
NANYANG
GIRLS' HIGH

The Scientific Method


Scientific
Method
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hypotheses
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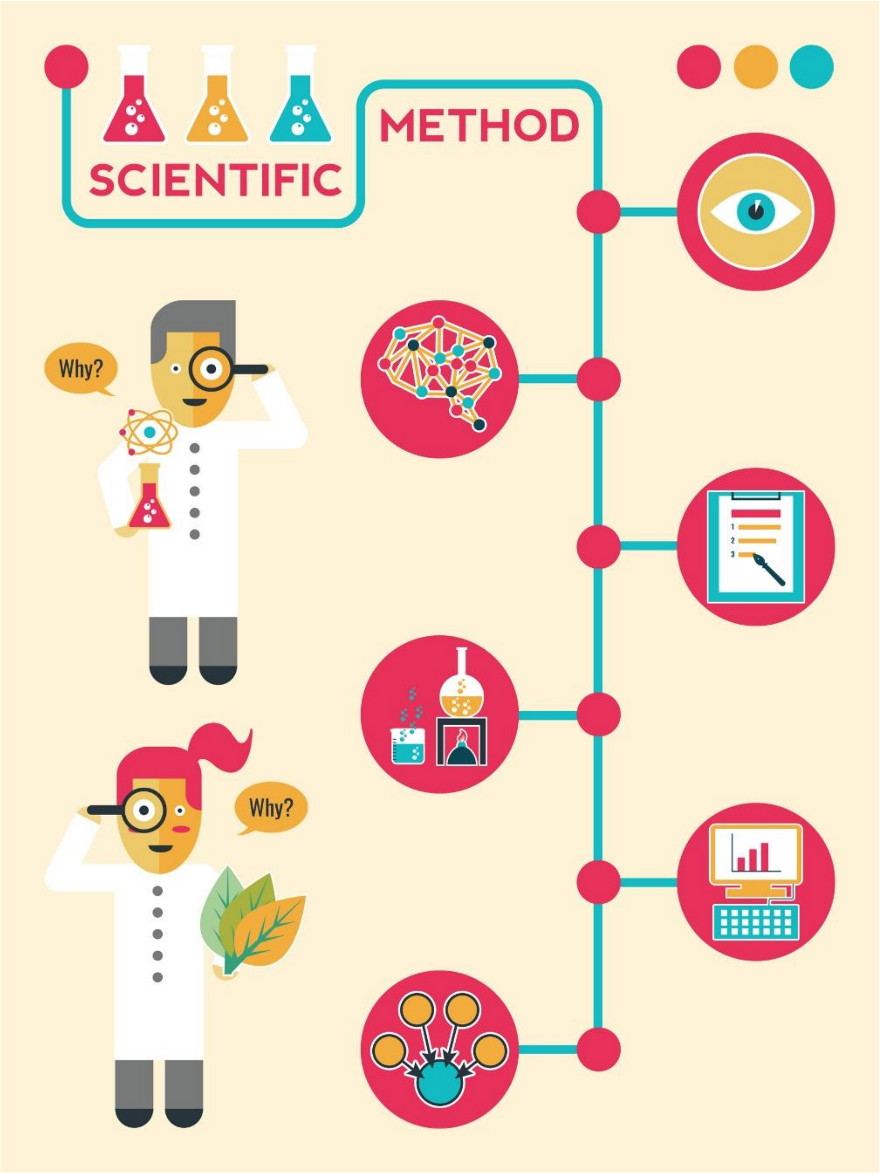
The Scientific Method



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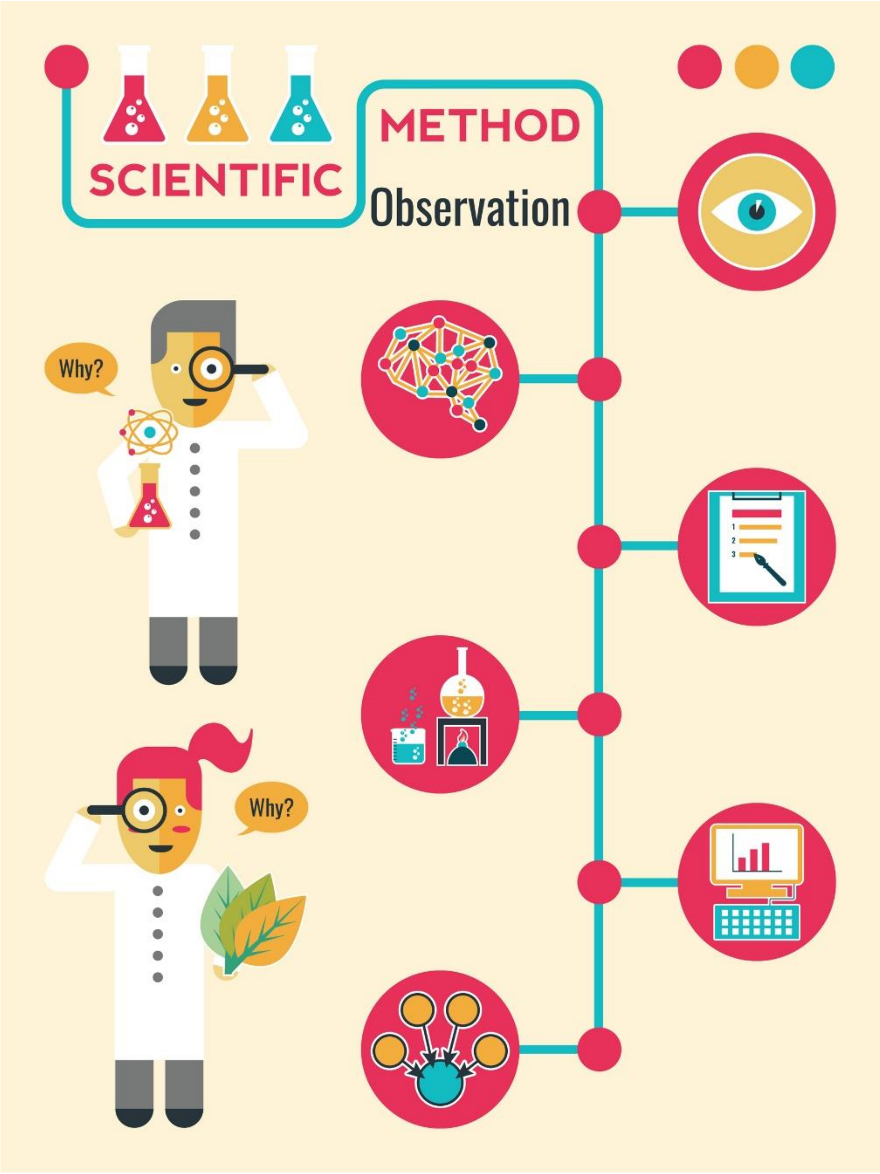

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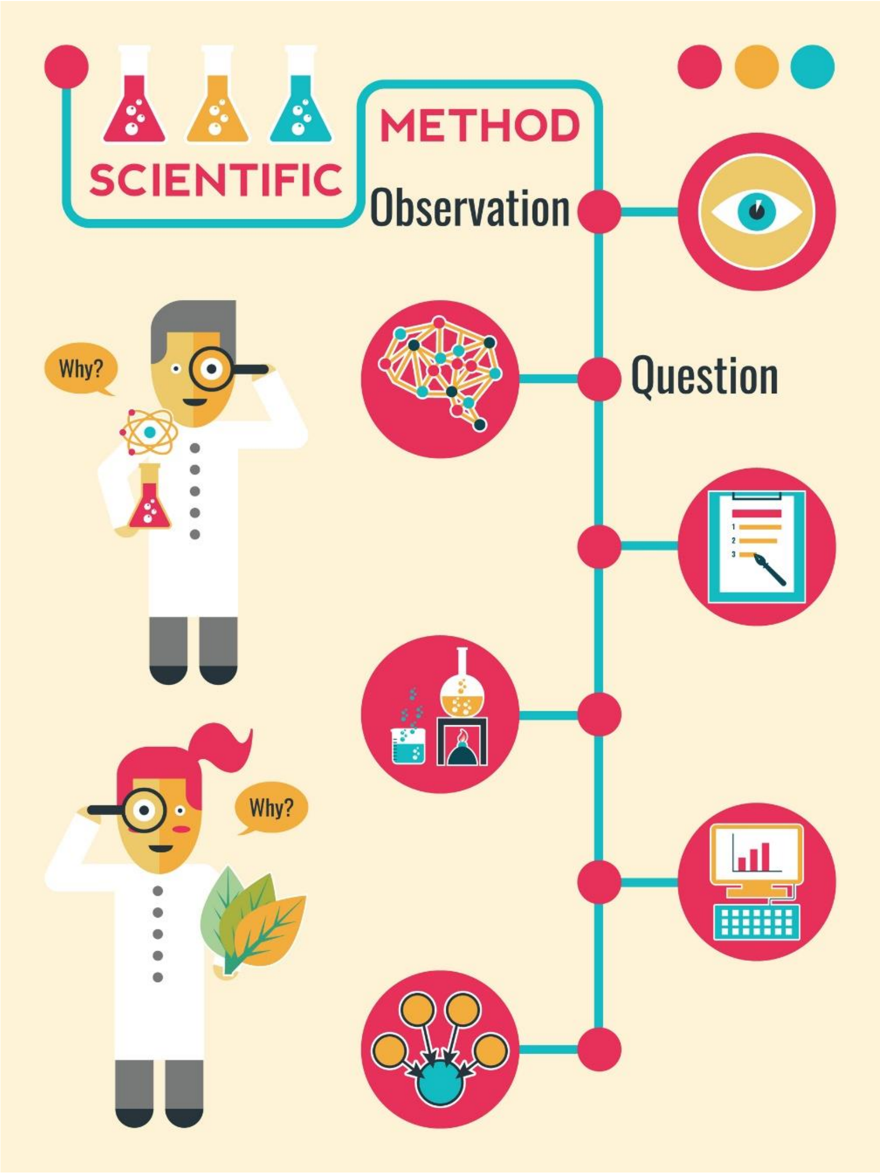

