Introducing Biomimicry (UK)

Subtitle: What can we learn from nature's principles for solving design-based challenges?

Summary
This module introduces students to biomimicry through the use of examples, a card sort and an activity where they learn to apply natures principles. This module can sit alone, or in preparation for the 'Big Biomimicry Challenge' or any of the other modules.

Age range: 13-15 years

Duration:
- preparation: varies (10-20 minutes)
- Activity: 30 – 50 minutes per activity. Two activities / lessons are included.

Subject(s):

This learning module can be used flexibly within the curriculum to support key knowledge about Biology, Design Engineering & Technology, and develop working scientifically competences. The learning links with the Sustainable Development Goals and provides a broader context for student learning. It is suitable for adapting as a STEM activity or Eco Club.

Programme of Study Reference	Working Scientifically
Biology: KS4 Ecosystems • some abiotic and biotic factors which affect communities; the importance of interactions between organisms in a community. • organisms are interdependent and are adapted to their environment. • the importance of biodiversity. • methods of identifying species and measuring distribution, frequency and abundance of species within a habitat. KS3 Interactions and interdependencies; Relationships in an ecosystem • the interdependence of organisms in an ecosystem, including food webs and insect pollinated crops. • how organisms affect, and are affected by, their environment, including the accumulation of toxic materials. Genetics and evolution; Inheritance, chromosomes, DNA and genes • differences between species. • the variation between species and between individuals of the same species means some organisms compete more successfully, which can drive natural selection.	Students successfully completing this module will have had the opportunity to access these statements: 1d, 2a, 2b, 2d, 2e, 2f See Annex 1 for full statements.

• changes in the environment may leave individuals within a species, and some entire species, less well adapted to compete successfully and reproduce, which in turn may lead to extinction. Design, Technology and Engineering: KS4 • Design and making principles (links with most areas). KS3 • Design (links with most areas).	

Nature Principles:

- All

Learning Objectives:

- Students are able to define biomimicry and cite examples of nature-inspired design.
- Students are able to apply natural functions to design problems.
- Students are able to discuss the benefits of nature-inspired design for solving problems.

Learning Outcomes:

- Students consider and discuss the merits of a biomimicry approach
- Students understand the application of natural functions to design problems.
- Students consider the natural world in a new way.

BioLearn Competences:

- Students are able to abstract principles of sustainability from the way the natural world functions.
- Students are able to identify functional design in Nature, develop greater awareness and appreciation for design excellence in Nature, and appreciate how nature works as a system which is elegant and deeply interconnected.
- Students are able to identify important needs and opportunities that can be addressed through design innovation for products, processes and systems.
- Students are able to use analogical creativity to innovate, using biological models to inspire solutions to design challenges.
- Students are able to assess the consequences of applying biomimicry solutions (values)
- Students are able to work in groups.

Keywords:
Biomimicry introduction; natural design; functions;

Summary of the activities:

Number	**Activity Name**	**Short description**	**Method**	**Duration**	**Location**

1.	What is Biomimicry?	Introduction to biomimicry – basic principles.	Presentation; discussion; group work; card sort;	30- 50	Indoor
2.	Seed Design Task	Students consider natural functions in a simple design task	Practical; presentation; observation; group work; discussion	50	Both / Either

Outline of the module:

This module takes students through the process of nature-inspired design, incorporating a basic introduction to biomimicry, and a structured set of design tasks, involving individual and group work. The module is designed to stand alone, or as part of a large scheme of work. While many of the concepts are relevant to Design Technology and Biology, the module will also appeal to teachers looking to develop study skills including team work and presentation competences in students. The module can be easily adapted to suit a range of time-allocations, and might be delivered in different arrangements – for example:

1. Lessons 1-2: Introduction to Biomimicry
2. Lessons 1-6: Introduction to Biomimicry + Biomimicry challenge

The module utilises accompanying presentations which contain detailed teaching notes, in order that different teaching staff can deliver each lesson. More straightforward teaching notes are included in this guide under each lesson/activity overview below.

