
NANYANG
GIRLS' HIGH

International Science Education Conference

22nd – 24th June 2021

Organised by The National Institute of Education and The Science Centre Singapore

Asking the Right Questions: the Nature of Science

Concurrent Session 3.3

Wednesday 23rd June, 10.15 – 11.45 a.m.

Chris Slatter

Nanyang Girls' High School

The Nature of Science

- This Presentation can be found online at:

www.scientist.sg/the_nature_of_science.pdf

The Nature of Science

- Resources for the Nature of Science can be found online at: www.nygh.sg/nature_of_science/nature_of_science.htm

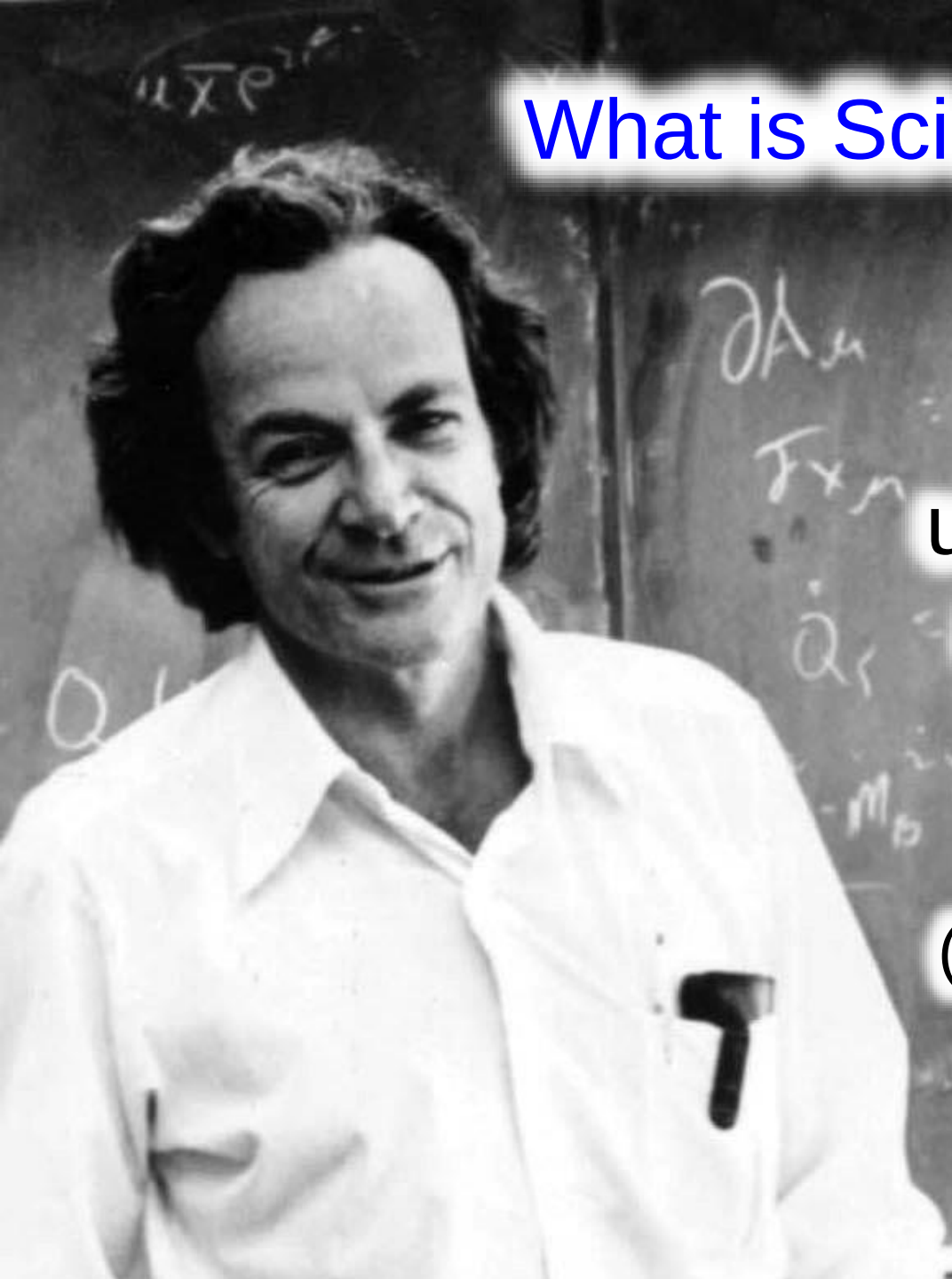
Overview of the Presentation

- What is Science?
- What do Scientists Say about Science?
- Why is it Important for *Everybody* to Understand a Little Science?
- Teaching the Nature of Science

What is Science?

- What constitutes Science?
- What is the objective of Science?
- Can Science ever “know” everything?
- Why teach Science?
- Why teach the Nature of Science?

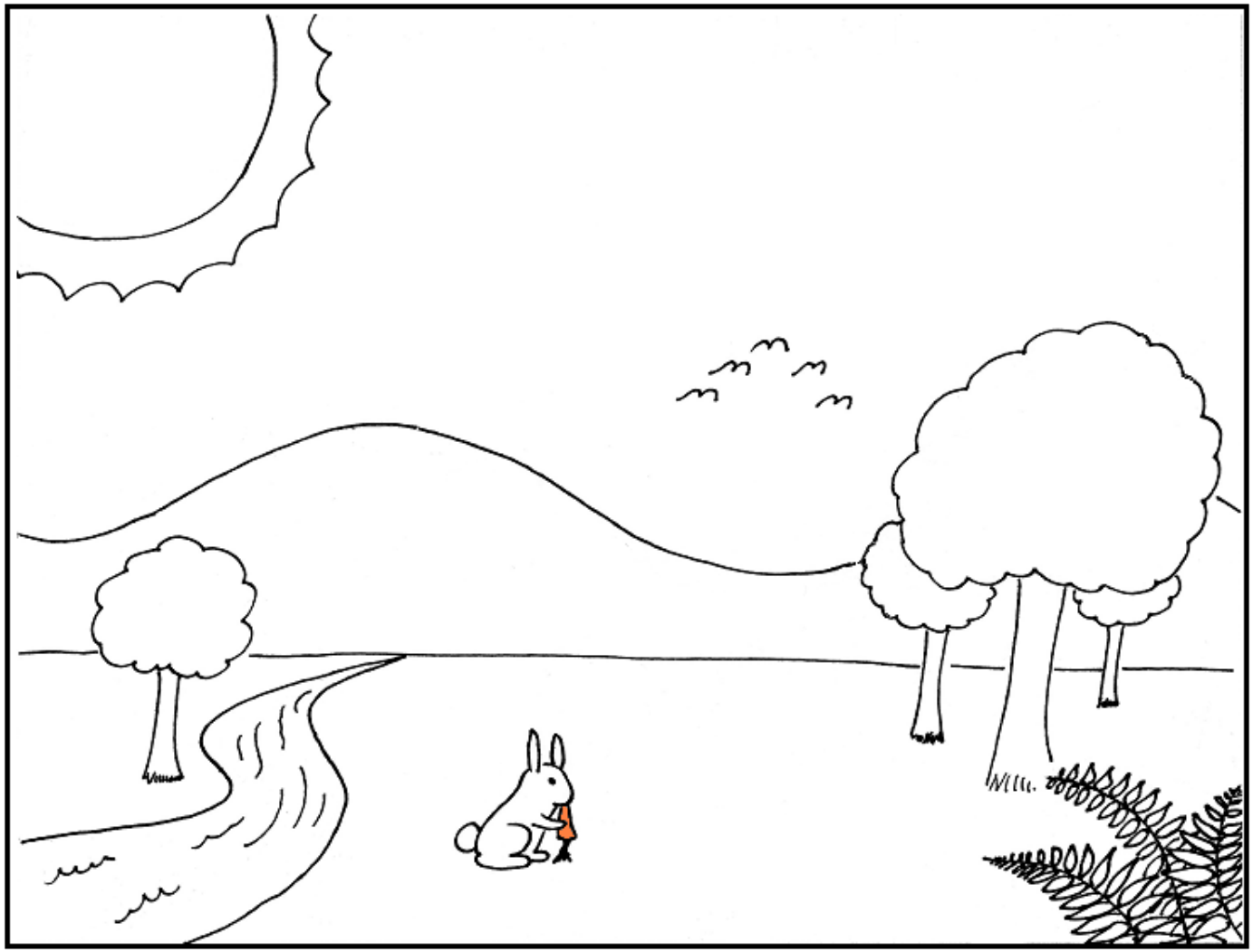
What is Science?



- Philosophy of science is as useful to scientists as ornithology is to birds.

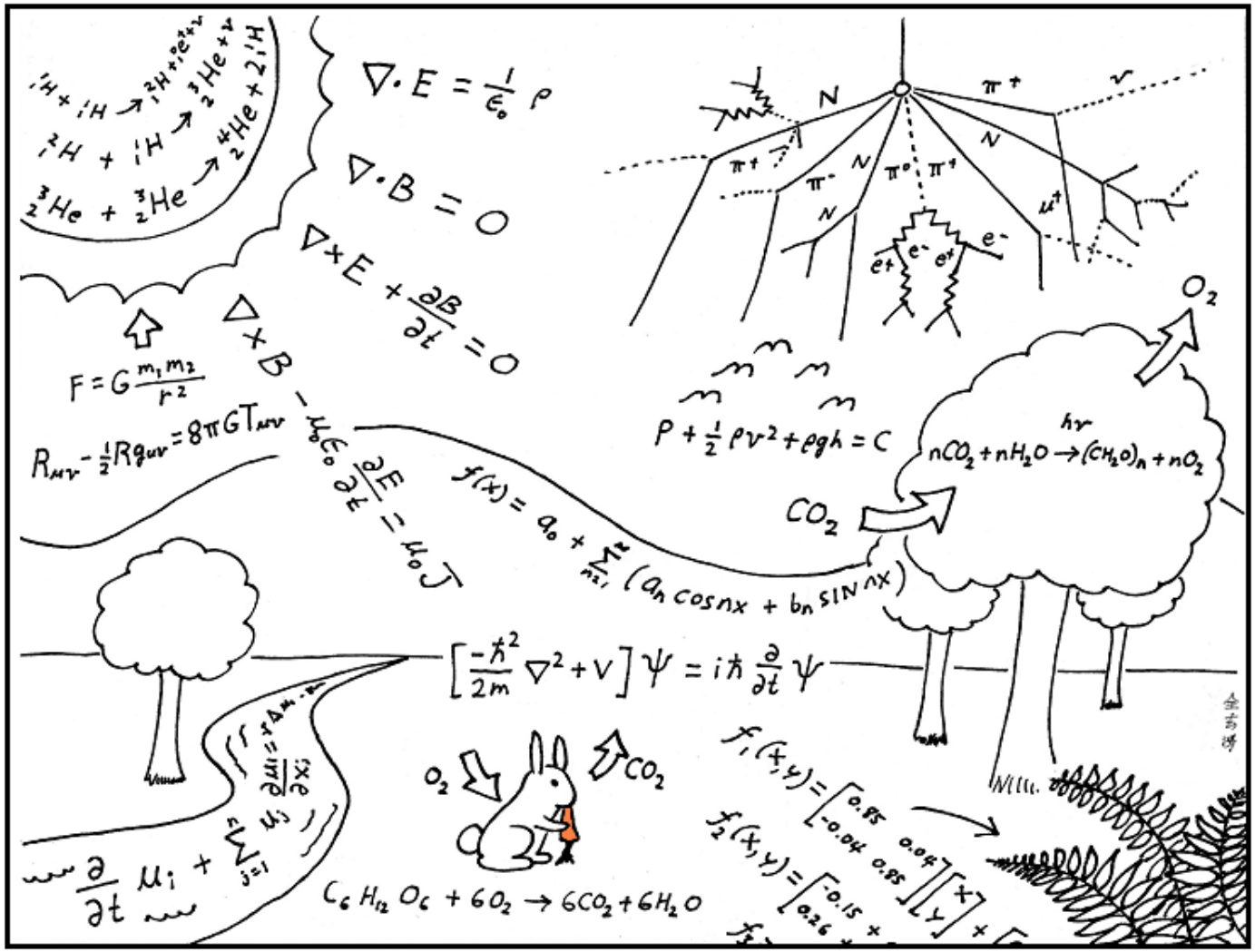
Richard Feynman
(Theoretical Physicist).

What is Science?



- How somebody *not* trained in Science sees the world.

What is Science?



- How somebody trained in Science sees the world.

What is Science?

- The word *Science* come from the Latin word *Scientia*, meaning *knowledge*.

- *Science*: Systematic knowledge of the physical or material world gained through observation and experimentation.

What is Science?

- We are familiar with *inductive* and *deductive* reasoning, but philosophers suggest that Science tends to be more *abductive* in nature.

- Inductive Reasoning: Is a method of reasoning in which the statements (premises) are viewed as supplying *some* evidence for the truth of the conclusion.

- Deductive Reasoning: Is the process of reasoning from one or more statements (premises) to reach a logically certain conclusion.

What is Science?

• *Abductive reasoning* is a form of logical inference which starts with an observation or set of observations then seeks to find the simplest and most likely explanation for the observations. This process, unlike deductive reasoning, yields a plausible conclusion but does not positively verify it, hence there is a degree of uncertainty or doubt.

What do Scientists Say about Science?

The scientific mind does not so much provide the right answers as ask the right questions.

Claude Levi-Strauss (Anthropologist)

What do Scientists Say about Science?

The important thing in Science is not so much to obtain new facts as to discover new ways of thinking about them.

Sir William Lawrence Bragg (Physicist)

What do Scientists Say about Science?

An experiment is a question which Science poses to Nature, and a measurement is the recording of Nature's answer.

Max Planck (Theoretical Physicist)

What do Scientists Say about Science?

Scientific principles and laws do not lie on the surface of nature. They are hidden, and must be wrestled from nature by an active and elaborate technique of inquiry.

John Dewey (Philosopher and Psychologist)

What do Scientists Say about Science?

Science, in the very act of solving problems, creates more of them.

Abraham Flexner (Educator)

What do Scientists Say about Science?

Science is a way of thinking much more than it is a body of knowledge. Its goal is to find out how the world works.

Carl Sagan (Astronomer)

What do Scientists Say about Science?

We especially need imagination in Science.
It is not all mathematics, nor all logic, but is somewhat beauty and poetry.

Maria Mitchell (Astronomer)

Why is it Important for *Everybody* to Understand a Little Science?

- From your experience, why is Science difficult to teach?

Why is it Important for *Everybody* to Understand a Little Science?

- Scientific knowledge has been developed by Scientists for use by Scientists.
- As a consequence, Scientific knowledge is not automatically useful for school students.
- The knowledge of Science needs to be transformed to be useful in schooling (the art and skill of the Science Teacher – pedagogy).

- Fensham, 2005.

Why is it Important for *Everybody* to Understand a Little Science?