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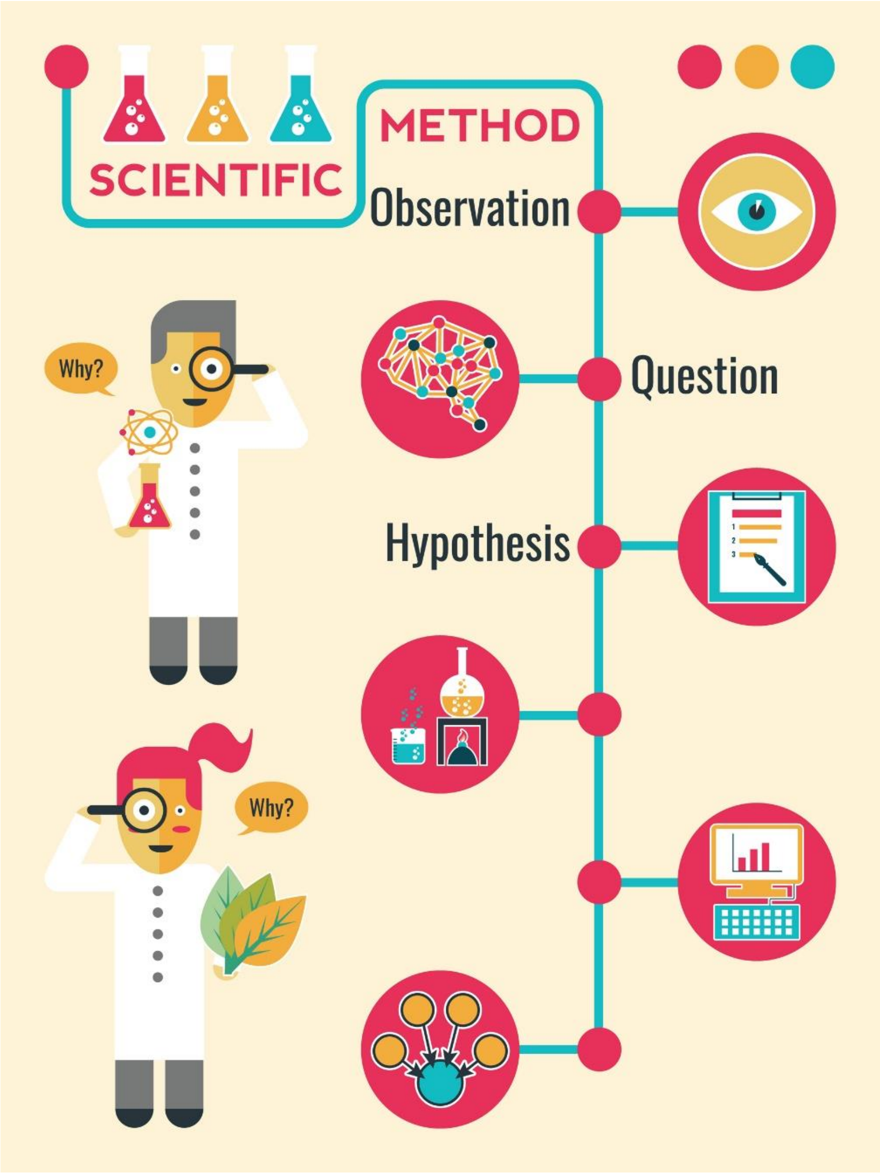

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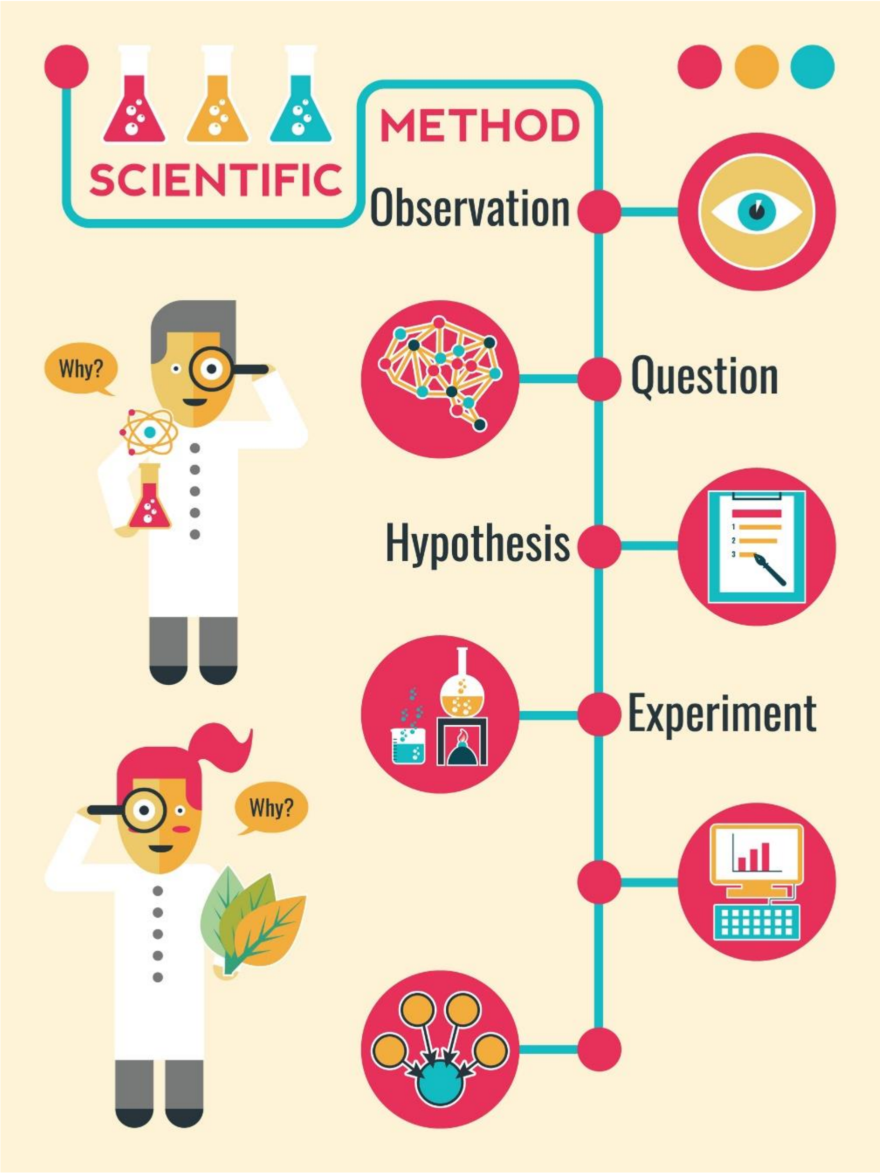