During the lessons, students will become familiar with the terms function and strategy. It is important to be clear about these terms and we offer the following definitions:

<u>Functions:</u> In biomimicry a function refers to an organism's adaptations which help it survive. For example, the purpose of bear fur is to keep warm, in technical terms its function is to conserve heat (insulation). A leaf is made to biodegrade, so one function of a leaf is to 'break down' after use. Human products also have functions; a kettle has the functions to both contain water and heat water (modify its physical state). In brief, a function is 'what it does.'

<u>Strategy:</u> Organisms meet functional needs through biological strategies. This is a characteristic, mechanism or process which performs the function for them. In the bear example, fur is the strategy for delivering insulation. In a kettle, electrical energy is transferred into physical heat which modifies the temperature of water. In brief, a strategy is 'how it does it.'

Health and Safety: Appropriate consideration needs to be given to health and safety when working outdoors, but this should not prohibit regular use of the outdoor learning environment.

For guidance on using the outdoor learning environment review the Council for Learning Outside the Classroom suggestions on Plan and Deliver. CLEAPSS also provides guidance for members. We recommend you read and act on L196 - Managing Risk Assessment in Science. Finally, check your school policy on learning outside the classroom.

The Institute for Outdoor Learning provides a good overview into the risks and benefits of outdoor learning here. They also offer specific guidance and advice for schools here.

Activity Details:

1. What is Biomimicry?

Tools and materials
Pens, Paper, Laptops / Overhead projector

Preparations
Indoor; arrange classroom to suit small group work; projector on with PowerPoint loaded; teacher notes visible

Resources
- PowerPoint presentation (Bullet Train - www.youtube.com/watch?v=YVU6YBPaaB8 and Janine Benyus - https://youtu.be/FBUpnG1G4yQ videos will require internet access)
- W1.1 and W2.1 card sort

Description
This activity is designed to introduce the concept of biomimicry to a group ahead of students embarking on a design challenge. It can be delivered together with activity 2, which is an introductory nature design-thinking challenge. During this lesson, students will learn about biomimicry: what it is, how it can be used as inspiration for problem solving, and consider examples of biomimicry. Students will work as a small team through this activity.

1.1. **Videos** (10 minutes including discussion)

Bullet Train Video (duration 1:30) – slide 5

Students watch BBC video about the development of the bullet train inspired by the kingfisher's bill. This is an example of biomimicry. Following the video, you can provide the students with a definition of biomimicry as stated in the accompanying PowerPoint. You might ask students to come up with their own definition after watching the video, and asking them to share with one another, if time permits).
https://www.youtube.com/watch?v=YVU6YBPaaB8

Janine Benyus Video (duration 2 minutes) – slides 6-7

This video gives a short explanation of what biomimicry is by its founding advocate Janine Benyus
https://youtu.be/FBUpnG1G4yQ

1.2. **Thinking activity** (10 minutes) – slides 9-10

Provide students with the examples of how nature has inspired design (W1.1). Ask them to consider in small groups how this might have helped with human design problems.

1.3. **Card Sort – see W1.2** (20 minutes) – slides 11-16

Now that students have had a chance to think about each aspect of nature, they can have a go at the card sort in pairs.

<u>Instructions:</u>

1) Students are given card sort and lay them out on the table. They then separate out cards into **two** piles:
   a) Green Challenge picture cards (these represent an aspect of nature). **NB. Make sure that they keep the Challenge sides facing upwards and the 'Nature's strategy' side facing down.**
   b) Brown picture cards (these represent a technology that imitates nature)
2) Students pick up a Green Challenge picture card and read through the challenge questions with their partner. **Prompt to discuss thoughts on the challenge question with partner.**
3) Next, they look at the brown picture cards and choose one that they think shows a human invention that imitates that aspect of nature.
4) Once students are confident in their choice and have discussed reasons with their partner, they turn over the challenge card and read the information on the back. This will tell them about how this technology was inspired by nature to overcome a problem.
5) Repeat steps 2 -4 with the other challenge cards in turn until all challenge cards have a matching imitation card.

As an extension to this activity (c.15 minutes), students can watch the accompanying videos for each of these examples, in the PowerPoint. There are detailed teaching notes for each of the examples in the PowerPoint slides.

1.4. **Group Assessment** (5 minutes)

Students complete the success criteria for the lesson.