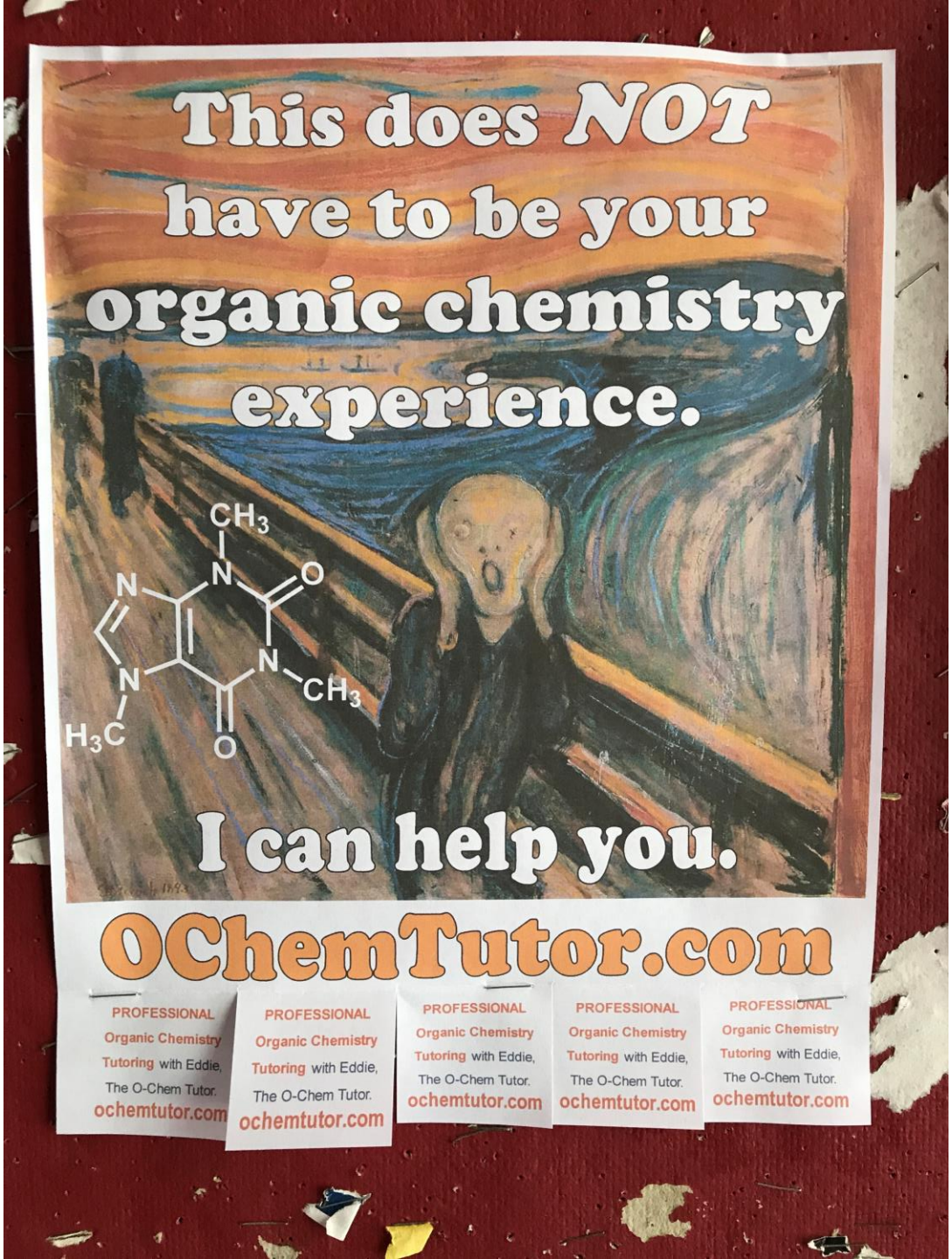
- Students' experience of learning Science at school:

→ Transmissively taught (soaked up like a sponge).

→ Boring and irrelevant content (compared to the students' lives).

→ Difficult to learn (compared to other subjects).

- Fensham, 2005.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Why is it Important for *Everybody* to Understand a Little Science?

- In your opinion, what purpose does Science have in compulsory education?

- Fensham, 2005.

Why is it Important for *Everybody* to Understand a Little Science?

- Public understanding of Chemistry:

→ Bottled water.

→ Clean energy.

→ Climate change and environment.

→ Contents labelling (ingredients).

→ Cosmetics advertisements.

→ Organic food.

→ Supermarket “best before” dates.

- Fensham, 2005.

Why is it Important for *Everybody* to Understand a Little Science?

- The challenge is that only a small percentage of our students will become creators of new Scientific knowledge (Scientists) or engage in Science related careers (*e.g.* Pharmacists).

- So why teach Science to all school children?

- McComas, 2017.

Why is it Important for *Everybody* to Understand a Little Science?

- Science is an essential and unique discipline.

→ Science is a body of knowledge:

Facts, concepts theories and laws.

→ Science is a way of thinking:

Curiosity, imagination, reasoning, objectivity, scepticism, cause and effect.

→ Science is a way of investigating:

Inquiring, observing, experimenting, concluding.

- McComas, 2017.

Why is it Important for *Everybody* to Understand a Little Science?

- Reasons for Teaching Science:
  Students See Themselves…

1. As *creators* of new Scientific knowledge (Scientists).
2. In Science *careers* (*e.g.* Doctors and Veterinarians).
3. As *citizens* who use Science in decision making.
4. As *consumers* who apply their Science knowledge.

- McComas, 2017.

Why is it Important for *Everybody* to Understand a Little Science?

- Reasons for Teaching Science:
  Students See Themselves…

5. As *critics* of the misuse of Science.

6. As *connoisseurs* who enrich their lives with Science.

7. As *collaborators* with Scientists.

8. As those who can make *connections* beyond Science.

- McComas, 2017.

Why is it Important for *Everybody* to Understand a Little Science?

- It is important for people who will work as Scientists to understand the Nature of Science and apply it to their professional work and everyday lives.

- It is also important for people who will not follow careers in Science to understand the Nature of Science and apply it to their everyday lives, allowing them to make rational and informed decisions.

Teaching the Nature of Science

- Start with the Nature of Science and disciplinarity before moving on to the main contents of the syllabus.

- Share with students what Science is, how it works and why it is important (disciplinarity).

- Lead the students to think like a Scientist.

- Reinforce these points throughout the students' education.

Teaching the Nature of Science

- Understanding the Nature of Science is important for all members of society, even for those who do not practice Science or follow Science related careers.

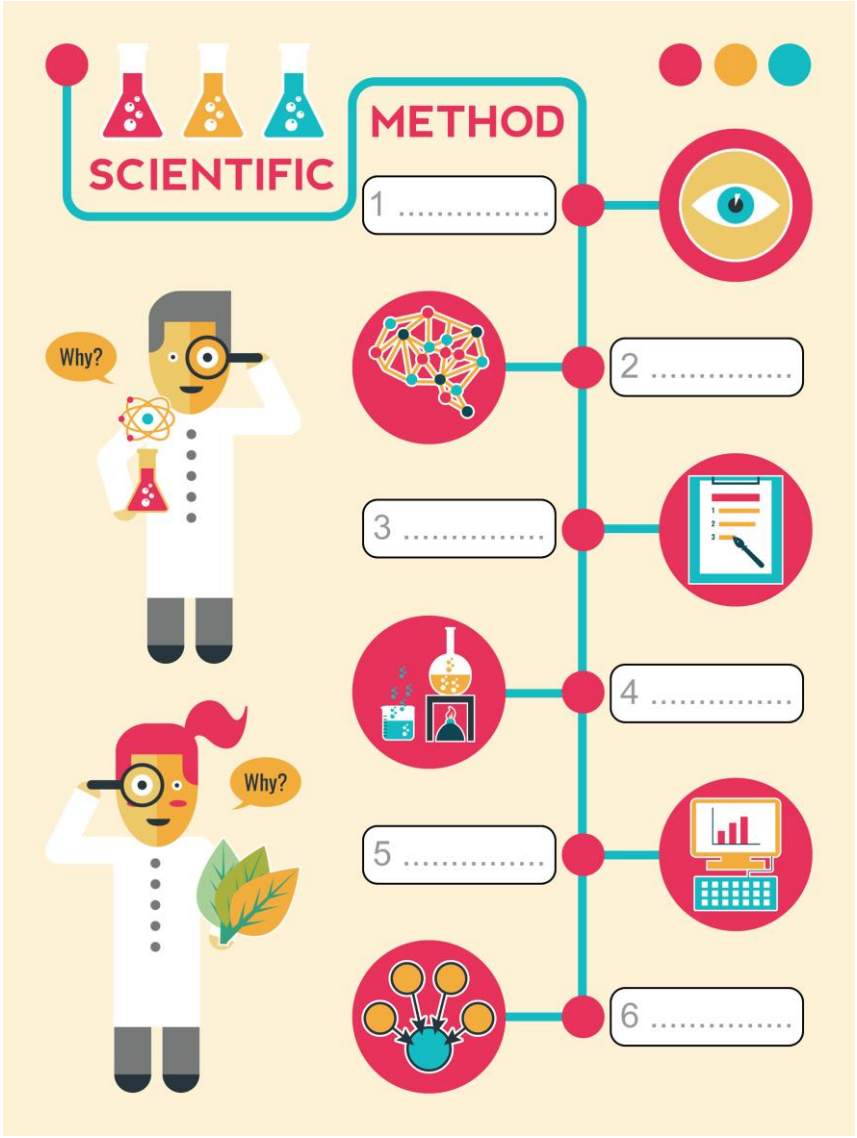
- Understanding the Nature of Science allows individuals to arrive at rational and informed conclusions about the things that they encounter in their everyday lives, whether it is an advertisement for an anti-dandruff shampoo, or a politician's comments on climate change.

Teaching the Nature of Science

- Essentially, practicing good Science, and using Science to navigate out everyday lives, all comes down to *asking the right questions*.

Teaching the Nature of Science

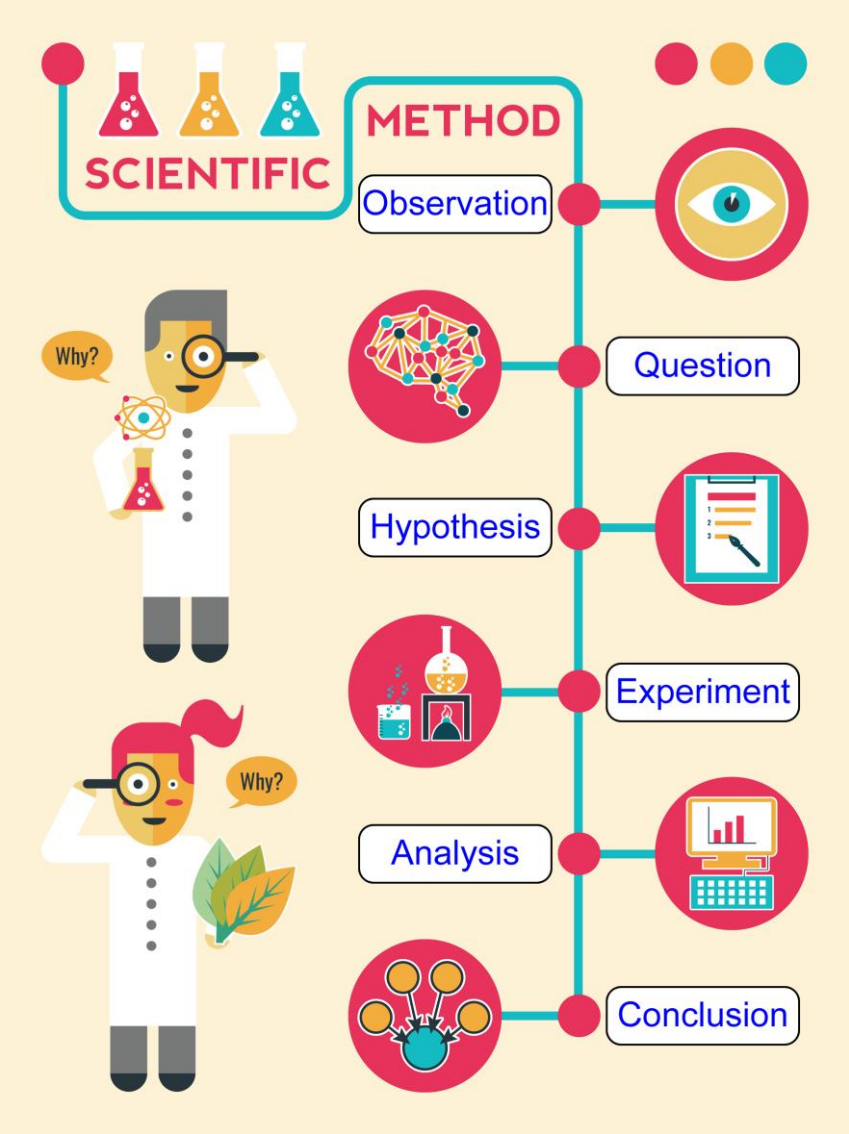
- The Scientific Method.



- Is there only one?

Teaching the Nature of Science

- The Scientific Method.



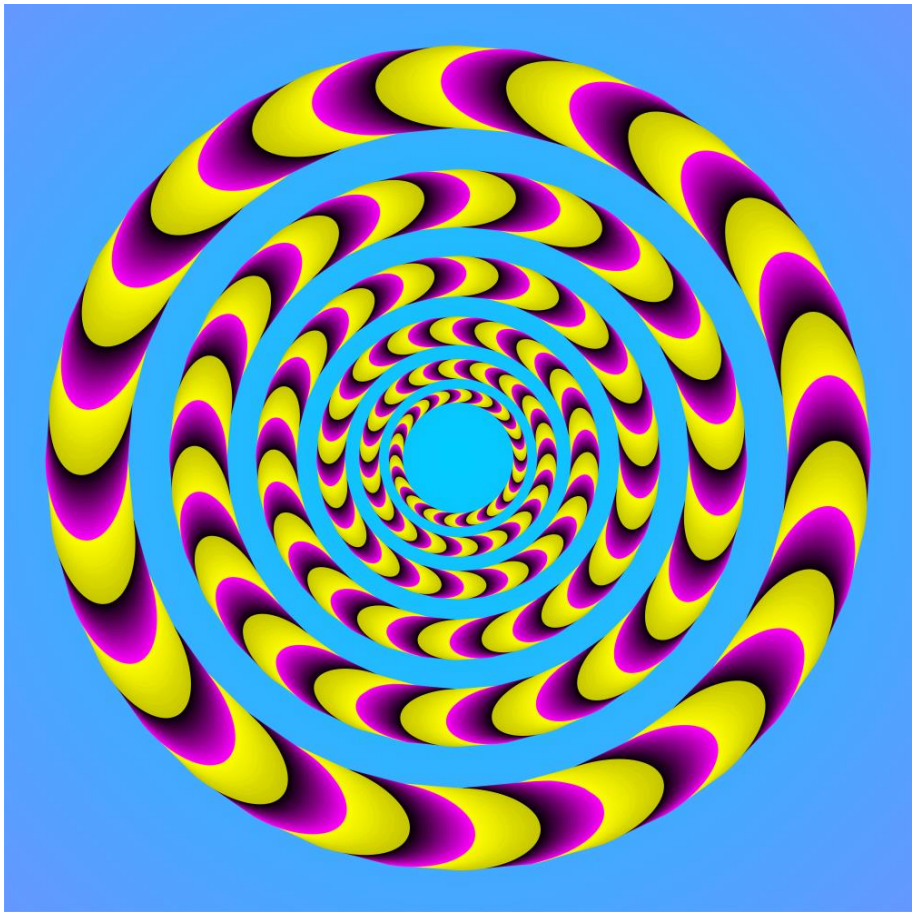
- Is there only one?