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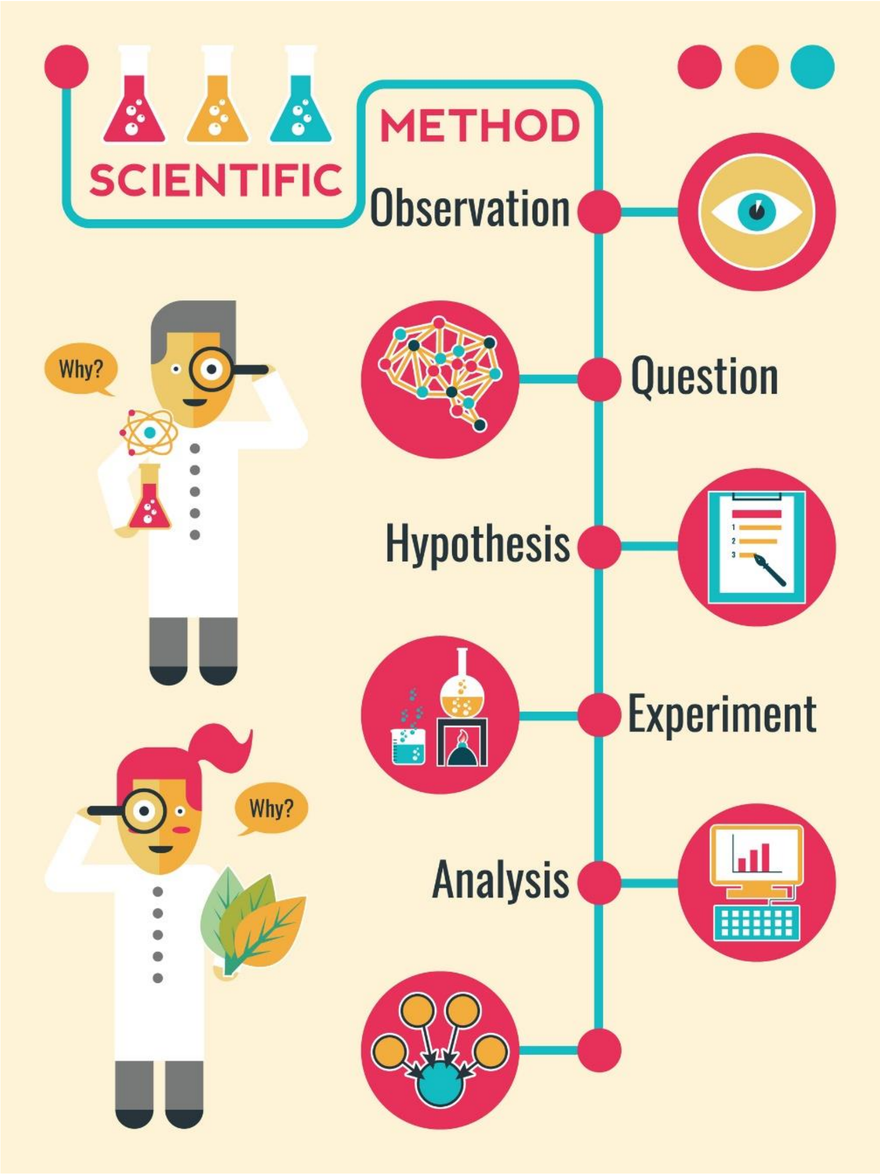

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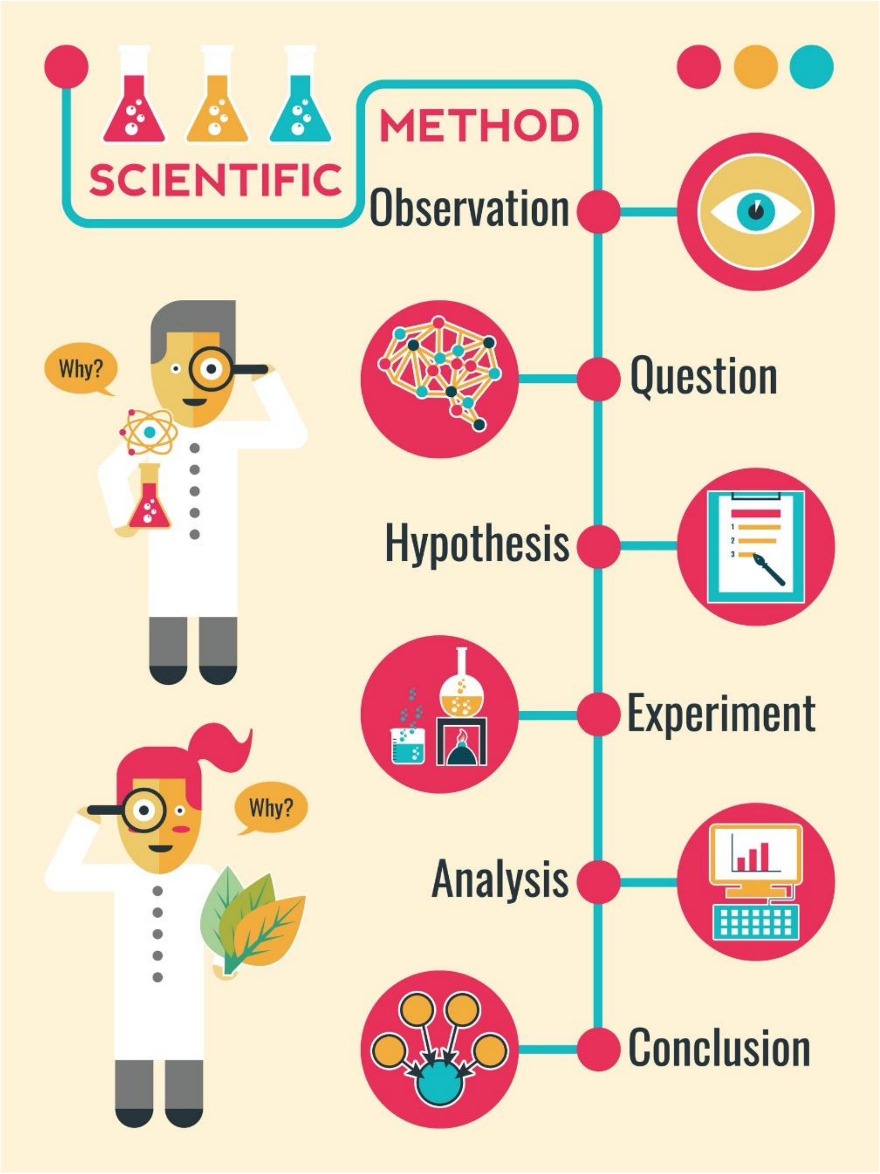


The Scientific Method

- The word *science* is derived from the Latin word *scire* which means *knowledge*.
- Today science is defined as a way of gathering and organising information (knowledge) about nature.
- There are many branches of science. *Can you name some of them*?
- The one common element among all sciences is the use of the *scientific method*.

The Scientific Method

- We will study the scientific method in detail, and examine some of the tools that are required:

→ Measurement.

→ Table and graph.

→ Model.

The Scientific Method

- What can you *observe*?

The Scientific Method

- What can you *infer*?

The Scientific Method

- In this section we will:

→ Define the scientific method.

→ Identify the steps of the scientific method.

→ Solve a problem using the scientific method.

The Scientific Method

Science is the process of explaining how the world works.

- In order to explain something, we first need to *observe* and *describe* it.
- *Observations* and *measurements* are used to describe the world around us.
- This information is often organised with *charts*, *tables* and *graphs*, but…

The Scientific Method

Charts and tables of information alone do not explain how the world works.

- *Questioning* our observations and *asking why* things happen as they do is the way to learn something new.
- Answering these questions, using our observations to prove or disprove our ideas, leads to *new discoveries*.

The Scientific Method

The process scientists use to solve a problem or answer a question is called the *Scientific Method*.

- The *Scientific Method* is a series of steps that leads an individual through the process of solving a problem.

- Although the Scientific Method is a useful process, there are some things you need to be aware of in order to use it properly.

The Scientific Method

Good measurements must be *accurate* and *precise*. Accuracy and precision are equally important when solving a problem.

- Humans have many biases, prejudices, and beliefs that can get in the way of solving a problem.
- The purpose of the scientific method is to eliminate these issues by ensuring (as far as it is possible) *accuracy* and *precision*.