2. **Seed Design Task** (20-25 mins) – slide 19

Tools and materials
- Paper and pens (for group work)
- Maple/Sycamore seed (one per student ideally); if maple/sycamore seeds are not easily available, use a video reference (see www.youtube.com/watch?v=HlK_Dfo6hq8 or link in PowerPoint).

Preparations
Arrange the room for small group work. Each table should have a pot of maple seeds, pens and paper. This activity can take place indoors or outside.

Resources
Accompanying PowerPoint; maple seeds; pens; paper; printed copies for each group of the W2.1 – observation sheet, and W2.2 – nine biomimicry principles.

Description
This activity follows on from the introduction activity (Activity 1) and provides students with a hands-on activity to encourage them to think about how functions in nature can be used as inspiration for solving human design challenges. The activity is very simple, and is not designed so that each student / group comes up with a different approach. Rather, it is to guide them through a particular method of problem solving which can be utilized in other biomimicry lessons.

2.1. **Think-Pair-Share** (8 mins) – slide 20

Ask students to recap on the previous activity and discuss in pairs 'what is biomimicry?' Ask them to describe two examples of biomimicry and how it has led to innovation. Feedback selectively if time.

2.2. **Biomimicry principles** (5 mins) – slide 21

Show the students the 9 principles of biomimicry. The accompanying worksheet (W2.2) can be given out (or viewed online) also.

2.3. **What can we learn from a seed?** (5-10 mins) – slides 22-23

- Give each group one sycamore seed- *Be careful not to damage the seed*
- Students spend 5 minutes playing around with it and analysing its movement and structure in as much detail as possible.
    - Examine the seed structure in detail
    - Throw it in the air
    - Look at how it flies – what allows it to move like this?
- As students are doing this, ask them to think about why the seed has these features.

2.4. **Seed Observations** (10 mins) – slides 24-25

Students work in pairs to fill in the attached worksheet (W2.1) – they are required to observe the seed closely to consider its structure and function. This activity is designed to encourage the students to think about how nature is well suited to a variety of tasks. The key here is getting the students to think about the function of the seed to serve a purpose (i.e. to fall slowly, to rotate, be aerodynamic), and then thinking about how we might *copy* these functions to solve design challenges.

Some examples of how the design and function of the seed has been applied:
Provide students with a few examples of how the design and the function of the seed can be seen in human designs e.g. pumping and electricity generation.

2.5. **Mini-Design Challenge** (15 mins) – slide 26

Using observations of how the maple seed flies as inspiration, in groups of 2 or 3 the task is to design a new system to prevent Torquay Seafront (*adapt to location) from flooding.

Encourage students to think about how they might be able to drain water from the town centre, pump it away or adjust the path of the water. Can your students incorporate a way of reducing the risk of flooding in the first place?

The purpose of this is to get students to consider how looking to nature's designs can help to prompt us to think and see differently, applying the ingenuity of the seed to a human design problem.

Students can draw their design and label it with functions as observed in the previous activity making use of the 9 principles of biomimicry already given out to assess their design (W2.2).

Ask the students to consider how their design performs against the biomimicry principles – are there any which it is particularly strong at; are there any which are weak?

Extension activity – can students figure out a way electricity could be generated as a result of their design?

2.6. **Group Assessment** (5 mins) – slide 27

Students complete the success criteria for the lesson.

2.7. **Extensions** – slide 28

If time, finish with a class discussion, with students sharing their designs and how the maple seed inspired them.

Literature, additional information

Below are a range of useful website links and book references.

WEBSITES

Ask Nature – https://asknature.org/
The key resource for exploring biomimicry examples; a rich resource to delve in to. Their resources area (https://asknature.org/?s=&p=0&hFR%5Bpost_type_label%5D%5B0%5D=Resources) offers teaching resources, videos and articles to explore.

Biomimicry Toolbox - https://toolbox.biomimicry.org/
Great resources explaining the core concepts of biomimicry and a step-by-step approach to applying a biomimicry approach to design.

Packaging Innovation Toolkit - https://synapse.bio/blog/2017/10/11/biomimicry-packaging-innovation-toolkit
Resources to expand ideas around packaging based on biomimicry thinking.