Teaching the Nature of Science

For something to be considered scientific, it must fulfil the six criteria of Science:

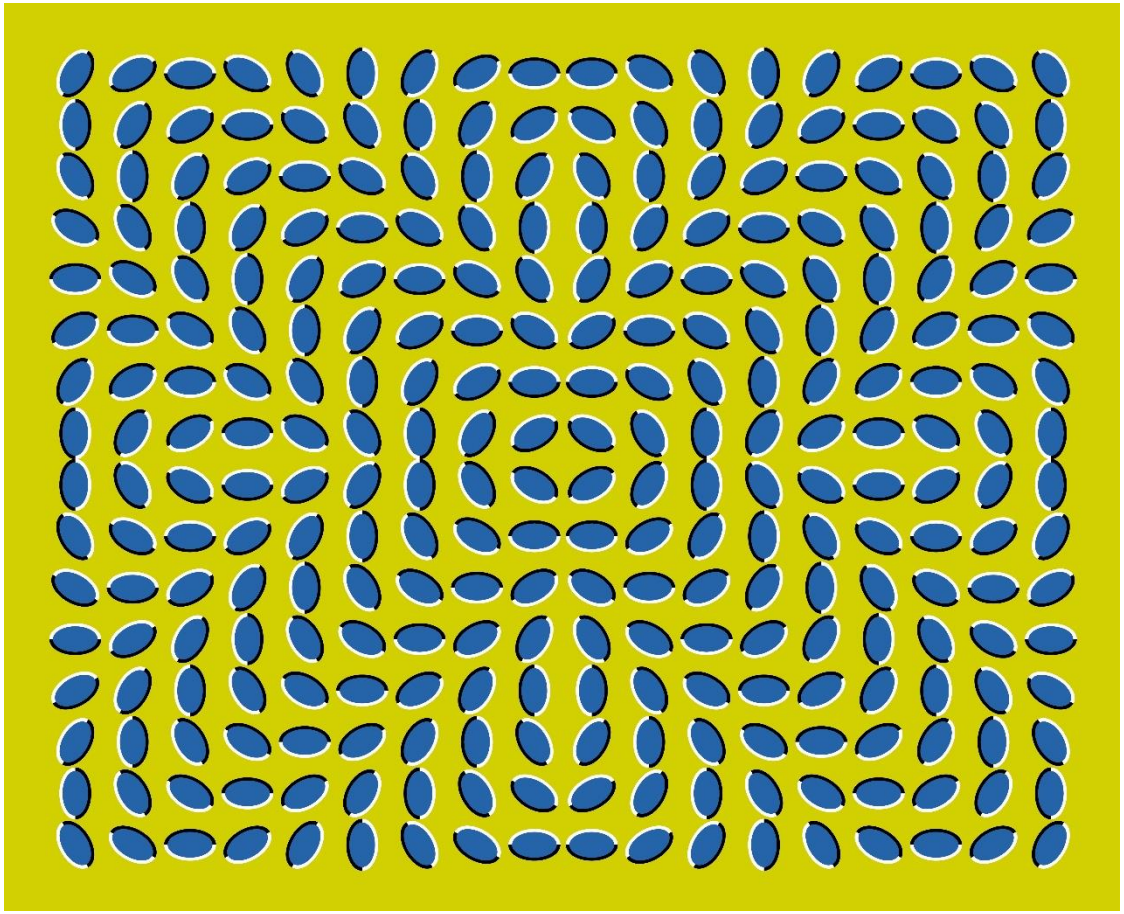
1. **C**onsistent
2. **O**bservable
3. **N**atural
4. **P**redictable
5. **T**estable
6. **T**entative

Teaching the Nature of Science



- Can you always trust your senses? What do you observe – is this image static or moving?

Teaching the Nature of Science



- Can you always trust your senses? What do you observe – is this image static or moving?

Teaching the Nature of Science

What Science is Not…

- Science is not a process that can solve all kinds of problems and questions.
- Science is not a process that can ignore rules.
- Science is not a process that seeks the truth or facts.
- Science is not a process that attempts to prove things.
- Science is not a process that can produce all kinds of explanations.

Teaching the Nature of Science

What Science is Not…

- Science is not a process that produces certainties, or absolute facts.
- Science is not a process that can always be relied upon due to its total objectivity and internal self-correction.
- Science is not a process that is always properly used.
- Science is not a process that is free from values, opinions or bias.

Teaching the Nature of Science

What Science is Not…

- Science is not a process in which the product (understanding) is based on faith or belief.
- Science is not a process in which one solution is as good as another, or is simply a matter of opinion.
- Scientific Theories are not *tentative ideas* or *hunches.*

Teaching the Nature of Science

Assumptions about Science

1. The world is real. The physical universe exists, whether we can sense it or not.

2. Humans can accurately perceive and understand the physical universe. Such understanding is possible.

Teaching the Nature of Science

Assumptions about Science

3. Natural processes are sufficient to explain the natural world. Non-natural processes are unnecessary.

4. Nature operates the same way everywhere in the universe, and at all times, except when we have contrary evidence.

Teaching the Nature of Science

Limitations of Science

1. Observations are confined to the biological limits of our senses, even with technological enhancement.

2. The mental processing of our sensory information is unconsciously influenced by previous experiences, which may result in inaccurate or biased perceptions of the world.

Teaching the Nature of Science

Limitations of Science

3. It is impossible to know if we have observed every possible aspect of a phenomenon, have thought of every possible alternative explanation, or controlled for every possible variable.

4. Scientific knowledge is necessarily contingent knowledge rather than absolute knowledge. It is based only on the available evidence which must be assessed, not on indisputable *proof.* The history of Science is filled with examples of scientific knowledge changing over time.

Teaching the Nature of Science

Limitations of Science

5. Science must follow certain rules, such as:

a) Scientific explanations must be based on careful observations and the testing of hypotheses.

b) It must be possible to disprove a hypothesis.

c) Scientific solutions cannot be based merely on personal opinion, judgement or belief.

d) The *best* hypothesis, out of the choices, must be one which fits several explicit criteria.

Teaching the Nature of Science

Limitations of Science

6. Science, as for any human endeavor, can be done poorly.

7. Science can be misused.

Teaching the Nature of Science

Limitations of Science

- Given so many limitations and uncertainties, why is Science still so useful?

- Because it is the most reliable knowledge we have about the natural world, meaning, most of the time… …*it works*!

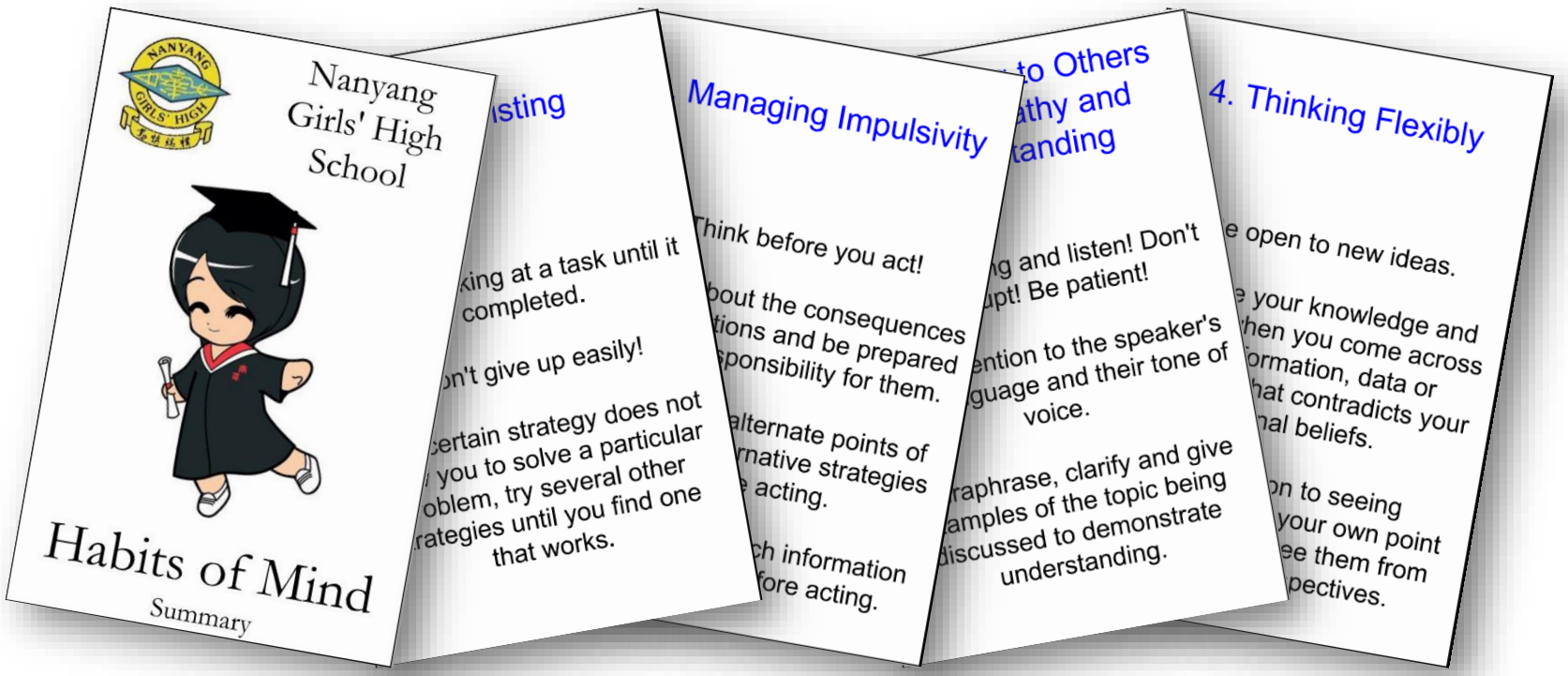
Teaching the Nature of Science

- Thinking is skilled work. It is not true that we are naturally endowed with the ability to think clearly and logically – without learning how, or without practicing. It is ridiculous to suppose that any less skill is required for thinking than for carpentering, or for playing tennis, golf, or bridge, or for playing some musical instrument. People with untrained minds should no more expect to think clearly and logically than those people who have never learnt and never practiced can expect to find themselves good carpenters, golfers, bridge players or pianists.

- A.E. Mander, Clearer Thinking, 1936.

Teaching the Nature of Science

Core Skills – The Sixteen Habits of Mind



Teaching the Nature of Science

Core Skills – The Sixteen Habits of Mind

1. Persisting

2. Thinking and Communicating with Clarity and Precision

3. Managing Impulsivity

4. Gathering Data Through All Senses

5. Listening with Empathy and Understanding

6. Creating, Imagining and Innovating

7. Thinking Flexibly

8. Responding with Wonderment and Awe

Teaching the Nature of Science

Core Skills – The Sixteen Habits of Mind

9. Thinking About Thinking (Metacognition)

10. Taking Responsible Risks

11. Striving for Accuracy and Precision

12. Finding Humour

13. Questioning and Posing Problems

14. Thinking Interdependently

15. Applying Past Knowledge to New Situations

16. Remaining Open to Continuous Learning

Teaching the Nature of Science

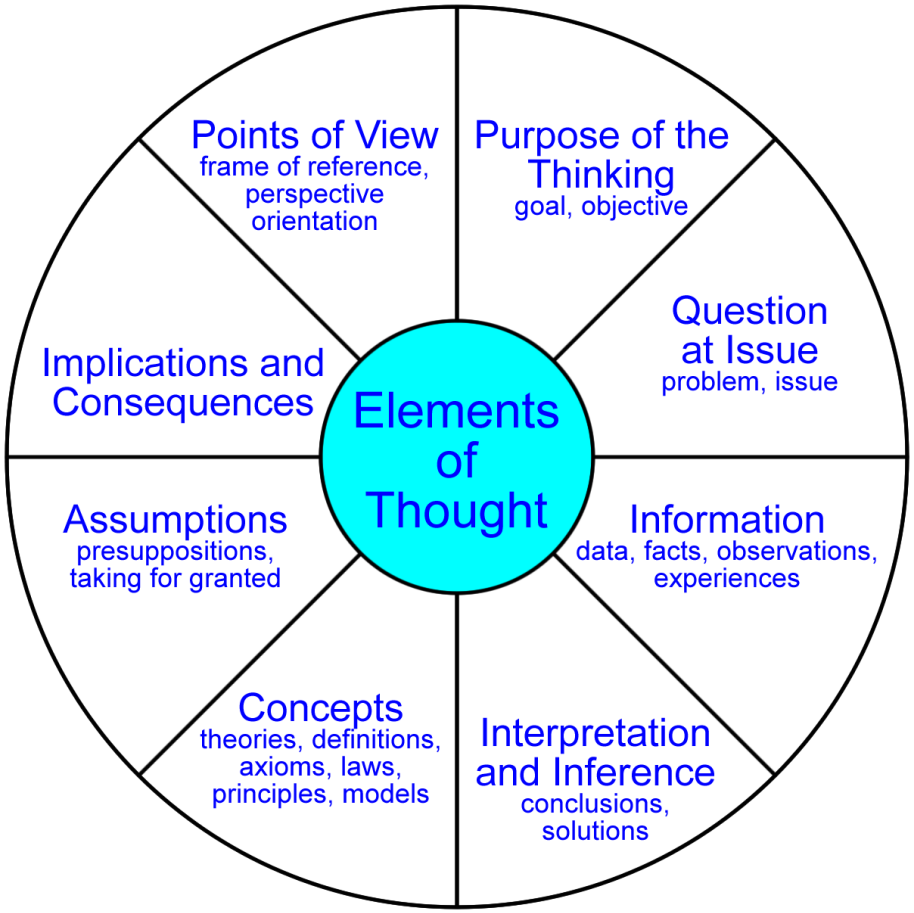
Core Skills – The Sixteen Habits of Mind

- The sixteen *Habits of Mind* inform students how to behave intelligently when they are faced with a novel problem that they do not know the immediate answer to.
- The Habits of Mind guide the students how to think in order to solve a complex problem.
- At the end of the problem solving process, students may reflect upon which of the sixteen Habits of Mind they relied upon the most.
- Students can be given brief biographies of famous Scientists and asked to suggest which Habits of Mind the Scientist exemplified the most.

Teaching the Nature of Science

Core Skills – Critical Thinking

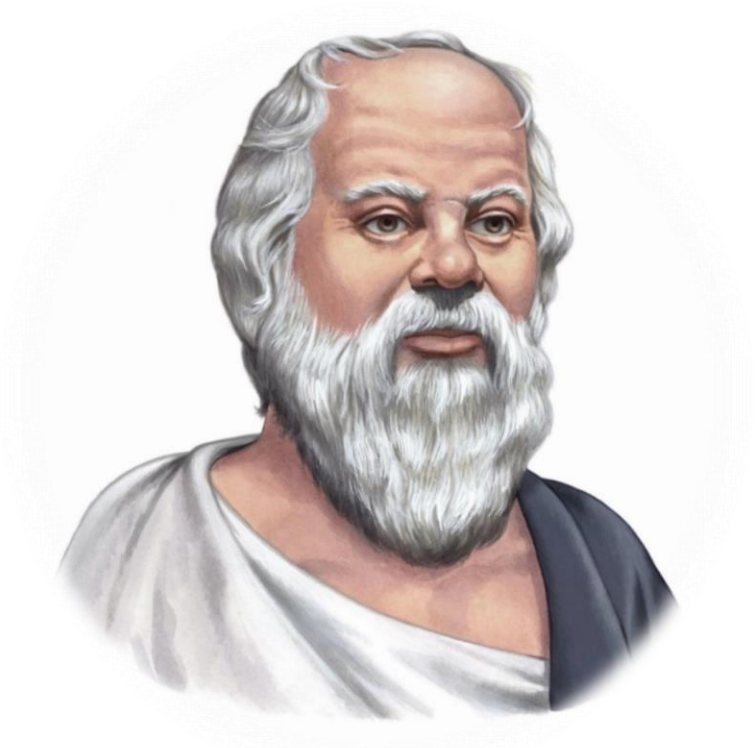
- Paul's Wheel of Reason.



- Guide to critical thinking.

Teaching the Nature of Science

Core Skills – Critical Thinking



- Socrates, Greek Philosopher

Clarify

- Could you elaborate further?
- Could you give me an example?

Accuracy

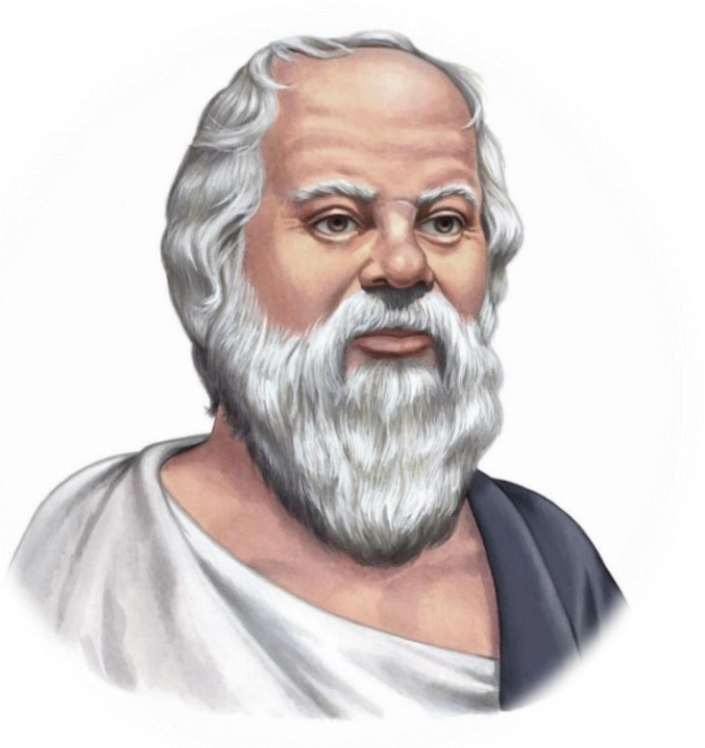
- How could we check on that?
- How could we verify or test that?

