

Activity 3.2

Are the "facts" true as stated? What evidence can the doctor give to support his claims?

Is there an alternative explanation? Could there be another reason for the doctor's "success stories".

Can the claims be tested? If not, the claims are pseudoscience.

Do the claims contradict accepted knowledge? If they do, they are pseudoscience.

Summary assessment

1.1 Exercise increases the pulse rate.

1.2 If a person exercises, their pulse rate should increase. When the person stops exercising, their pulse rate should return to normal.

1.3 When we exercise, our muscles need more oxygen. The heart pumps faster to increase the blood circulating through the muscles and back through the lungs. This experiment investigates how quickly the pulse rate increases during exercise, and how long it takes to return to normal.

1.4 The student measured his pulse rate while he was standing still. He then skipped for three minutes, and immediately measured his pulse rate again. He then measured his pulse rate each minute for the next four minutes.

1.5

Effect of exercise on pulse rate							
Time (min)	0	Skipping	3	4	5	6	7
Pulse rate (beats per min)	76		120	96	84	80	76

1.6 After 3 minutes of skipping, the student's pulse rate had increased from 76 to 120. Over the next four minutes, the pulse rate decreased steadily until it was back to normal. Exercise does increase the pulse rate. The pulse rate returns to normal a few minutes after exercise stops.

2.1 inductive reasoning

2.2 pseudoscience

2.3 bias

2.4 observation; experiment

2.5 replicable

2.6 deductive reasoning

2.7 inference

2.8 accuracy.

Subtopic 3: Science in society

Unit 1: The ethics of science

Unit 2: Social responsibilities of scientists

Assessment 3

1.1 The Green Revolution saved millions of people from starving. People eat 25% more food after the Green Revolution than before the Green Revolution.

1.2 The Green Revolution allows crops to grow in areas that are unsuitable for farming. Tropical rain forests are being cleared to make space for growing crops. The Green Revolution relies on fossil fuels for diesel and to make fertilisers. If fossil fuels run out, agriculture will collapse. The Green Revolution uses fertilisers and pesticides that upset the balance of nature.

1.3 A pesticide is any substance that kills insects or other organisms that eat crop plants or infect farm animals.

2. This is an open-ended question. You must choose your position (either for or against the proposal) and write an argument that shows why you have chosen that position. You must give evidence to support your opinion.

For example, if you decide that you are in favour of PrEP for schoolgirls, you could quote the figures for the number of schoolgirls who become HIV-positive because of having unprotected sex.

If you decide that you are against PrEP for schoolgirls, you could quote figures showing increased sexual activity among schoolgirls who are not using contraception. Your argument might be based on moral grounds.

3. Humans must be informed about what the research is about and what risks may be attached to participating in the research. They must give signed consent to participate in the research. They must be allowed to withdraw from the research if they wish to.

4. She was dishonest about her data.

Summary assessment

1.1 Kiara was investigating how to make soil hold water for longer so that crops can grow during a drought.

1.2 Add water-holding materials to the soil.

1.3 The plants will die from lack of water.

1.4 Benefits:

- Kiara made water-holding materials from waste products (orange and avocado peels).
- Kiara's water-holding materials are natural products, not synthetic products.
- Her water-holding materials worked better than commercial water-holding materials.
- Kiara's water-holding materials are biodegradable.

- Her water-holding materials could help farmers during periods of drought.

1.5 Disadvantages of synthetic water-holding materials

- They are not biodegradable.
- They cost too much for local farmers.
- They do not hold as much water as Kiara's natural water-holding materials.

1.6 A serious drought means that farmers produce much less food than in normal years. Cows have less grass to eat, so they produce less milk. Animal feed becomes more expensive. Crop plants do not grow and produce crops as well as normal years.

GLOSSARY OF TERMS

Law: An overarching statement that describes how the universe works

Basic research: Research that investigates an aspect of the natural world because it is interesting

Applied research: Research that uses science to create machines or processes for commercial gain or to benefit humans

Technology: the application of scientific research for commercial or industrial goals]

Magnetic field: A magnetic field is the force that a magnet emits

Electrical field: An electric field describes the area near any electrically-charged object

Electromagnetic wave: a form of radiant energy that reacts with matter by being transmitted, absorbed or scattered

Experiment: the setup that tests the effect of a change in the environment.

Control: the setup that makes sure that the results are due only to the change in the environment

Variable: factors that cause or influence the outcome of an experiment.

Independent variable: the variable that the scientist changes during the experiment.

Dependent variable: the variable that indicates the effect of changing the independent variable.

Controlled variables: Variables that must be kept constant in an experiment

Data: the observations and measurements that a scientist records about a natural event

Replicability: another scientist can repeat an experiment and get similar results

Inference: a conclusion based on evidence and reasoning

Unbiased: impartial, not influenced by expectations

Reasoning: the process of connecting evidence with conclusions

Inductive reasoning: making a general statement that describes a number of specific observations

Deductive reasoning: predicting what observations will result if a theory is correct

Ethics: moral principles that govern a person's behaviour.