The Scientific Method

- Accuracy

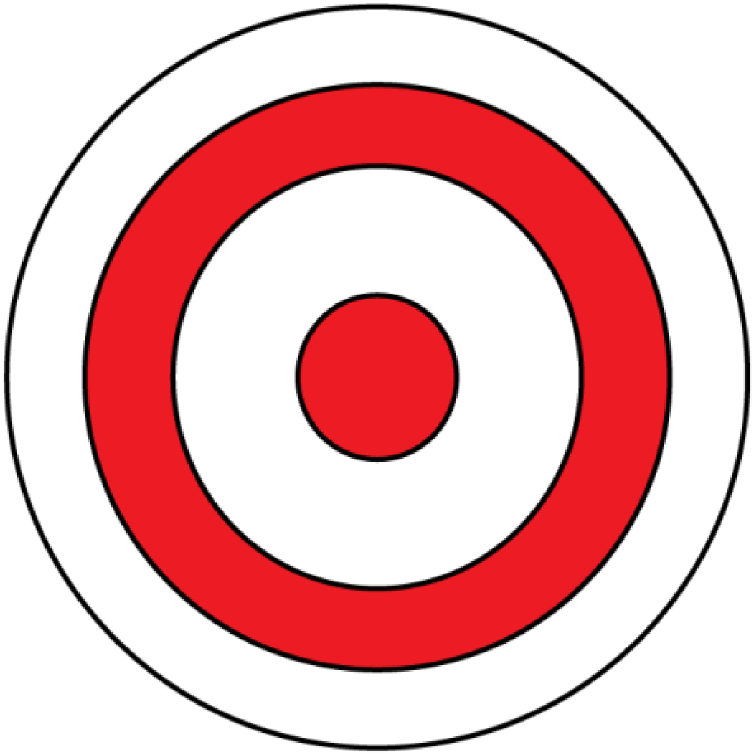
Accuracy is how *close* to the *true value* a given measurement is.

- Precision

Precision is how *closely* two measurements of the same quantity *are similar to each other*.

The Scientific Method

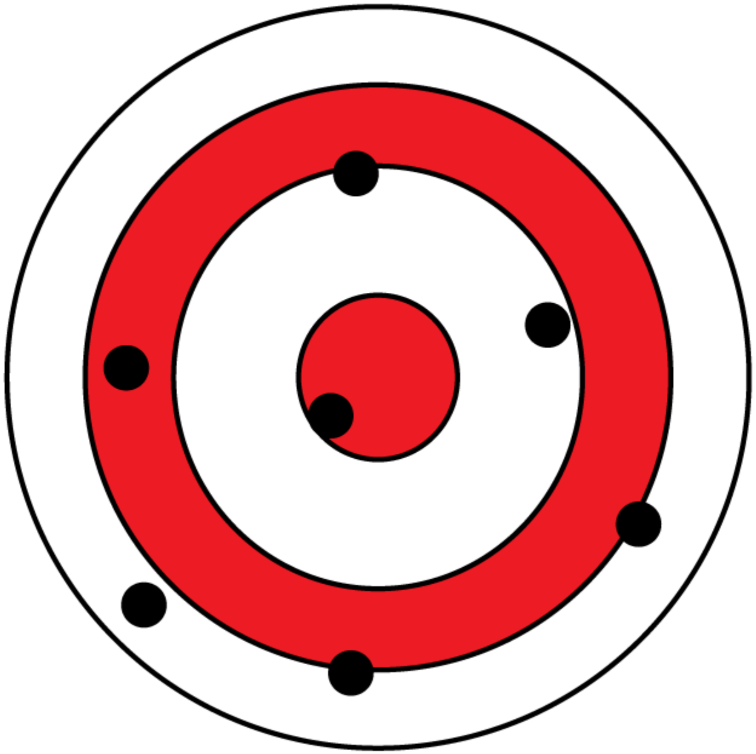
- Low Accuracy
- Low Precision



- If you had seven arrows and you fired them at the target with *low accuracy* and *low precision*, what would it look like?

The Scientific Method

- Low Accuracy
- Low Precision



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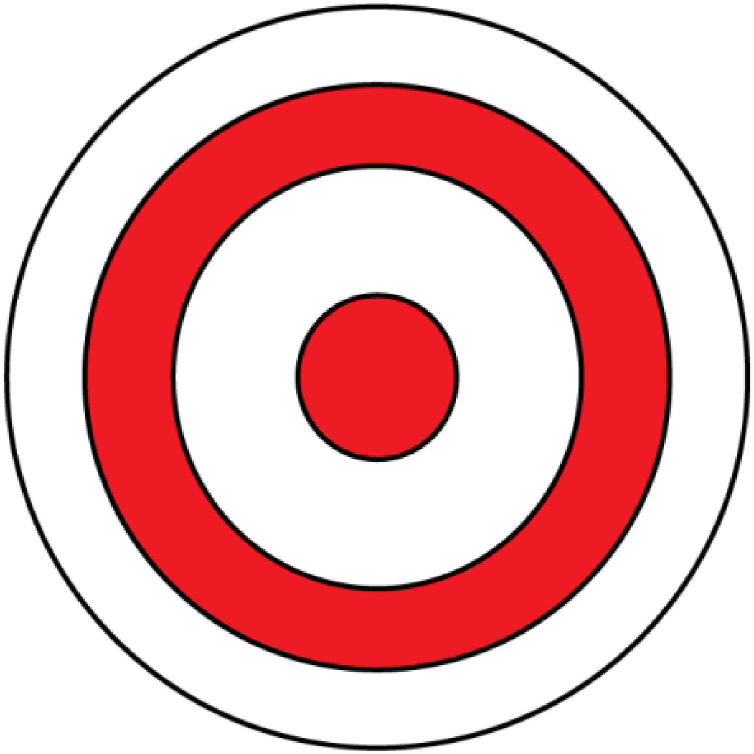
The Scientific Method

- Low Accuracy
- High Precision



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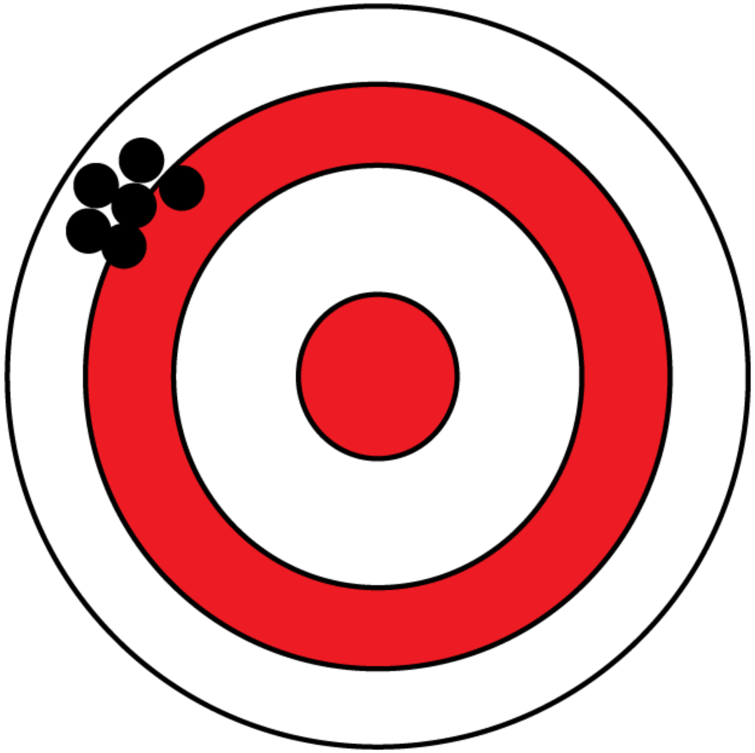

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The Scientific Method

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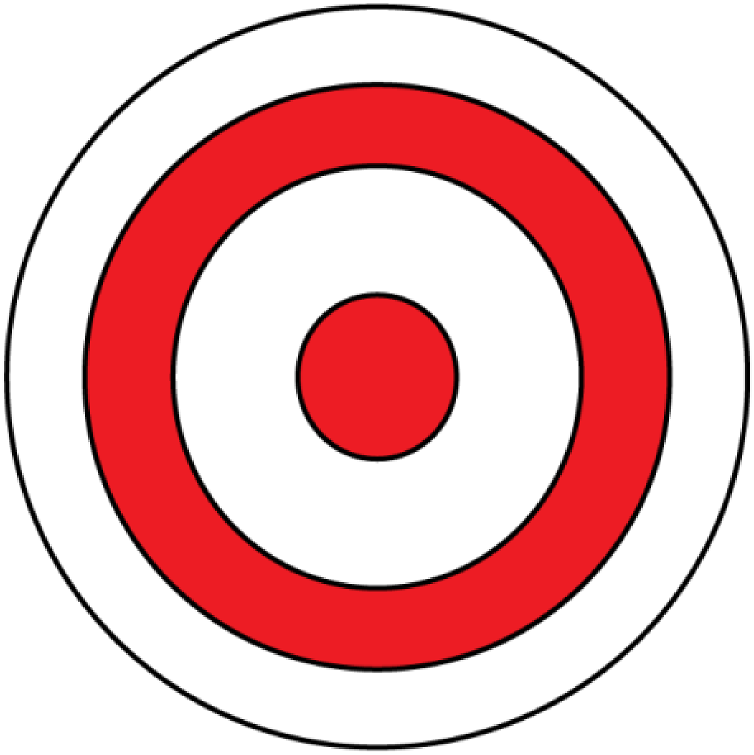
- Low Precision