Precision

- Could you be more specific?
- Could you give me more details?

Teaching the Nature of Science

Core Skills – Critical Thinking



- Socrates, Greek Philosopher

Relevance

- How does that relate to the problem?

Depth

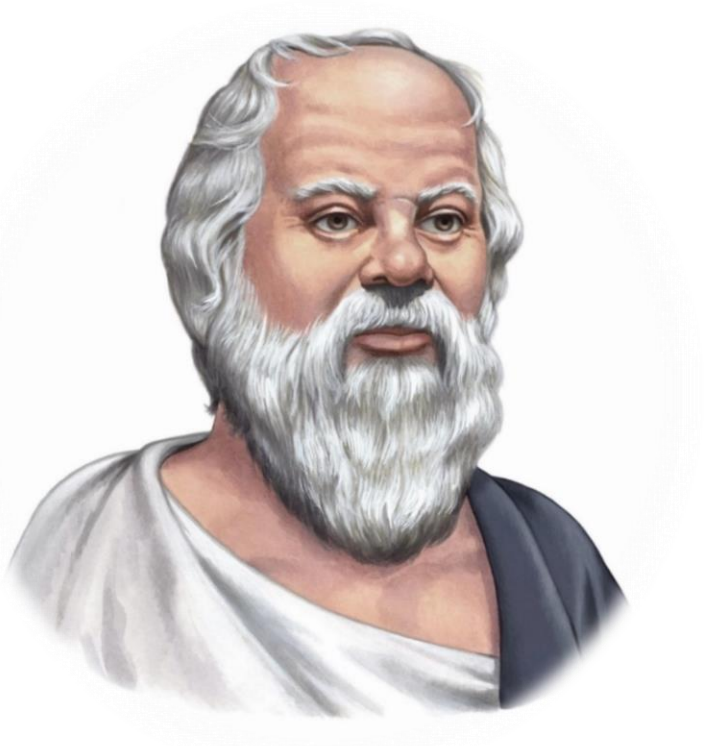
- What are some of the complexities of this problem?

Breadth

- What other perspectives should be considered?

Teaching the Nature of Science

Core Skills – Critical Thinking



- Socrates, Greek Philosopher

Logic

- Does this all make sense?
- Does it all follow the evidence?

Significance

- Is this the most important problem to consider?

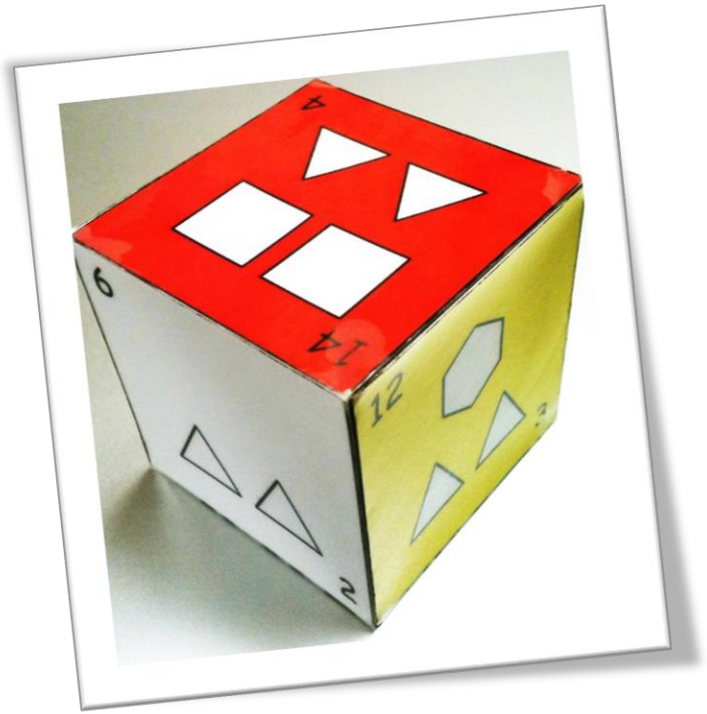
Fairness

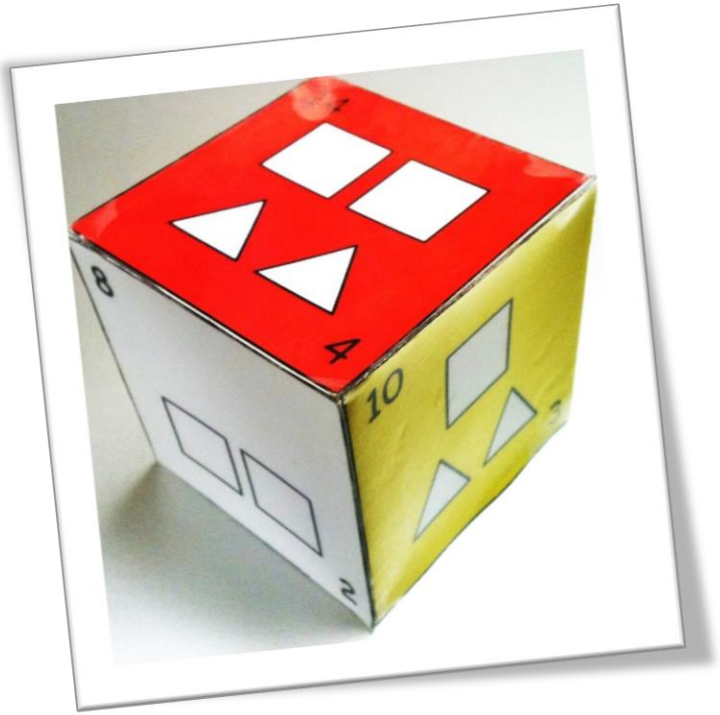
- Do I have any vested interest in the issue?

Teaching the Nature of Science

- Scientists often use *models* in their work.
- Models help Scientists to visualise abstract ideas and understand complex data.
- Models may be physical, mathematical or conceptual.
- All models have limitations.
- Models are used to simplify and present abstract and or complex ideas to students while teaching the Nature of Science.

Teaching the Nature of Science





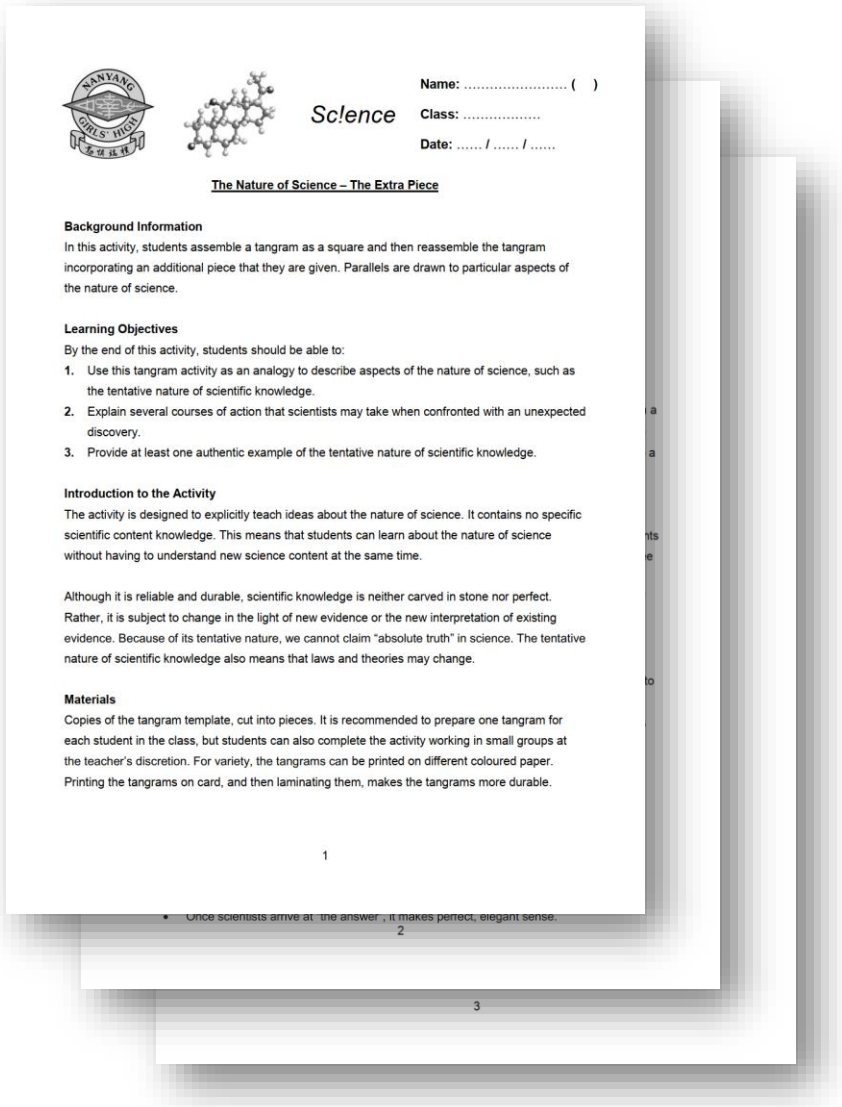
- Based upon what can be observed, students try to deduce what pattern is printed on the bottom of the cube.
- Students think out loud as they reason with their peers.
- The activity demonstrates how Scientists try to understand what cannot be directly observed.

Teaching the Nature of Science

Teaching the Nature of Science

- Each cardboard tube has four holes, through which a piece (or pieces) of string has been threaded.
- Students gently pull the pieces of string and observe what happens.
- Students discuss their observations and suggest possible relationships between the variables.
- In doing so, students draw conclusions about what cannot be observed directly.
- The activity challenges the students to think critically.
- The activity can be used as an introduction to atomic structure.

Teaching the Nature of Science



Science

Name: ..... ( )
Class: .....
Date: ..... / ..... / .....

The Nature of Science – The Extra Piece

Background Information

In this activity, students assemble a tangram as a square and then reassemble the tangram incorporating an additional piece that they are given. Parallels are drawn to particular aspects of the nature of science.

Learning Objectives

By the end of this activity, students should be able to:

1. Use this tangram activity as an analogy to describe aspects of the nature of science, such as the tentative nature of scientific knowledge.
2. Explain several courses of action that scientists may take when confronted with an unexpected discovery.
3. Provide at least one authentic example of the tentative nature of scientific knowledge.

Introduction to the Activity

The activity is designed to explicitly teach ideas about the nature of science. It contains no specific scientific content knowledge. This means that students can learn about the nature of science without having to understand new science content at the same time.

Although it is reliable and durable, scientific knowledge is neither carved in stone nor perfect. Rather, it is subject to change in the light of new evidence or the new interpretation of existing evidence. Because of its tentative nature, we cannot claim "absolute truth" in science. The tentative nature of scientific knowledge also means that laws and theories may change.

Materials

Copies of the tangram template, cut into pieces. It is recommended to prepare one tangram for each student in the class, but students can also complete the activity working in small groups at the teacher's discretion. For variety, the tangrams can be printed on different coloured paper. Printing the tangrams on card, and then laminating them, makes the tangrams more durable.

1

• Once scientists arrive at "the answer", it makes perfect, elegant sense.

2

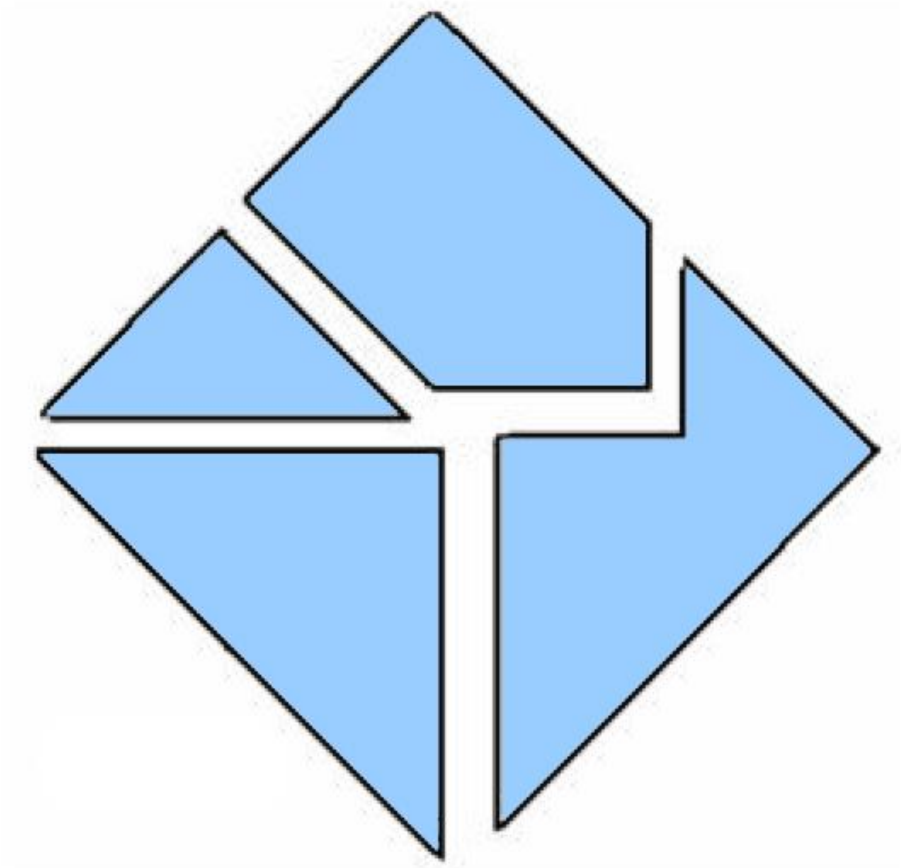
3

- An example of a classroom activity #1

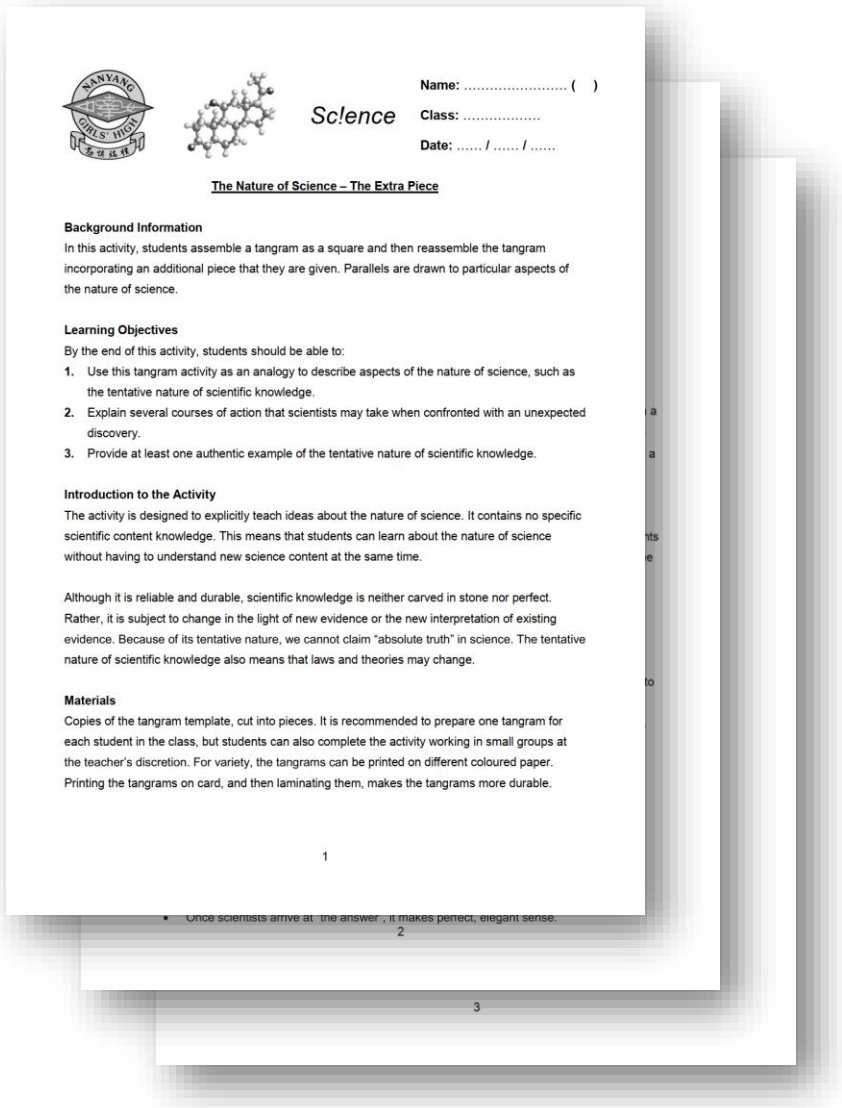
1. Students are given four pieces of card. Each piece represents a piece of experimental data.