Genius of Place – https://synapse.bio/blog/ultimate-guide-to-genius-of-place
In the Genius of Place process, biomimics look to native organisms and ecosystems to provide guidance, models, and metrics for how to be generous and resilient as we design for a particular place.

BOOKS & JOURNALS

Biomimicry Resource Handbook
The key resource for biomimicry thinking, processes and applications. A huge amount of information and ideas; expensive but well worth it.

Baumeister, Dayna (2014). Biomimicry Resource Handbook 2014: A Seed Bank of Best Practices. Biomimicry 3.8.

Biomimicry: Innovation Inspired by Nature
The book by Janine Benyus which first brought biomimicry to wide attention. Lots of good examples to use and descriptions of the nine principles of biomimicry.

Benyus, Janine (2002). Biomimicry: Innovation Inspired by Nature. HarperCollins.

Zygote Quarterly
Showcases examples of science, technology and creativity in the field of biologically inspired design.

https://biomimicry.org/zygote-quarterly/

Student worksheets

W1.1

Take a look at these species. Each has inspired a human invention…can you guess which one it is?

W1.2 (please see separate file for printable sets of cards)

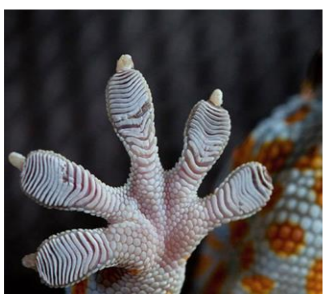
Fold & glue

Nature's strategy to meet the challenge:

The Kingfisher dives from the air (low drag) into rivers to catch fish, creating very little splash as it enters to water (high drag). It achieves this due to its streamlined beak which steadily increases from tip to head. Engineers mimicked this on the train and found it not only removed the boom, but also saved 10-15% more energy by being more aerodynamic.

Challenge 1:

Japanese Bullet trains travel so fast they produce a loud boom when they exit tunnels caused by a cushion of air building up in front of the train. This cushion of air slows them down. How does the Kingfisher transition between different environments and how has it helped to inspire the new design of Bullet train?



Nature's strategy to meet the challenge:

Geckos adhere (stick) to vertical surfaces using millions of tiny setae (microscopic hairs) on their feet. Unlike glue they leave no residue behind. Gecko tape mimics the concept of Gecko feet using millions of synthetic fibers which replicate the function of these setae (hairs). Used appropriately, these can provide enough attractive force to hold the weight of a human!

Challenge 2:

We want things to stick together tightly yet come apart easily and readily; seemingly an impossible challenge.
Q: How can we use nature to help us design a material that holds two surfaces strongly together, yet allows them to detach easily?

Fold & glue

Nature's strategy to meet the challenge:

Lotus leaves stay clean without detergents. The plant's cuticle is extremely water repellent. This is accomplished through microscopic bumps on their leaf surface. This reduces the stickiness of water droplets to the surface so they run off easily and take dirt away at the same time.

This is now being mimicked in self cleaning paints and glass. Clever stuff!

Challenge 3:

Newly painted buildings quickly get dirty, requiring time and effort to clean them. How does nature keep surfaces clean? How could we learn from this?

Nature's strategy to meet the challenge:

The Burdock seed has tiny hook-tipped burrs. As an animal brushes past, the hooks connect with the animal's fur and the seed detaches from the plant; it is then carried to a new location and will eventually drop off the fur and into a new environment where it can grow.

Observing this inspired the creation of Velcro which is commonly used in clothing, tents and work equipment where two pieces are material need to be regularly sealed and unsealed.

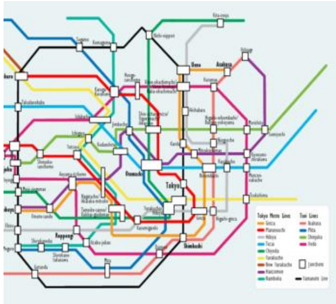
Challenge 4:

How could we connect two things quickly and easily, yet in a way that they could also be taken apart just as quickly? How would nature attach things together in this way?

Fold & glue

Nature's strategy to meet the challenge:

Slime mould grows in patterns which efficiently find the quickest route to food sources.
Using oat seeds to represent neighbourhoods in Tokyo, scientists observed how over a number of days the slime mould created a network of connecting "nutrient-tunnels" which closely replicated the Tokyo rail system.