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The Scientific Method

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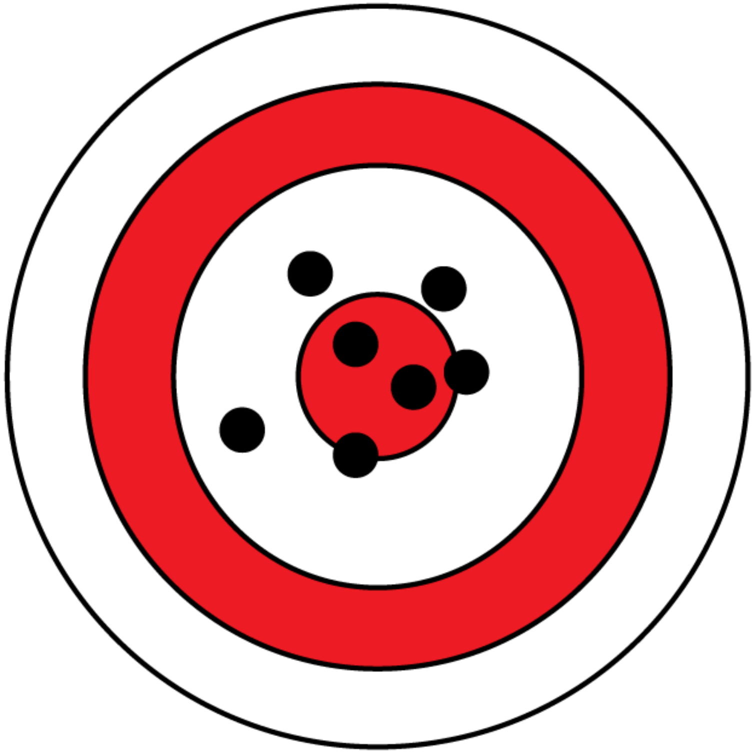
- Low Precision



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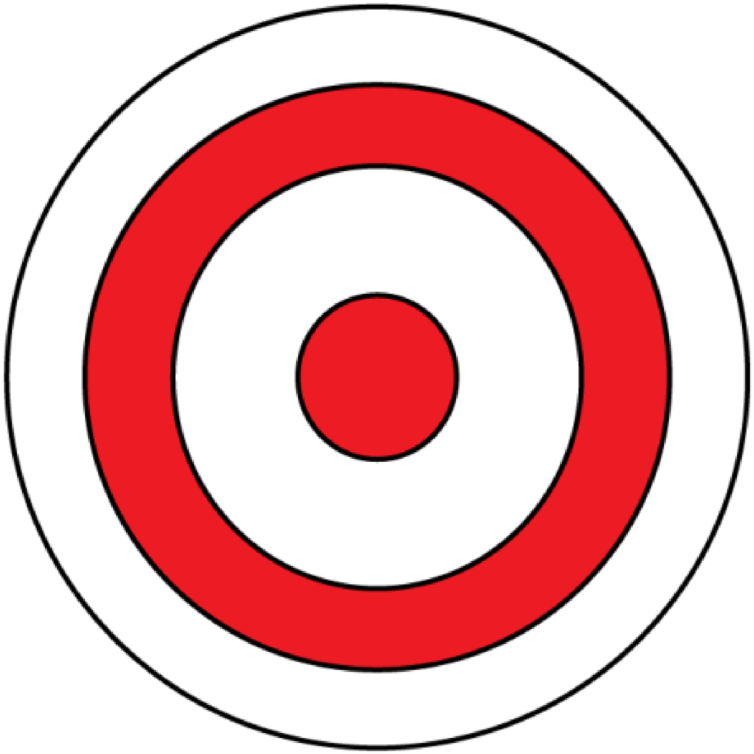

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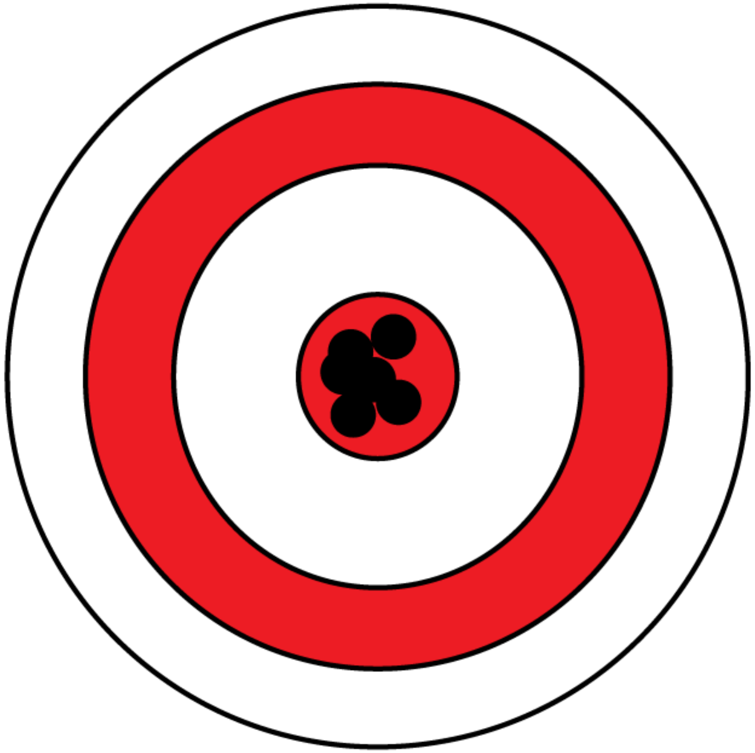

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The Scientific Method

Documentation of your processes is one of the requirements of the scientific method. Other people should be able to follow your procedure and get the same results.

- Any biases in your thinking will be offset by different biases of others. This way mistakes in your procedure will be identified.
- If your explanation is a good one then it should work no matter who answers the question.
- Documentation insures precision (repeatability).

The Scientific Method

- In 1989 a team of scientists claimed to have solved the problem of controlled nuclear fusion under moderate conditions (cold fusion).

- This would have meant a revolution in the way energy is produced so scientists around the world wanted to know how they had solved the problem.

The Scientific Method

- When they shared their procedures, no one else could repeat the process and get the same results.

- Their results were not precise because they could not be repeated. This lead everyone to conclude they had not solved the fusion problem.

The Scientific Method

Basing conclusions on observations is another way in which bias is minimized.

- Smart people can create very good arguments for incorrect ideas. The scientific method requires that you back up any ideas with research and observations.

- Before the scientific method, people thought they could figure things out through reason alone. In other words, if you came up with a logical explanation for a problem it would be correct.

The Scientific Method

A logical explanation, however, is not always a correct explanation. In fact, there could be more than one logical explanation to a given question.

- Scientists do not accept solutions just because they *sound* logical. You need to *prove* your ideas are correct based on facts not opinions or beliefs.
- When solutions to problems are backed up with facts, the answers will be *accurate*.
- The facts are the standards to which we compare our ideas.

The Scientific Method

- The Earth was thought to be flat many years ago. This is an example of a logical answer the question "What is the shape of the Earth?"
- It is difficult to tell by looking at the horizon that you are standing on a sphere. The horizon is almost a perfect straight line.
- If the Earth is a sphere, you might expect the horizon to be more curved.

The Scientific Method

- The *flat Earth* explanation may be logical but it is certainly not accurate because it can not be supported by other facts.

The Scientific Method

- Imagine that you are standing on the shore looking out to sea. Now imagine that a ship is sailing towards you.

- If the flat Earth idea is true, then you will see the whole ship getting bigger and bigger.

The Scientific Method

- Imagine that you are standing on the shore looking out to sea. Now imagine that a ship is sailing towards you.

- If the flat Earth idea is true, then you will see the whole ship getting bigger and bigger.

The Scientific Method

- If the round Earth idea is true, then the ship will appear from the top down. You will first see smoke, then the funnel, then the rest of the ship.