2. Students must arrange the four pieces of card into a square. This is their theory or hypothesis based upon the evidence that they have gathered so far.

Teaching the Nature of Science



Teaching the Nature of Science



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1

- Once scientists arrive at "the answer", it makes perfect, elegant sense.

2

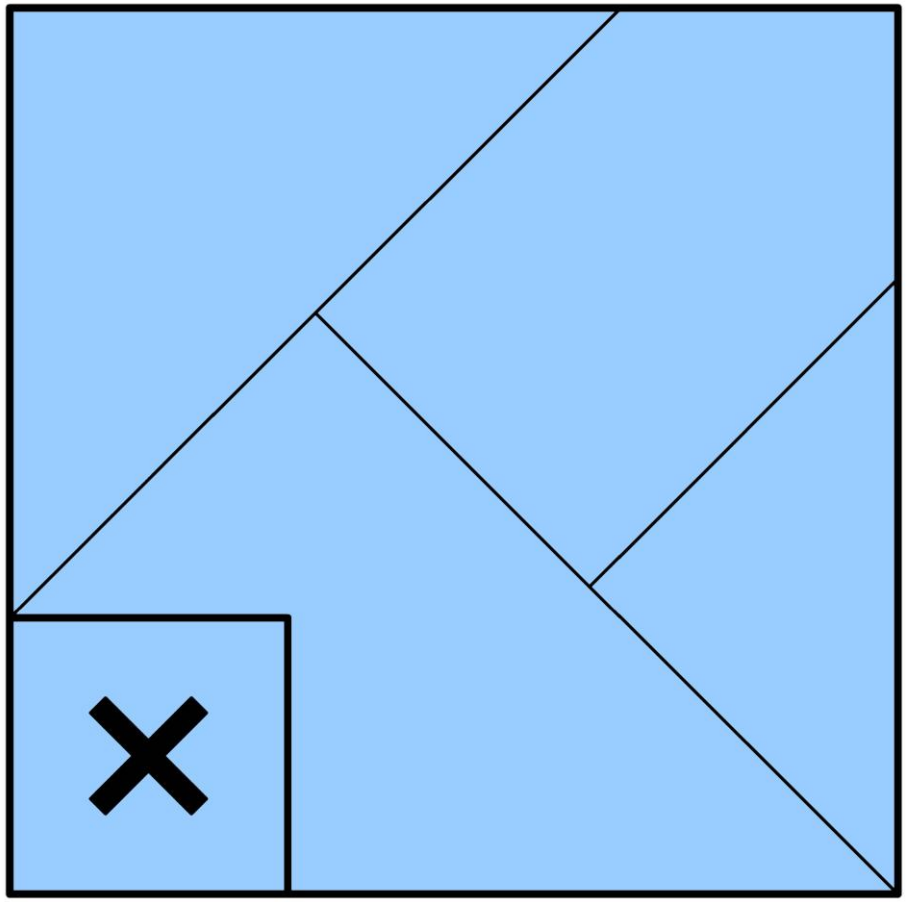
3

- An example of a classroom activity #1

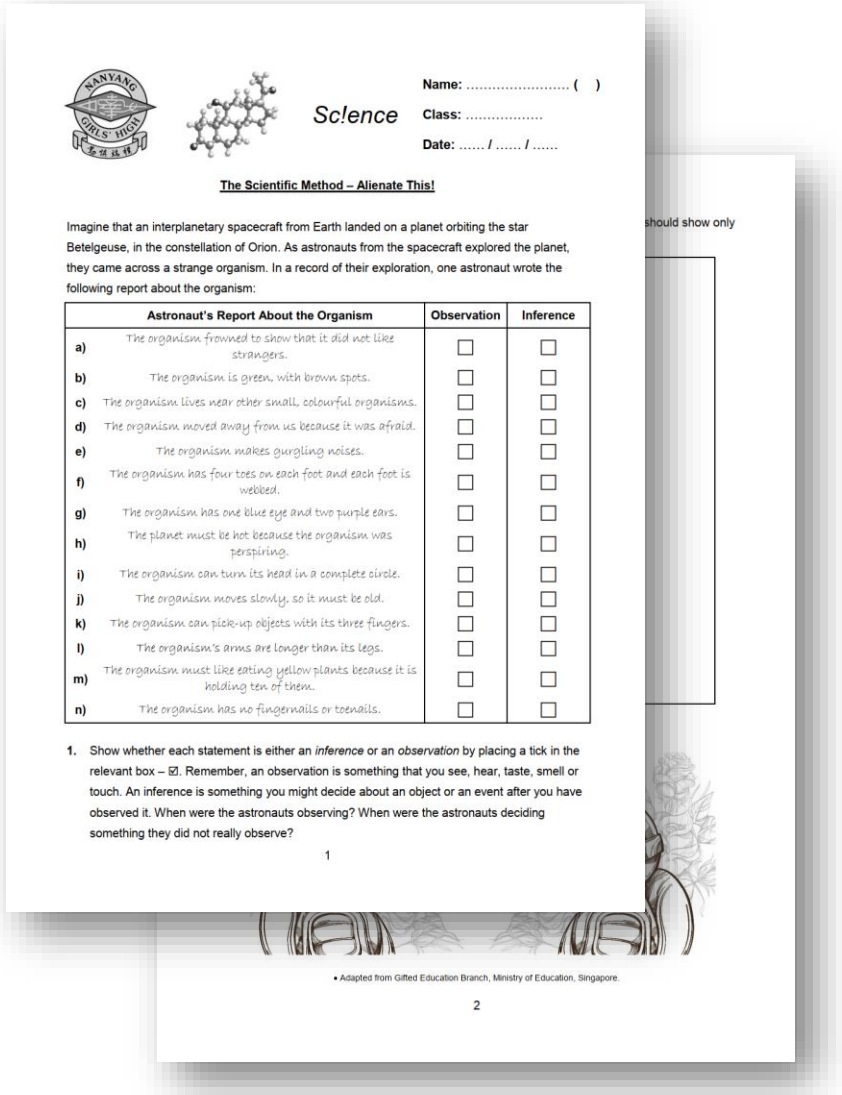
3. Students are then given a fifth piece of card. This is equivalent to a scientist discovering a new piece of data.

4. Students must now arrange the five pieces of card into a square. Can the new piece of data be incorporated into the existing hypothesis?

Teaching the Nature of Science



Teaching the Nature of Science



Sc!ence

Name: ..... ( )
Class: .....
Date: ..... / ..... / .....

The Scientific Method – Alienate This!

Imagine that an interplanetary spacecraft from Earth landed on a planet orbiting the star Betelgeuse, in the constellation of Orion. As astronauts from the spacecraft explored the planet, they came across a strange organism. In a record of their exploration, one astronaut wrote the following report about the organism:

	Astronaut's Report About the Organism	Observation	Inference
a)	The organism frowned to show that it did not like strangers.	☐	☐
b)	The organism is green, with brown spots.	☐	☐
c)	The organism lives near other small, colourful organisms.	☐	☐
d)	The organism moved away from us because it was afraid.	☐	☐
e)	The organism makes gurgling noises.	☐	☐
f)	The organism has four toes on each foot and each foot is webbed.	☐	☐
g)	The organism has one blue eye and two purple ears.	☐	☐
h)	The planet must be hot because the organism was perspiring.	☐	☐
i)	The organism can turn its head in a complete circle.	☐	☐
j)	The organism moves slowly, so it must be old.	☐	☐
k)	The organism can pick-up objects with its three fingers.	☐	☐
l)	The organism's arms are longer than its legs.	☐	☐
m)	The organism must like eating yellow plants because it is holding ten of them.	☐	☐
n)	The organism has no fingernails or toenails.	☐	☐

1. Show whether each statement is either an *inference* or an *observation* by placing a tick in the relevant box – ☑. Remember, an observation is something that you see, hear, taste, smell or touch. An inference is something you might decide about an object or an event after you have observed it. When were the astronauts observing? When were the astronauts deciding something they did not really observe?

1

should show only

• Adapted from Gifted Education Branch, Ministry of Education, Singapore.

2

- An example of a classroom activity #2

1. Students are given an astronaut's description of an alien creature.

2. Students must decide whether the things that the astronaut has written are *observations* or *inferences*.

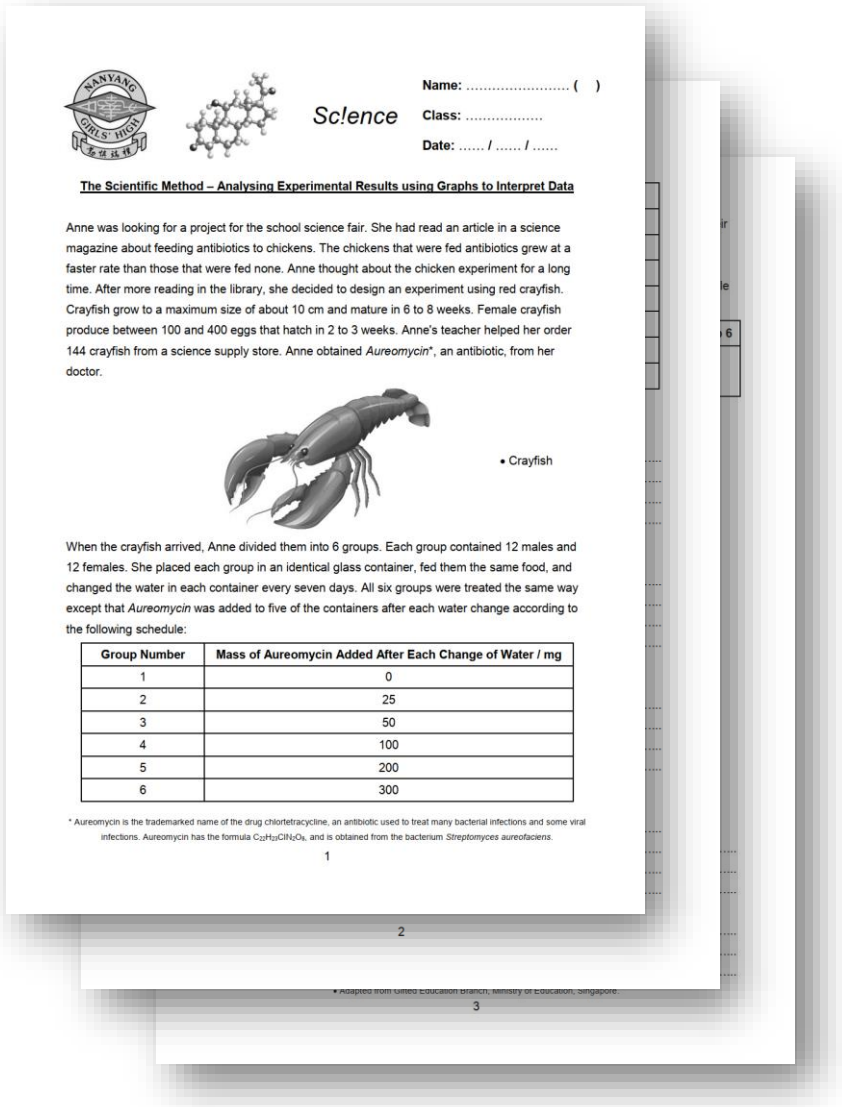
Teaching the Nature of Science

- What can you *observe*?

Teaching the Nature of Science

- What can you *infer*?

Teaching the Nature of Science



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The Scientific Method – Analysing Experimental Results using Graphs to Interpret Data

Anne was looking for a project for the school science fair. She had read an article in a science magazine about feeding antibiotics to chickens. The chickens that were fed antibiotics grew at a faster rate than those that were fed none. Anne thought about the chicken experiment for a long time. After more reading in the library, she decided to design an experiment using red crayfish. Crayfish grow to a maximum size of about 10 cm and mature in 6 to 8 weeks. Female crayfish produce between 100 and 400 eggs that hatch in 2 to 3 weeks. Anne's teacher helped her order 144 crayfish from a science supply store. Anne obtained *Aureomycin**, an antibiotic, from her doctor.

• Crayfish

When the crayfish arrived, Anne divided them into 6 groups. Each group contained 12 males and 12 females. She placed each group in an identical glass container, fed them the same food, and changed the water in each container every seven days. All six groups were treated the same way except that *Aureomycin* was added to five of the containers after each water change according to the following schedule:

Group Number	Mass of Aureomycin Added After Each Change of Water / mg
1	0
2	25
3	50
4	100
5	200
6	300

* Aureomycin is the trademarked name of the drug chlortetracycline, an antibiotic used to treat many bacterial infections and some viral infections. Aureomycin has the formula $C_{22}H_{23}ClN_2O_8$, and is obtained from the bacterium *Streptomyces aureofaciens*.

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• Adapted from Gifted Education Branch, Ministry of Education, Singapore

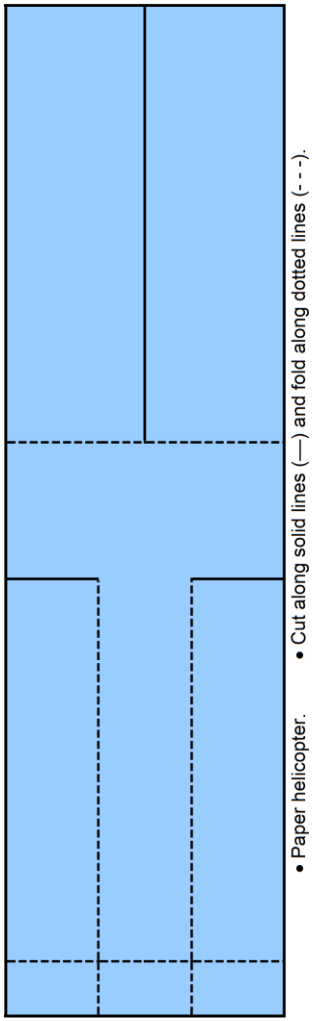
3

- An example of a classroom activity #3

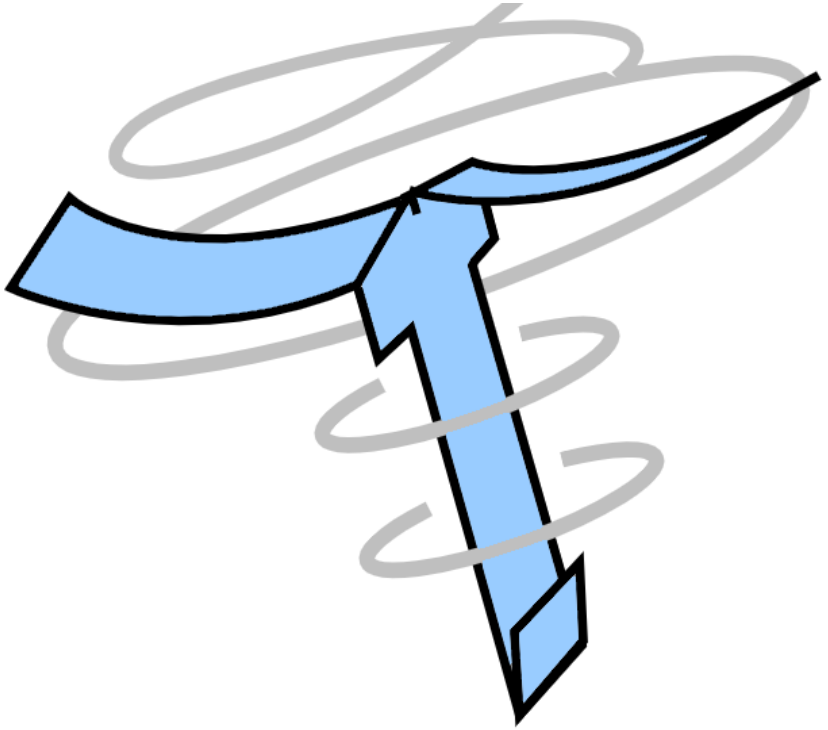
1. Students are given data pertaining to a scientific experiment.

2. Students must interpret the data, identifying variables, plotting graphs and suggest possible errors.

Teaching the Nature of Science

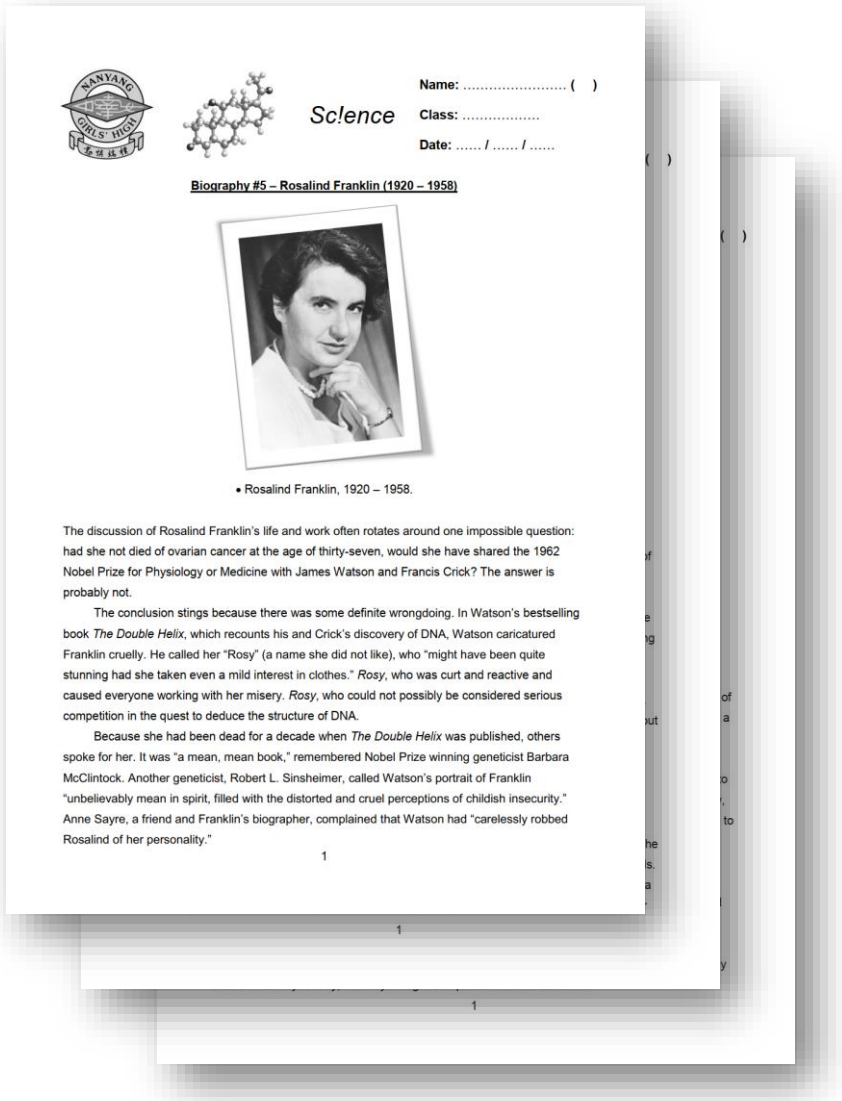


- Investigating variables.



- Paper helicopter experiment.

Teaching the Nature of Science



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Biography #5 – Rosalind Franklin (1920 – 1958)

• Rosalind Franklin, 1920 – 1958.

The discussion of Rosalind Franklin's life and work often rotates around one impossible question: had she not died of ovarian cancer at the age of thirty-seven, would she have shared the 1962 Nobel Prize for Physiology or Medicine with James Watson and Francis Crick? The answer is probably not.

The conclusion stings because there was some definite wrongdoing. In Watson's bestselling book *The Double Helix*, which recounts his and Crick's discovery of DNA, Watson caricatured Franklin cruelly. He called her "Rosy" (a name she did not like), who "might have been quite stunning had she taken even a mild interest in clothes." *Rosy*, who was curt and reactive and caused everyone working with her misery. *Rosy*, who could not possibly be considered serious competition in the quest to deduce the structure of DNA.

Because she had been dead for a decade when *The Double Helix* was published, others spoke for her. It was "a mean, mean book," remembered Nobel Prize winning geneticist Barbara McClintock. Another geneticist, Robert L. Sinsheimer, called Watson's portrait of Franklin "unbelievably mean in spirit, filled with the distorted and cruel perceptions of childish insecurity." Anne Sayre, a friend and Franklin's biographer, complained that Watson had "carelessly robbed Rosalind of her personality."

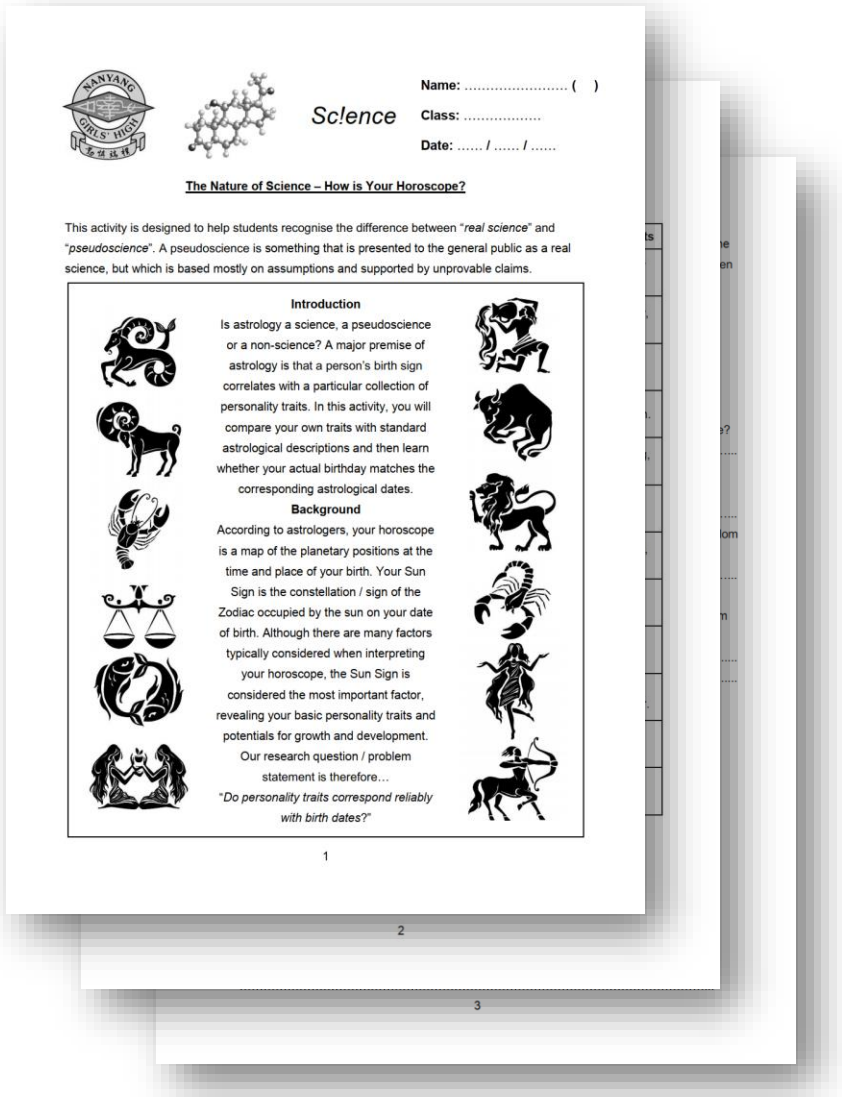
1

- An example of a classroom activity #4

1. Students are given biographies of famous female Scientists to read.

2. With reference to the Habits of Mind cards, students identify certain characteristics in the Scientists' personalities and behaviours.

Teaching the Nature of Science



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The Nature of Science – How is Your Horoscope?

This activity is designed to help students recognise the difference between "*real science*" and "*pseudoscience*". A pseudoscience is something that is presented to the general public as a real science, but which is based mostly on assumptions and supported by unprovable claims.

Introduction

Is astrology a science, a pseudoscience or a non-science? A major premise of astrology is that a person's birth sign correlates with a particular collection of personality traits. In this activity, you will compare your own traits with standard astrological descriptions and then learn whether your actual birthday matches the corresponding astrological dates.

Background

According to astrologers, your horoscope is a map of the planetary positions at the time and place of your birth. Your Sun Sign is the constellation / sign of the Zodiac occupied by the sun on your date of birth. Although there are many factors typically considered when interpreting your horoscope, the Sun Sign is considered the most important factor, revealing your basic personality traits and potentials for growth and development.

Our research question / problem statement is therefore…

"*Do personality traits correspond reliably with birth dates?*"

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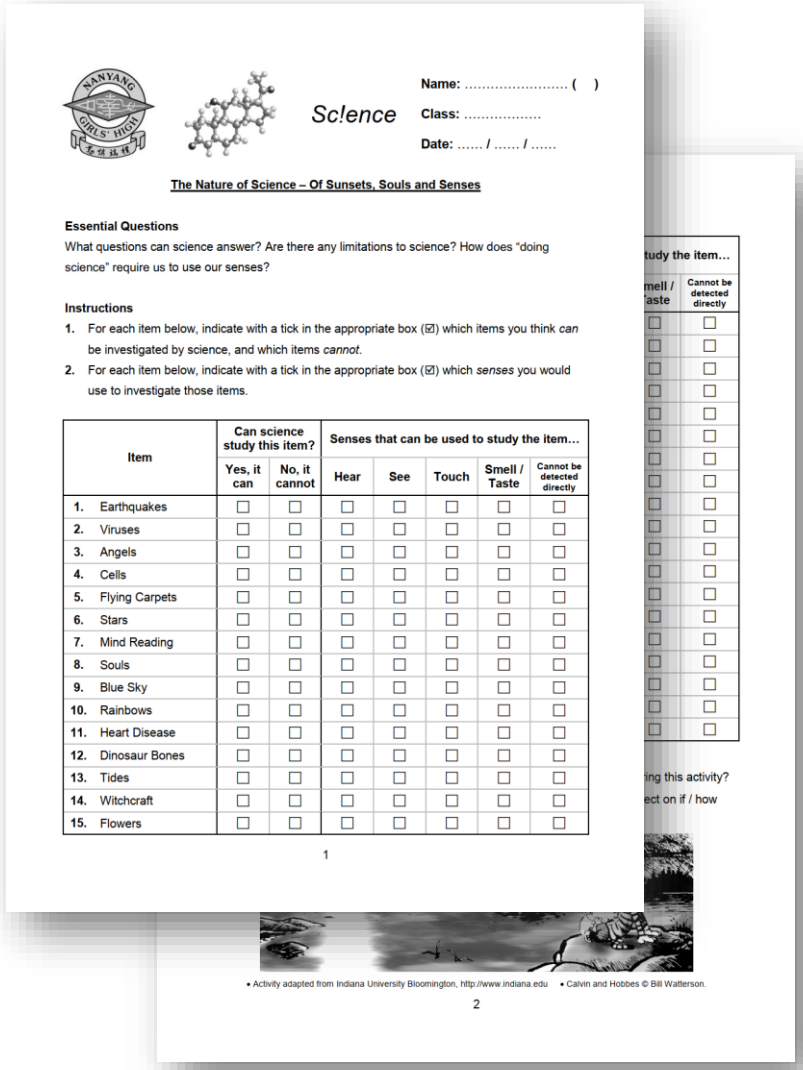
- An example of a classroom activity #5

1. Students engage in an experiment to determine whether astrology is a real Science or a pseudoscience.

Teaching the Nature of Science



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The Nature of Science – Of Sunsets, Souls and Senses

Essential Questions

What questions can science answer? Are there any limitations to science? How does "doing science" require us to use our senses?

Instructions

1. For each item below, indicate with a tick in the appropriate box (☑) which items you think *can* be investigated by science, and which items *cannot*.
2. For each item below, indicate with a tick in the appropriate box (☑) which *senses* you would use to investigate those items.

Item	Can science study this item?		Senses that can be used to study the item…				
	Yes, it can	No, it cannot	Hear	See	Touch	Smell / Taste	Cannot be detected directly
1. Earthquakes	☐	☐	☐	☐	☐	☐	☐
2. Viruses	☐	☐	☐	☐	☐	☐	☐
3. Angels	☐	☐	☐	☐	☐	☐	☐
4. Cells	☐	☐	☐	☐	☐	☐	☐
5. Flying Carpets	☐	☐	☐	☐	☐	☐	☐
6. Stars	☐	☐	☐	☐	☐	☐	☐
7. Mind Reading	☐	☐	☐	☐	☐	☐	☐
8. Souls	☐	☐	☐	☐	☐	☐	☐
9. Blue Sky	☐	☐	☐	☐	☐	☐	☐
10. Rainbows	☐	☐	☐	☐	☐	☐	☐
11. Heart Disease	☐	☐	☐	☐	☐	☐	☐
12. Dinosaur Bones	☐	☐	☐	☐	☐	☐	☐
13. Tides	☐	☐	☐	☐	☐	☐	☐
14. Witchcraft	☐	☐	☐	☐	☐	☐	☐
15. Flowers	☐	☐	☐	☐	☐	☐	☐

1

• Activity adapted from Indiana University Bloomington, http://www.indiana.edu • Calvin and Hobbes © Bill Watterson.

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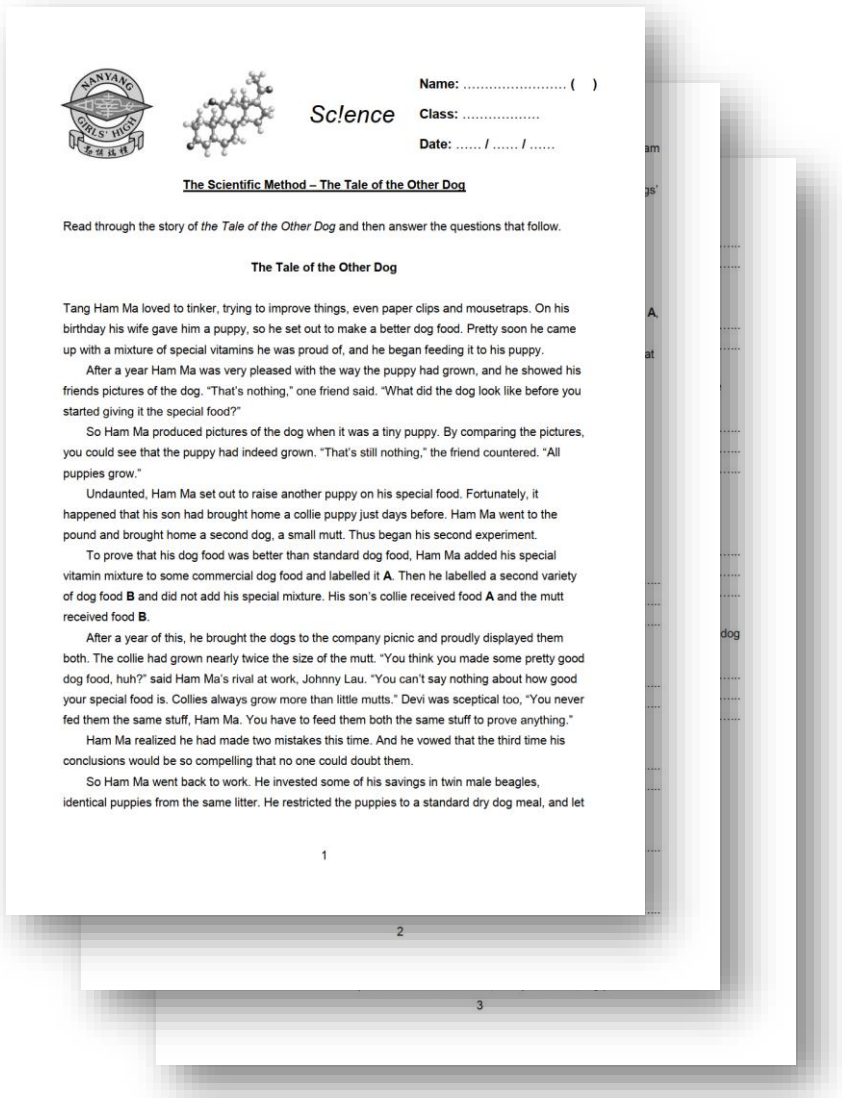
- An example of a classroom activity #6

1. Students suggest what can and what cannot be detected with the five human senses.

Teaching the Nature of Science



Sc!ence

Name: ..... ( )
Class: .....
Date: ..... / ..... / .....