The Scientific Method

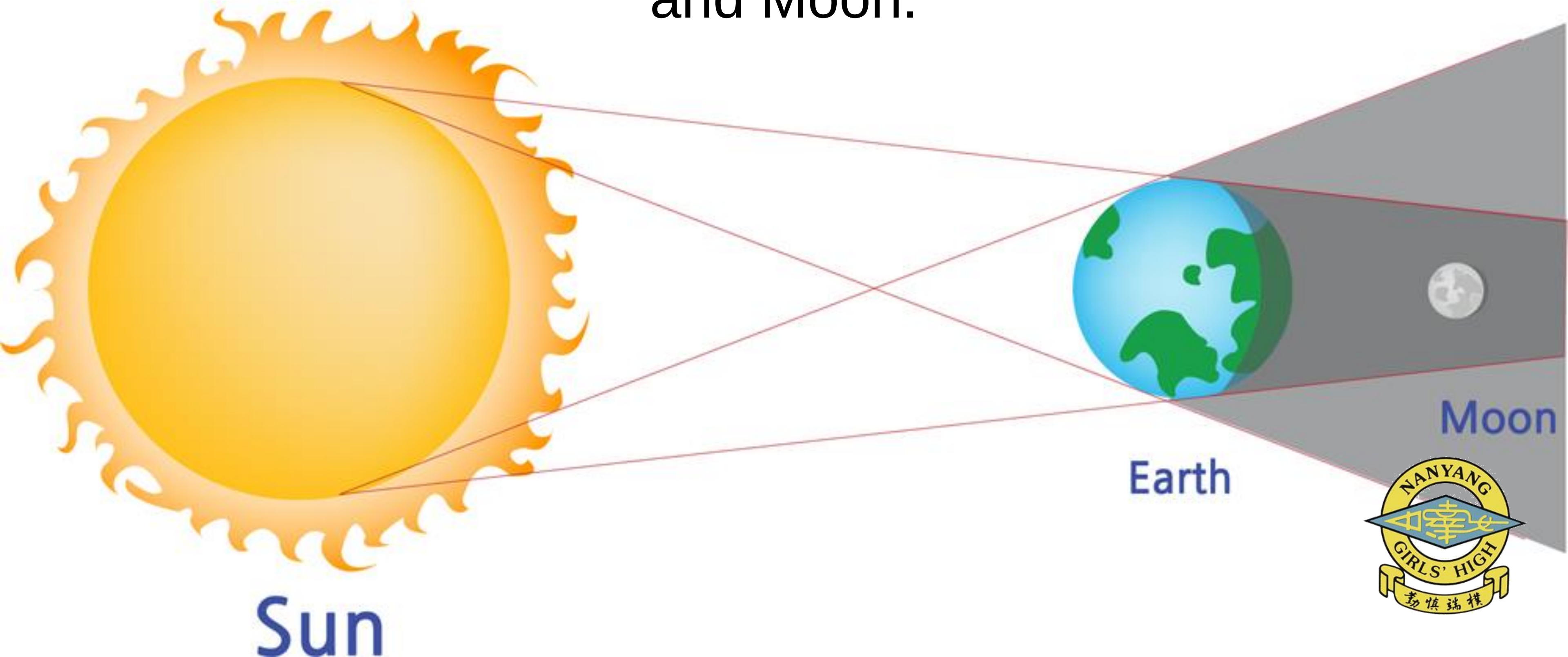
- If the round Earth idea is true, then the ship will appear from the top down. You will first see smoke, then the funnel, then the rest of the ship.

The Scientific Method

- This observable fact directly contradicts the flat Earth idea and provides empirical evidence in support of the round Earth idea.

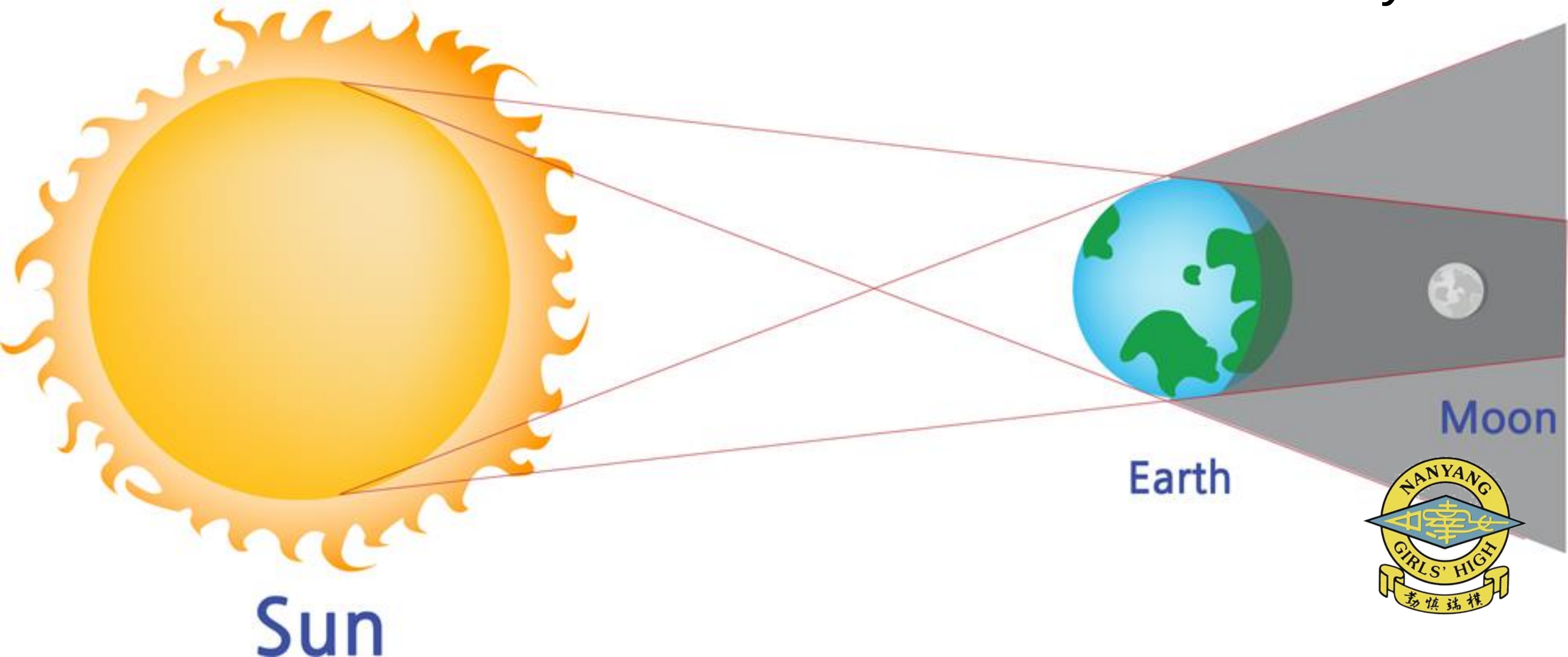
The Scientific Method

- Another contradiction to the flat Earth idea is the appearance of the lunar eclipse.
- A lunar eclipse is the shadow the Earth casts on the Moon when the Earth moves between the Sun and Moon.



The Scientific Method

- If the Earth were flat you would expect the shadow of the Earth on the Moon to be a straight line.
  - However, the lunar eclipse produces a curved shadow on the Moon.
- This observation does not fit the flat Earth theory.



The Scientific Method

Basing ideas on verifiable observations also eliminates the reliance on belief.

- You can determine the Earth is round by making these observations for yourself. You can observe a lunar eclipse or watch a ship sailing out at sea. You do not have to trust that someone is telling you the truth.
- Science requires proof, not belief, to determine what is true.
- If ideas are based on facts, then we can say our explanation is an accurate or true description of the way the world works.

The Scientific Method

How does the scientific method ensure reliability?

- The scientific method insures reliability through the documentation of the procedures used to solve the problem. If others can follow the procedures and get the same result (repeatability) then the solution is reliable.

The Scientific Method

How does the scientific method ensure accuracy?

- The scientific method ensures accuracy by backing up ideas with verifiable facts. Facts are the standards to which we compare our ideas. If the facts do not support the idea, then the idea is not accurate. It is not a complete description of the way the world works.

The Scientific Method

- If an idea can not be supported by the facts it will not be considered scientifically valid no matter how logical the argument may sound.
- Facts are the standards to which we compare our ideas.
- Ideas are accurate if they are supported by facts.

The Scientific Method

- The *Scientific Method* is a series of steps that scientists follow to solve a problem.

→ Observe the natural world and define the problem.

→ Formulate a hypothesis.

→ Test the hypothesis.

→ Collect observations.

→ Draw conclusions.

The Scientific Method

Observe the Natural World and Define the Problem

- This may seem like an obvious and simple part of the scientific method but it is the most important and often most difficult part.

- Something is observed about which a person becomes curious. It is then posed as questions and these questions are investigated through observation and experimentation.

- There are limitations on the questions that the Scientific Method can help us answer.

The Scientific Method

Observe the Natural World and Define the Problem

- First, you must have a clear idea about what it is you want to know.
- For example, you pick-up your pen but it will not write, no ink flows out.
- You ask, “How do I get the pen to write?” This may be the problem you want to solve but it is not the first question that you must answer.

The Scientific Method

Observe the Natural World and Define the Problem

- Before you can get your pen to write, you have to answer the question, “Why will my pen not write?”
- This may seem trivial but a small change in the question can mean a big change in the way you go about answering it.

The Scientific Method

Observe the Natural World and Define the Problem

- Second, questions should be very focused.
- Broad problems are broken into smaller questions that are addressed one at a time.
- For example, no single scientist is working on the question, “What is the cause of cancer?” That question is so broad that no single experiment could be designed to address it. Instead, thousands of scientists searching for answers to smaller related questions.