The Scientific Method – The Tale of the Other Dog

Read through the story of *the Tale of the Other Dog* and then answer the questions that follow.

The Tale of the Other Dog

Tang Ham Ma loved to tinker, trying to improve things, even paper clips and mousetraps. On his birthday his wife gave him a puppy, so he set out to make a better dog food. Pretty soon he came up with a mixture of special vitamins he was proud of, and he began feeding it to his puppy.

After a year Ham Ma was very pleased with the way the puppy had grown, and he showed his friends pictures of the dog. "That's nothing," one friend said. "What did the dog look like before you started giving it the special food?"

So Ham Ma produced pictures of the dog when it was a tiny puppy. By comparing the pictures, you could see that the puppy had indeed grown. "That's still nothing," the friend countered. "All puppies grow."

Undaunted, Ham Ma set out to raise another puppy on his special food. Fortunately, it happened that his son had brought home a collie puppy just days before. Ham Ma went to the pound and brought home a second dog, a small mutt. Thus began his second experiment.

To prove that his dog food was better than standard dog food, Ham Ma added his special vitamin mixture to some commercial dog food and labelled it **A**. Then he labelled a second variety of dog food **B** and did not add his special mixture. His son's collie received food **A** and the mutt received food **B**.

After a year of this, he brought the dogs to the company picnic and proudly displayed them both. The collie had grown nearly twice the size of the mutt. "You think you made some pretty good dog food, huh?" said Ham Ma's rival at work, Johnny Lau. "You can't say nothing about how good your special food is. Collies always grow more than little mutts." Devi was sceptical too, "You never fed them the same stuff, Ham Ma. You have to feed them both the same stuff to prove anything."

Ham Ma realized he had made two mistakes this time. And he vowed that the third time his conclusions would be so compelling that no one could doubt them.

So Ham Ma went back to work. He invested some of his savings in twin male beagles, identical puppies from the same litter. He restricted the puppies to a standard dry dog meal, and let

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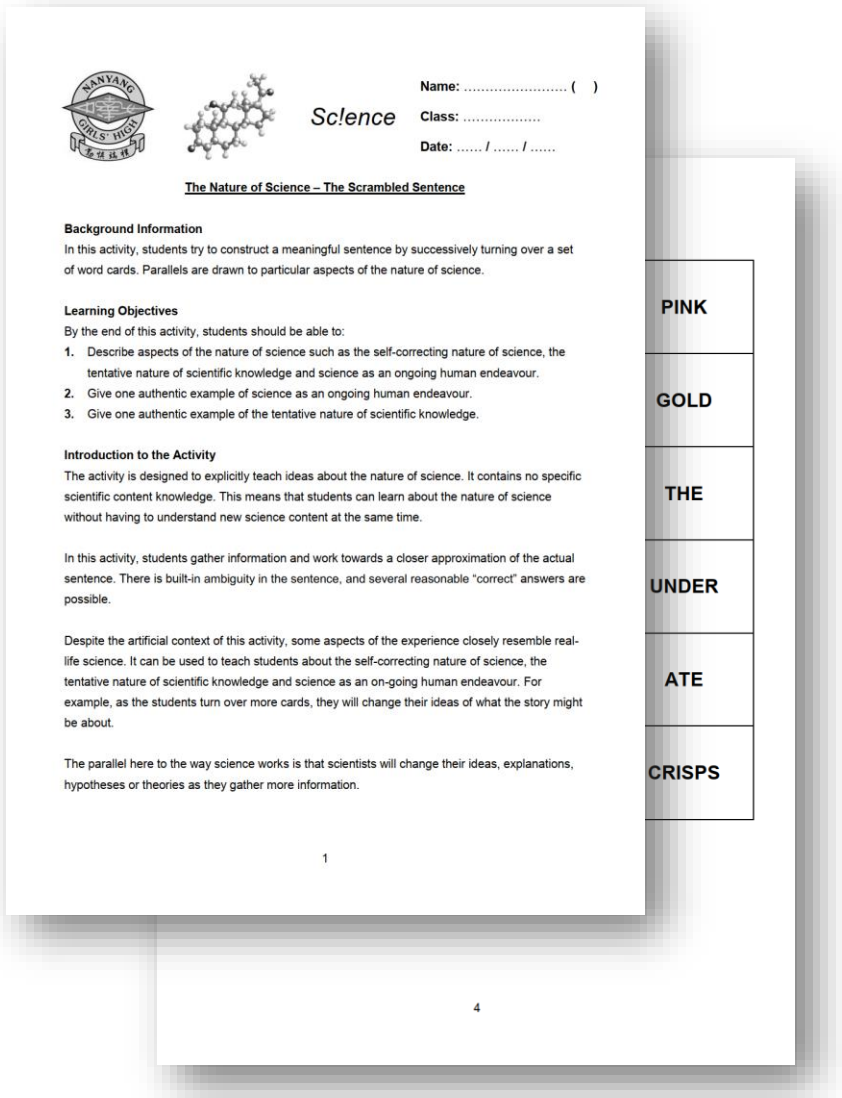
- An example of a classroom activity #7

1. Students are given a story about how a person investigated the way in which diet affected the health of their pet dog.

2. With reference to the scientific method, students critique the person's approach to the investigation.

Teaching the Nature of Science



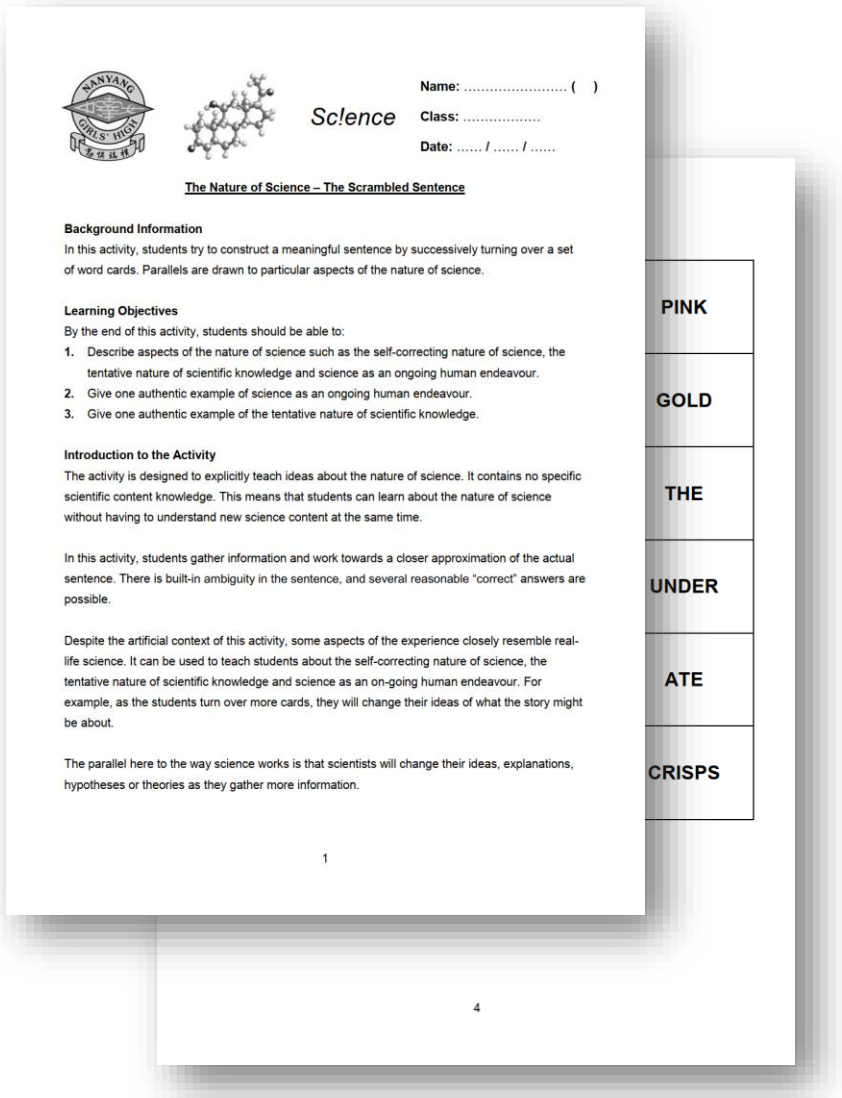
- An example of a classroom activity #8

1. Students are given 25 cards, with a different word written on each card.

2. The cards are placed face down, so that the words cannot be seen.

Teaching the Nature of Science

Teaching the Nature of Science



Sc!ence

Name: ..... ( )
Class: .....
Date: ..... / ..... / .....

The Nature of Science – The Scrambled Sentence

Background Information
In this activity, students try to construct a meaningful sentence by successively turning over a set of word cards. Parallels are drawn to particular aspects of the nature of science.

Learning Objectives
By the end of this activity, students should be able to:
1. Describe aspects of the nature of science such as the self-correcting nature of science, the tentative nature of scientific knowledge and science as an ongoing human endeavour.
2. Give one authentic example of science as an ongoing human endeavour.
3. Give one authentic example of the tentative nature of scientific knowledge.

Introduction to the Activity
The activity is designed to explicitly teach ideas about the nature of science. It contains no specific scientific content knowledge. This means that students can learn about the nature of science without having to understand new science content at the same time.

In this activity, students gather information and work towards a closer approximation of the actual sentence. There is built-in ambiguity in the sentence, and several reasonable "correct" answers are possible.

Despite the artificial context of this activity, some aspects of the experience closely resemble real-life science. It can be used to teach students about the self-correcting nature of science, the tentative nature of scientific knowledge and science as an on-going human endeavour. For example, as the students turn over more cards, they will change their ideas of what the story might be about.

The parallel here to the way science works is that scientists will change their ideas, explanations, hypotheses or theories as they gather more information.

1

PINK
GOLD
THE
UNDER
ATE
CRISPS

4

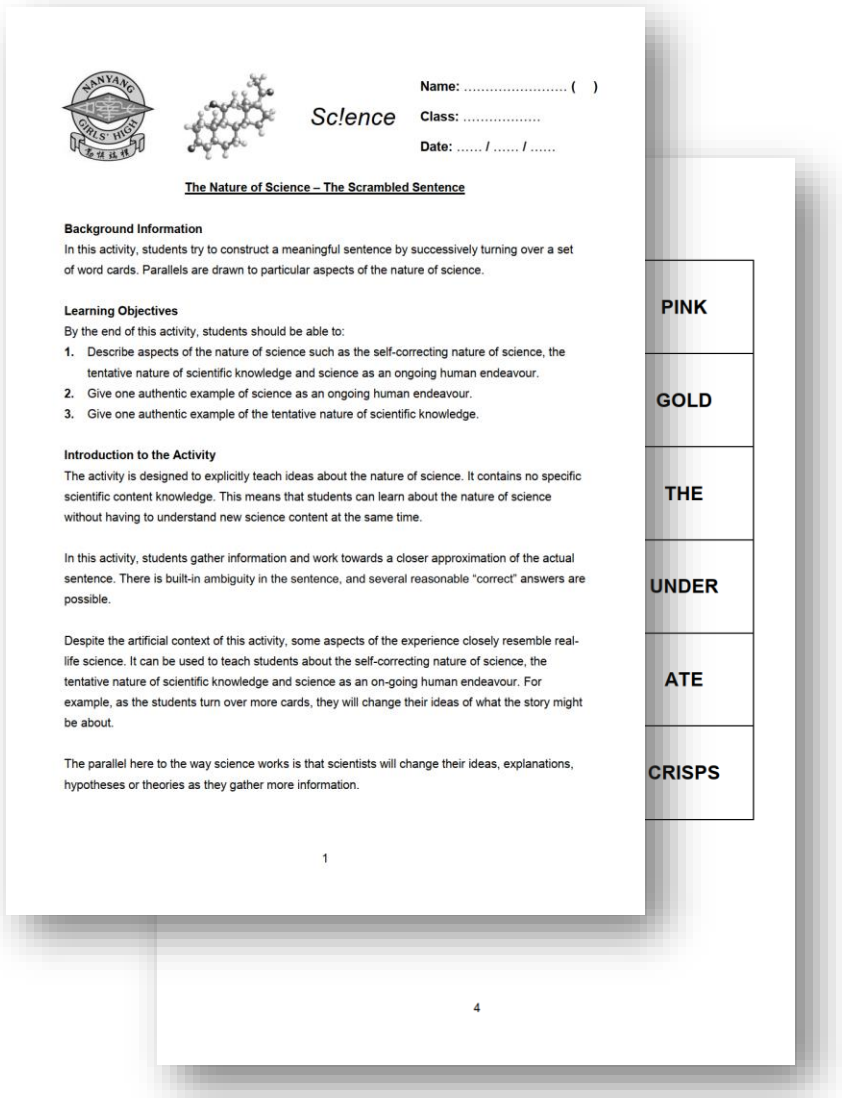
- An example of a classroom activity #8

3. Students turn over five cards and make a sentence out of the words that are revealed.

Teaching the Nature of Science

the		soft	
	tree	and	
			crisps

Teaching the Nature of Science



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Date: ..... / ..... / .....

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1

PINK
GOLD
THE
UNDER
ATE
CRISPS

4

- An example of a classroom activity #8

4. Like discovering a new piece of Scientific evidence, students turn over another five cards and try to incorporate the new words into the sentence. Does the new evidence fit, or must the Scientists come up with a new theory?

Teaching the Nature of Science

the		soft	
flamingo			gold
	jumped		
little			under
	tree	and	
			crisps

Teaching the Nature of Science

the	tall	soft	pink
flamingo	carrying	a	gold
ring	jumped	onto	the
little	wooden	table	under
the	tree	and	ate
the	bowl	of	crisps

Teaching the Nature of Science

Predict, Observe, Explain

- Students are given a scenario, *e.g.* experiment.
- Students predict what will happen.
- Students observe what happens.
- Students reflect, comparing their prediction to the observation to develop an explanation for the phenomenon.

Teaching the Nature of Science

- Students *predict* what will happen when a hard boiled egg is placed on top of a glass milk bottle that contains a piece of burning tissue paper.

Teaching the Nature of Science

- Students *predict* what will happen when a hard boiled egg is placed on top of a glass milk bottle that contains a piece of burning tissue paper.

- Students *observe* what happens when the experiment is allowed to run its course.

Teaching the Nature of Science

- Students *predict* what will happen when a hard boiled egg is placed on top of a glass milk bottle that contains a piece of burning tissue paper.

- Students *observe* what happens when the experiment is allowed to run its course.

- Students *explain* the scientific principles behind what has been observed.