The Scientific Method

Observe the Natural World and Define the Problem

- The previous question, “Why will the pen not write?” may be too broad.
- This problem should be broken-down into smaller questions.
- For example: Has the pen run out of ink? Or is there a problem with the pen nib or the paper?

→ Has the ink run out?

→ Is the pen nib blocked?

→ Is the paper too smooth / glossy?

The Scientific Method

Observe the Natural World and Define the Problem

- Third, only questions that are testable can be answered by the scientific method.
- You must be able to prove or disprove a solution based on facts or observation.
- “Is there a god?” or “Is there a particle that is unobservable?” These are not valid questions because they can not be proved or disproved.

The Scientific Method

Observe the Natural World and Define the Problem

- The question, “Is there a God?” can not be tested because it is based on belief rather than fact.

- “Is there a particle that is unobservable?” This question is not valid because it can not be tested by observation.

- This does not mean these types of questions are not important. It just means the scientific method will not help you answer them.

The Scientific Method

Observe the Natural World and Define the Problem

- Why is it important to define the problem?

→ You need a clear picture of what you want to know before you can try to figure it out.

→ Very broad problems should be broken into smaller related questions.

→ You want to make sure the question you are asking is one that can be answered using the scientific method.

The Scientific Method

Develop a Hypothesis

- You asked a very specific question when you defined the problem.
- A hypothesis is a statement that answers the question, or provides a tentative explanation to why the observed event occurred.
- The hypothesis can be viewed as an educated guess about the solution to the problem.

The Scientific Method

Develop a Hypothesis

- Suggest some hypotheses for the problem, "Why will my pen not write?"

→ One hypothesis may be, "The nib is broken."

→ Another hypothesis may be, "The ink has hardened."

The Scientific Method

Develop a Hypothesis

- The hypothesis is a way to narrow your search for the answer to your question.
- If the hypothesis is, “The ink has hardened.” then our search for a solution will be limited to the ink.
- This does not mean that the hypothesis is always correct. Through observations, we may find out that the hypothesis was wrong.

The Scientific Method

Develop a Hypothesis

- The second function of a hypothesis, is to give us something to prove or disprove.
- A hypothesis is a statement. “The ink has hardened.” statement can be verified or proven wrong.
- The problem, “Why will my pen not write?” is a question. Questions are not right or wrong, they are just questions.

The Scientific Method

What are the Reasons for Developing a Hypothesis?

- A hypothesis can help to narrow the search for the solution to the problem.

- A hypothesis is a statement not a question.

- A hypothesis can be verified through experiments and observations or proven incorrect. Questions can not be proven.

The Scientific Method

The Scientific Method

- Exercise:

Write a problem and a hypothesis for the following. You are an avid bird watcher and you would like to see more sunbirds at your birdfeeder.

- Define the Problem:

How can I attract more sunbirds to my birdfeeder?

- Hypothesis:

Sunbirds like nectar.

The Scientific Method

Test the Hypothesis

- In this step you determine how you will prove or disprove your hypothesis.
- There are two different methods for testing a hypothesis.

→ Research

→ Controlled Experiments

The Scientific Method

Test the Hypothesis

Research

- Testing a hypothesis by research means that you look at information that others have collected.
- You want to look for facts that either support or disprove your hypothesis.
- Look at the following example of a problem and a hypothesis that we want to test.

The Scientific Method

Test the Hypothesis

Research

- Problem: How can I attract sunbirds to my birdfeeder?

- Hypothesis: Sunbirds like nectar.

- Test the Hypothesis: Research

I could get book about birds and look up what sunbirds like to eat.

- My hypothesis may be correct or incorrect.

The Scientific Method

Test the Hypothesis

Controlled Experiment

- An experiment is a test that is designed to prove or disprove a hypothesis.

- A *controlled* experiment means running the test twice while changing only one variable.
  A variable is the thing we are testing.

The Scientific Method

Test the Hypothesis

Controlled Experiment

- A controlled experiment means running the test twice while changing only one variable.
- You may test the same group twice, changing the variable between tests or...
- You may test two different groups that are identical except for a single variable.
- Let's take another look at the sunbird problem.

The Scientific Method

Test the Hypothesis

Controlled Experiment

- Problem: How can I attract more sunbirds to my birdfeeder?
- Hypothesis: Sunbirds like nectar.
- Test the Hypothesis: Controlled Experiment

Fill the birdfeeder with the fruit juice for one week and record the number of sunbirds I see.

The next week I would fill the birdfeeder with (sugar solution) nectar and record the number of sunbirds.

The Scientific Method

Test the Hypothesis

Controlled Experiment

- In a controlled experiment the same test is run twice while changing only one variable.
- This results in two testing groups.
- The control is the group under normal or usual circumstances.
- The experimental is the one to which the variable is applied .

The Scientific Method

Test the Hypothesis

Controlled Experiment

- In the sunbird problem, the variable is the sugar solution. So...
- The birds that visited the feeder during the week we use the fruit juice are the control group.
- The birds that visited the feeder during the week we use the sugar solution (nectar) are the experimental group.

The Scientific Method

Test the Hypothesis

Controlled Experiment

- Why do you think it is important to have a control group?

- A control group is a usual or normal condition to which we can *compare* our experimental group.

- If we had not counted the sunbirds while using the normal feed (control group), then we wouldn't know if we were attracting more or less when we switched to the nectar (experimental group).

The Scientific Method

Test the Hypothesis

Controlled Experiment

- Sometimes the control and experimental groups are made up of different individuals.
- In this example, we tested the same population of birds but at different times.
- What is important is that the two groups are as similar as possible except for the variable.
- In other words, we try to change only one variable at a time.

The Scientific Method

Test the Hypothesis

Controlled Experiment

- Why do you think it is important to change only one variable at a time?
  - If you change more than one variable then you won't know which variable caused the effect.
    - If we bought a different birdfeeder when we changed to nectar and fewer sunbirds showed up, we wouldn't know if we had fewer sunbirds because they didn't like the nectar or because they didn't like the feeder.

The Scientific Method

Test the Hypothesis

- What two methods were used to test our hypothesis, Sunbirds like nectar?

→ Research

→ Controlled Experiments

The Scientific Method

Test the Hypothesis

- Which method (Research or Controlled Experiments) do you think was better?

- Researching the problem was more effective because it took advantage of work that had already been done.

- Setting up a controlled experiment is time consuming and costly. We do not want to do this if someone else has already done it. We should always start with research.

The Scientific Method

Clarifying the terms

- *Variables* are things in the experiment which can vary. Because they can vary, they can effect the outcome of the experiment.

1. *Independent variable* (*manipulated variable*) is the variable which the experiment is designed to test.

→ In the Sunbird experiment, the independent variable is the sugar solution (nectar).

The Scientific Method

Clarifying the terms

2. *Controlled variables* are the factors which must be controlled in the experiment so that they will not effect the outcome.

→ In the Sunbird experiment, the type of birdfeeder that is used must be the same for all experiments *i.e.* it must be *controlled*.

The Scientific Method

Clarifying the terms

3. *Dependent variable* (value) is the variable which the experiment is designed to measure.

→ In the Sunbird experiment, the dependent variable is the number of Sunbirds that visit the bird feeder.

- A good way to think of the *independent variable* is to think of it as being the *cause* and the *dependent variable* as being the *effect*.

The Scientific Method

Collect Observations - what data is collected?

- In this step you actually do the research or run the experiment.
- Collecting observations includes two functions.

→ First, decide what data should be collected.

→ Second, organize your data.

The Scientific Method

Collect Observations - what data is collected?

- When researching our sunbird problem, we obviously want to collect data about sunbirds and nectar.

- But is there any other data we may want?

→ We might want to gather information about sunbirds' preference for other foods besides nectar.

The Scientific Method

Collect Observations - what data is collected?

- What information do we record from our controlled experiment on the sunbirds?
- We certainly want to count the number of sunbirds each week but we may also want to record the number of other birds as well.

The Scientific Method

Collect Observations - what data is collected?

- Why might it be a good idea to collect additional information?
- Counting *all* the birds may give us some very useful information.

Fruit Juice	Sugar Solution (Nectar)
80 Sunbirds	70 Sunbirds
400 Birds in Total	280 Birds in Total

The Scientific Method

Collect Observations - what data is collected?

- Looking only at the sunbird numbers, it appears that nectar was less effective. But if you look at *all* the data, you find a greater percentage (25% vs 20%) of the birds were sunbirds when we fed nectar. The additional data lead us to a different conclusion.