Teaching the Nature of Science

- Students reflect individually about what they have observed, and its scientific explanation.
- Students discuss in small groups and try to arrive at an explanation for the phenomenon.
- Students present their solutions to their peers, who offer constructive criticism where appropriate.

Teaching the Nature of Science

Connect, Extend, Challenge

- Students connect new information to what they already know.
- Students extend / stretch the information and think of the consequences.
- Students reflect on the challenges they faced during their thinking.

Teaching the Nature of Science

Claim, Support, Question

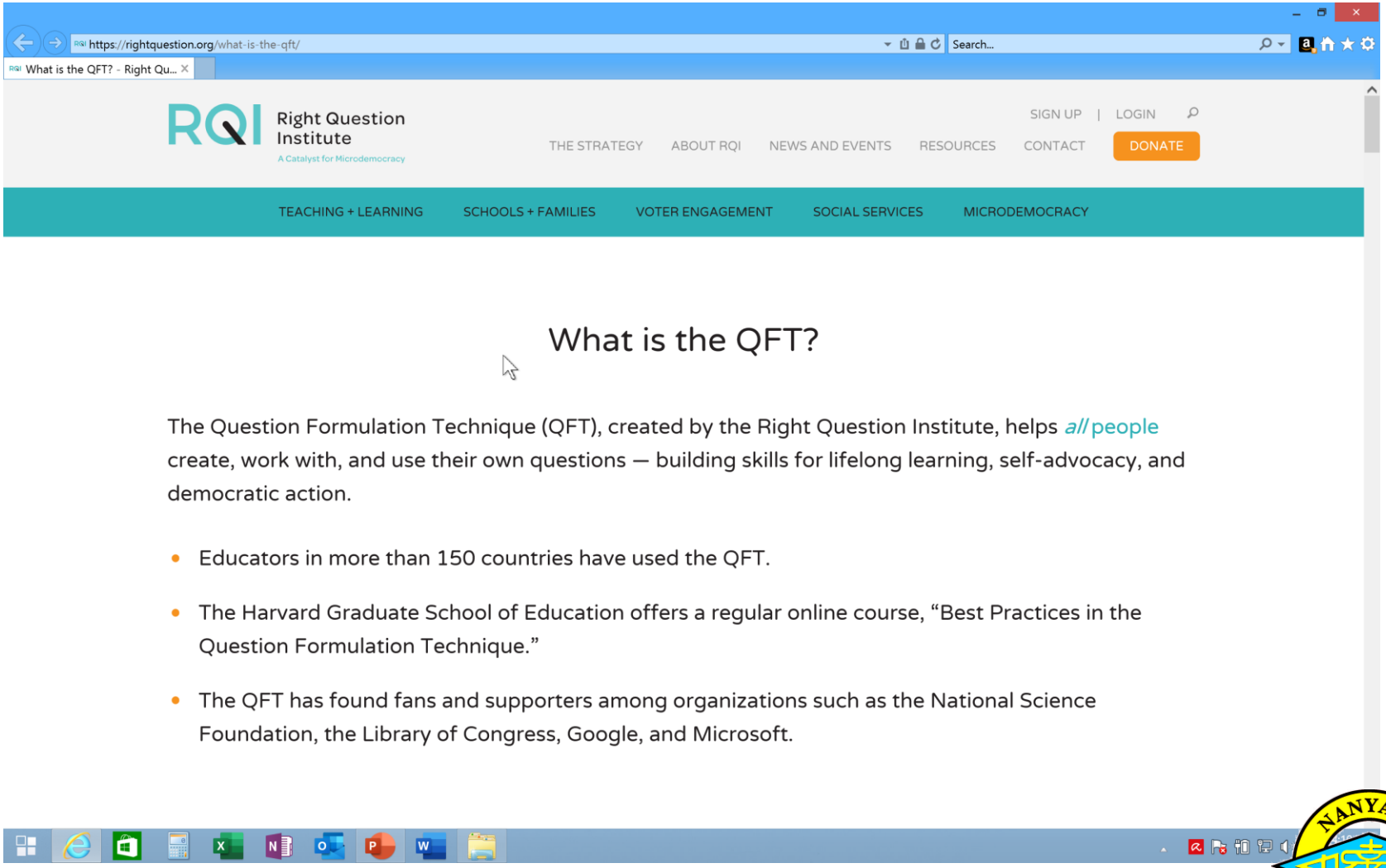
- Claim – What is the hypothesis?
- Support – What is the evidence?
- Question – What new questions arise?

Teaching the Nature of Science

- The Question Formulation Technique

https://rightquestion.org/what-is-the-qft/

Teaching the Nature of Science



Teaching the Nature of Science

Teaching the Nature of Science

In a Nutshell…

- Students should be introduced to the Nature of Science to help them make sense of their studies (disciplinarity) and, in turn, help them to ask the right questions.
- This will benefit students who do not follow careers in Science as they will still have a conceptual understanding of Science that guides their thinking and decision making.
- For non-scientists, knowing facts and formulae may not be useful, but understanding the Nature of Science may benefit their lives.

The Nature of Science – Survey Results

Sec. 1 Students' Responses to Survey

n = 195

Question 1:

I found the Nature of Science lessons interesting and engaging.

Strongly Agree = 65 (33.3%)

Agree = 124 (63.6%)

Disagree = 6 (3.1%)

Strongly Disagree = 0 (0.0%)

The Nature of Science – Survey Results

Sec. 1 Students' Responses to Survey

n = 195

Question 2:

I thought the Nature of Science activities, *e.g.* the Scrambled Sentence, were enjoyable.

Strongly Agree = 98 (50.3%)

Agree = 92 (47.2%)

Disagree = 4 (2.1%)

Strongly Disagree = 1 (0.5%)

The Nature of Science – Survey Results

Sec. 1 Students' Responses to Survey

n = 195

Question 3:

By the end of the Nature of Science unit, I had a better understanding of what Science is, and what Science is not.

Strongly Agree = 71 (36.4%)

Agree = 120 (61.5%)

Disagree = 4 (2.1%)

Strongly Disagree = 0 (0.0%)

The Nature of Science – Survey Results

Sec. 1 Students' Responses to Survey

n = 195

Question 4:

I was challenged to think *critically* during the Nature of Science unit.

Strongly Agree = 63 (32.3%)

Agree = 122 (62.6%)

Disagree = 10 (5.1%)

Strongly Disagree = 0 (0.0%)

The Nature of Science – Survey Results

Sec. 1 Students' Responses to Survey

n = 195

Question 5:

I was challenged to think *creatively* during the Nature of Science unit.

Strongly Agree = 86 (44.1%)

Agree = 101 (51.8%)

Disagree = 8 (4.1%)

Strongly Disagree = 0 (0.0%)

The Nature of Science – Survey Results

Sec. 1 Students' Responses to Survey

n = 195

Question 6:

I was required to cooperate / collaborate with my peers during the Nature of Science unit.

Strongly Agree = 115 (59.0%)

Agree = 79 (40.5%)

Disagree = 1 (0.5%)

Strongly Disagree = 0 (0.0%)

The Nature of Science – Survey Results

Sec. 1 Students' Responses to Survey

n = 195

Question 7:

The pace of the Nature of Science lessons was...

Too fast = 4 (2.1%)

Just right = 180 (92.3%)

Too slow = 11 (5.6%)

The Nature of Science – Survey Results

Sec. 1 Students' Responses to Survey

n = 195

Question 8:

The Nature of Science unit has helped me to recognise that Science is important in my everyday life.

Strongly Agree = 82 (42.1%)

Agree = 110 (56.4%)

Disagree = 3 (1.5%)

Strongly Disagree = 0 (0.0%)

The Nature of Science – Survey Results

Sec. 1 Students' Responses to Survey

n = 195

Question 9:

I understand how a knowledge of Science can help me to make good decisions in my everyday life.

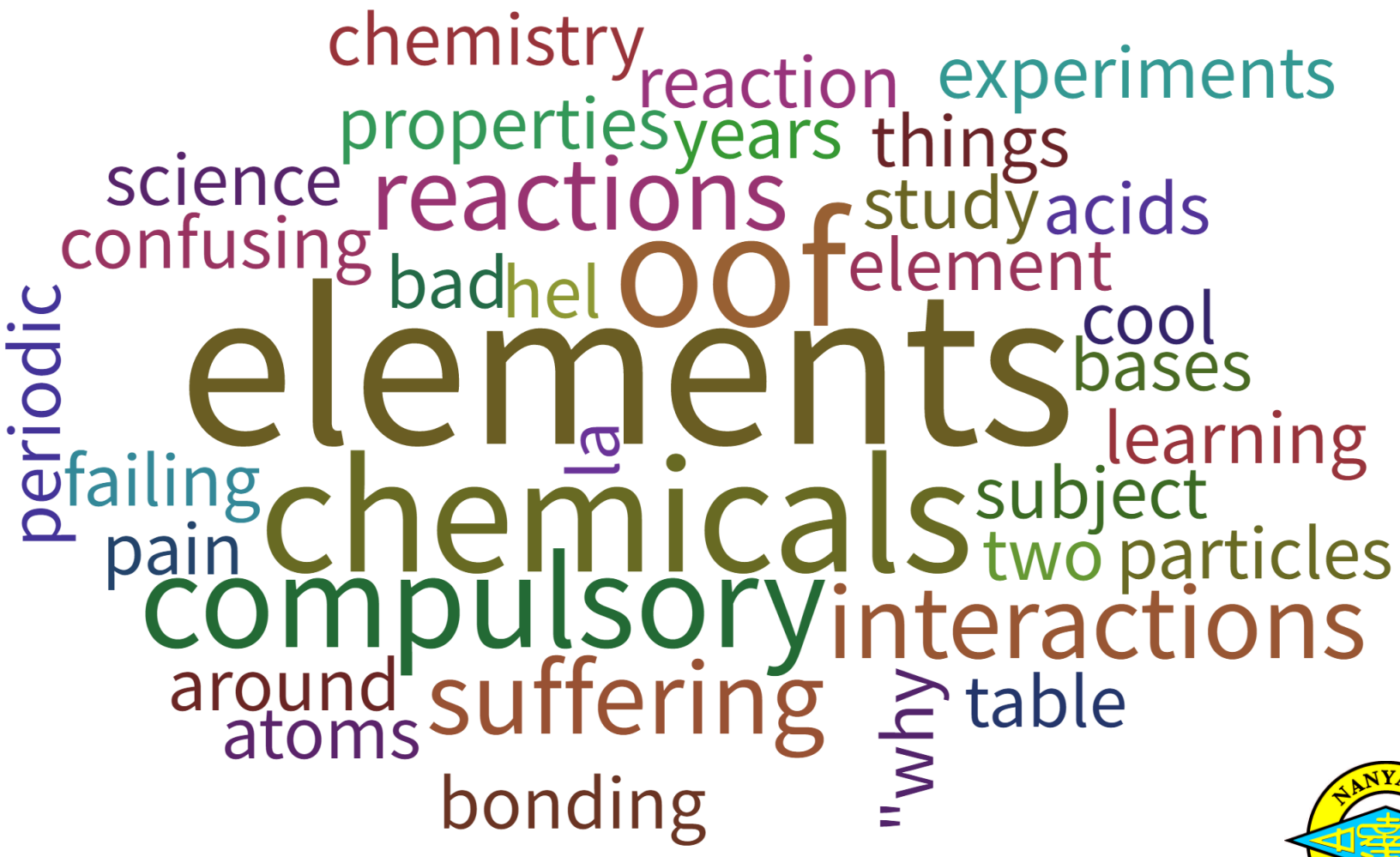
Strongly Agree = 63 (32.3%)

Agree = 127 (65.1%)

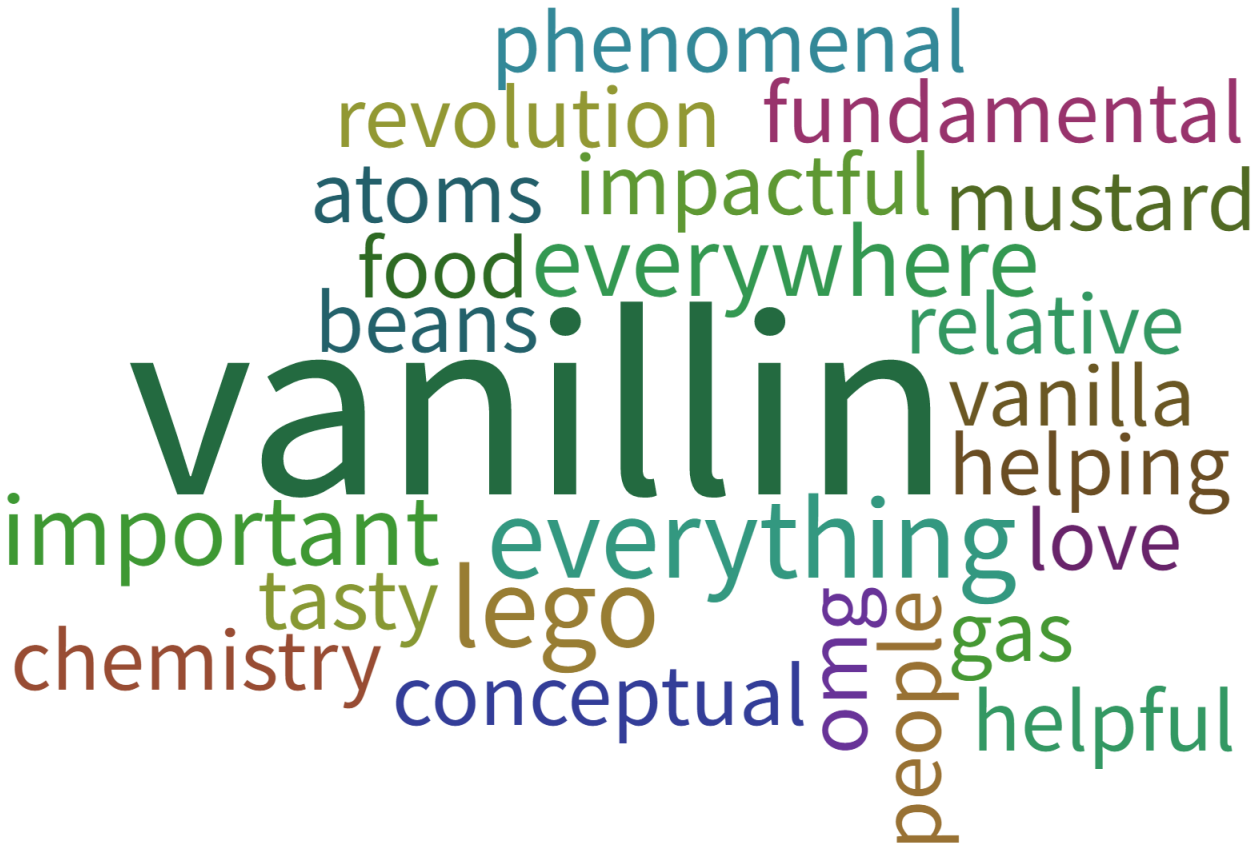
Disagree = 5 (2.6%)

Strongly Disagree = 0 (0.0%)

Teaching the Nature of Chemistry – Before



Teaching the Nature of Chemistry – After



End of presentation.

Thank you for your attention.

What questions do you have?

References

- Fensham, P. J. (2005, December). *Scientific literacy's challenge to chemical education*. Keynote address presented at the 4th Singapore International Chemistry Conference, Singapore.

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References

- All images taken from:

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- Resources adapted from:

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https://en.wikipedia.org

- Documents adapted from Singapore's Ministry of Education's Gifted Education Branch

Presentation on

Asking the Right Questions – The Nature of Science

by Dr. Chris Slatter

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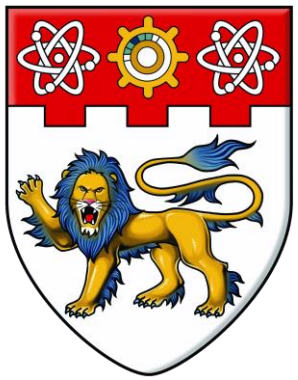
15th June 2021



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