Fruit Juice	Sugar Solution (Nectar)
80 Sunbirds	70 Sunbirds
400 Birds in Total	280 Birds in Total

The Scientific Method

Collect Observations - what data is collected?

- Once you have decided what information you want to collect, you will do the research or run the experiment and gather the data.
- The data you gather may be a few numbers or it may be hundreds of measurements.
- The most common means of organizing data is with charts, tables, and graphs.

The Scientific Method

Collect Observations - what data is collected?

- Why is it a good idea to organize data?
- Organizing information with charts, tables and graphs makes the data easier to read and interpret.
- Another benefit of organizing data will show up in the next step *Drawing Conclusions*.
- It is difficult to see trends or patterns in raw numbers until you organize your data with tables and graphs.

The Scientific Method

Drawing Conclusions

- In this step you determine if the data you collected from your research or experiment supports or disproves your hypothesis.
- This is not always a clear decision.
- You will often find that one reference book or one experiment will not answer the question.
- Many times a little research or an experiment raises more questions than it answers.

The Scientific Method

Drawing Conclusions

- The conclusion in our sunbird problem changed based on available information.
- When we looked only at the number of sunbirds it looked like the nectar did not work.
- When we looked at the *total* number of birds we were lead to the opposite conclusion.

Fruit Juice	Sugar Solution (Nectar)
80 Sunbirds	70 Sunbirds
400 Birds in Total	280 Birds in Total
20% are Sunbirds	25% are Sunbirds

The Scientific Method

Drawing Conclusions

- While researching the problem, we may find that sunbirds do like fruit juice.
- But we may also find that sunbirds are not normally found in our area.
- Our hypothesis (Sunbirds like nectar) may be true but it may not help us solve the problem (How can I attract more sunbirds to my birdfeeder?)

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The Scientific Method

Drawing Conclusions

- It is not unusual to find that your experiment or research did not turn out as you expected.
- It is not a bad thing to have your hypothesis proven wrong. It may help you narrow your search for a solution.
- Some incredible discoveries were made because experiments did not turn out as expected.

The Scientific Method

Hypothesis vs Theory

- A good experiment is repeatable.
- Any other scientist should be able to repeat the experiment and expect to get similar results.
- If other scientist repeat an experiment and usually get similar results, the hypothesis may become a *theory*.
- A theory is a well-tested hypothesis which experiments show to be true most of the time.

The Scientific Method

Statistics

- When scientist get the results of an experiment, they apply mathematical procedures known as *statistical procedure* to their results.
- This procedure allows the scientist to know the probability that they obtained their experimental results by pure chance alone.

The Scientific Method

Statistics

- In general, if a scientist could not expect their results to have occurred by chance more than 5% or 1% of the time, they say that they obtained a *significant difference*.
- Only repetition gives scientists the assurance that their results were not just luck alone.

The Scientific Method

The Scientific Method

Define the Problem

- Remember, the problem is stated as a question and it should not be too broad. Pick one.

For example…

- I have been having some problems getting my house plants to grow. It may have to do with the amount light they get.

The Scientific Method

Define the Problem

- How much light do plants need? Do plants really need light? Does the amount of light depend on the plant?

- These are all good questions but we can not answer them all at once. So, let us start with the most basic question…

- Can plants grow in the dark?

The Scientific Method

- Define the Problem:

Can plants grow in the dark?

- Formulate a Hypothesis.

A hypothesis is a statement that answers your question. It is your educated guess.

Can plants grow in the dark?

- What is your educated guess? Hypothesis:

Plants Need Light to Grow.

The Scientific Method

- Define the Problem: *Can plants grow in the dark*?
- Hypothesis: *Plants need light to grow.*

Test the Hypothesis

- This involves research or experimentation.
- We are going to set up a controlled experiment to answer our question.
- This means we need to identify the variable and decide on a control and experimental procedure.

The Scientific Method

Test the Hypothesis

- The variable in this experiment is light. Everything else about the plants should be the same.
- The plants should all come from the same packet of seeds.
- The plants should all get the same amount of water.
- The plants should all be planted in the same types of pots using the same soil.

The Scientific Method

Test the Hypothesis

- How would you design control and experimental groups?
- A control group is the normal condition.
- It is normal for plants to have light so the plants that are exposed to light make up the control group.
- The plants in the dark will be the experimental group.

The Scientific Method

Collect Observations

- Collecting observations involves 2 functions:

→ First, decide what data you need to collect.

→ Second, collect and organize your data.

- We want to know if the plants are growing.
- What types of measurements could we make to decide this?
- We could measure the height of the plants and the number of leaves.

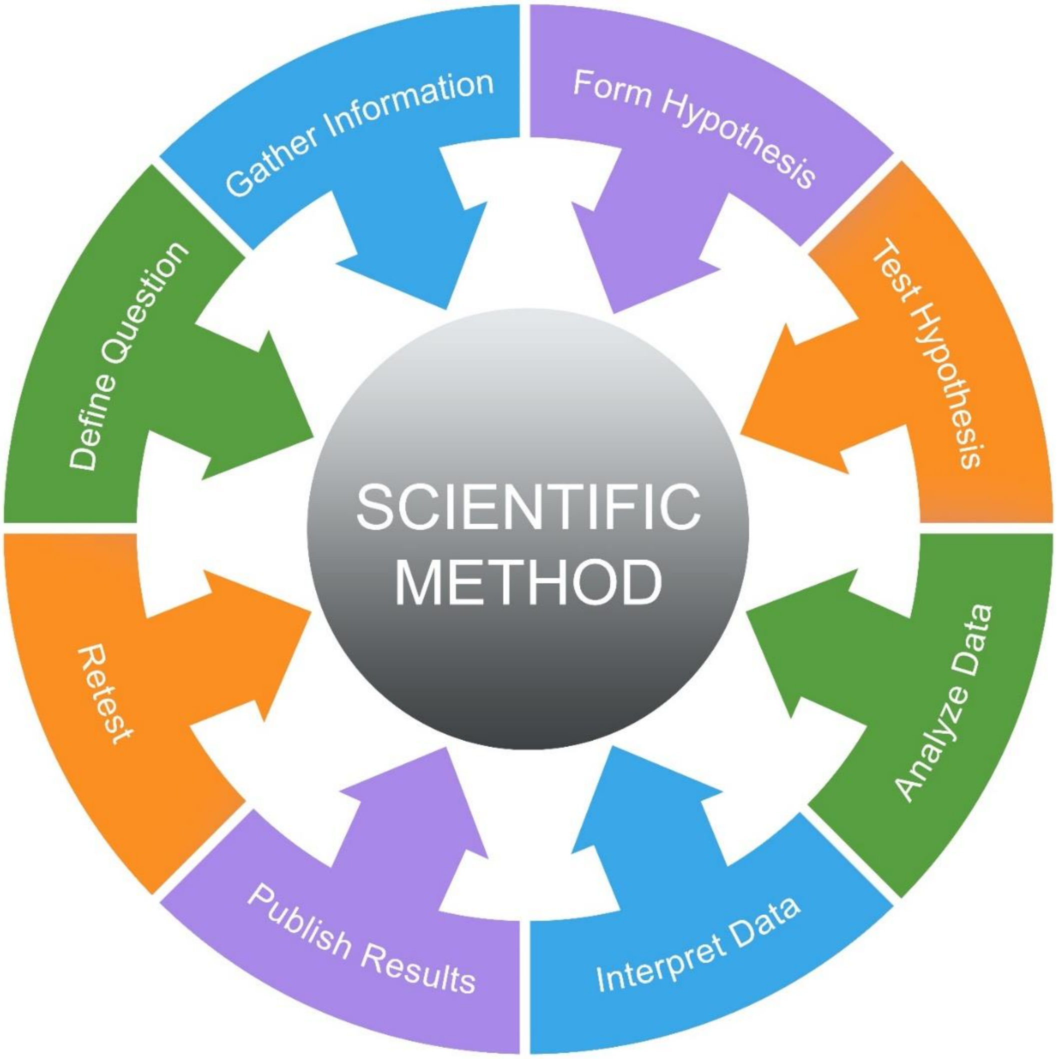
The Scientific Method

- Define the Problem: *Can plants grow in the dark*?
- Hypothesis: *Plants need light to grow*.
- Test the Hypothesis:

→ *Independent (Manipulated) Variable – Light.*
→ *Dependent Variable (Value) – Height of plants and number of leaves*.
→ *Control Group – Plants exposed to light*.
→ *Experimental Group – Plants left in the dark*.

- Collect observations.

The Scientific Method



NANYANG GIRLS' HIGH
勤慎端樸

Presentation on

The Nature of Science – The Scientific Method

by Dr. Chris Slatter

christopher_john_slatter@nygh.edu.sg

Nanyang Girls' High School

2 Linden Drive

Singapore

288683

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