Challenge 5:

Working out the most efficient* way to connect a large number of different points requires huge computing power. There are lots of examples in nature where this happens naturally. What is nature's elegant solution?
(*achieving maximum productivity with minimum wasted effort or expense)

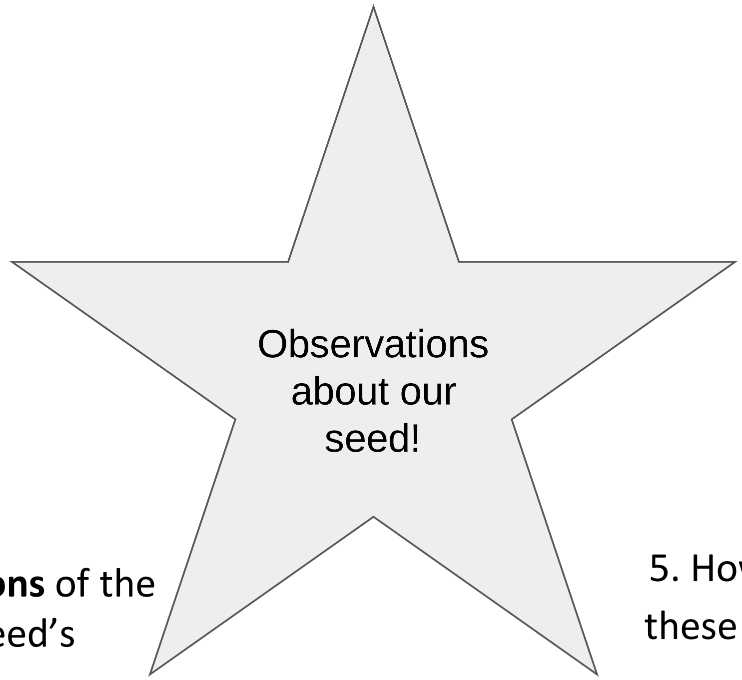
Image references:

Kingfisher – Creative Commons from www.pexels.com.
Bullet train – Creative Commons from www.pexels.com.
Gecko foot - This Photo by Unknown Author is licensed under CC BY-NC-ND.
Gecko tape – Richard Dawson.
Lotus leaf - This Photo by Unknown Author is licensed under CC BY-SA.
Paint roller – Creative Commons from www.pexels.com.
Burdock - This Photo by Unknown Author is licensed under CC BY-SA.
Velcro - This Photo by Unknown Author is licensed under CC BY-SA-NC.
Slime mould - This Photo by Unknown Author is licensed under CC BY-SA-NC.
Transport map - This Photo by Unknown Author is licensed under CC BY-SA.

Can you make some observations about your seed?
Use the prompt questions below to help you.

1. Describe its **structure** (e.g. shape/ size/weight)

2. What do you notice about the fine details of the seed (when you look really closely)



3. What are the **functions** of the seed (e.g.what is the seed's purpose?)

4. Describe its **movement** when you drop it from above your head

5. How might we be able to use these functions to solve real-life challenges?

W2.2: What is Biomimicry? Introducing the principles.

Janine Benyus describes biomimicry as “learning to live gracefully on this planet by consciously emulating life’s genius. It’s not really technology or biology; it’s the technology of biology. It’s making a fibre like a spider, or lassoing the sun’s energy like a leaf.” Designing for sustainability is also important to biomimicry thinking. It’s this kind of thinking that’s inspired some remarkable designs in recent decades, including a Japanese bullet train partially modelled after the aerodynamics of the kingfisher bird; a shopping center in Harare, Zimbabwe that mimics the cooling strategies of a termite mound; and a synthetic surface called Sharklet that inhibits bacterial growth through texture alone, inspired by the bacteria-repellent skin of a shark.

Here are the **nine Basic Principles of Biomimicry** that we are working with. They are very simple, but once you unpack them you discover they lead everywhere. It is possible to use these principles as starting points for design, or as a way of checking our design work and then making improvements.

<u>Nature runs on sunlight:</u>
Nature uses sunlight as the main source of energy. Organisms use heat and UV radiation from this never-ending source. We can say that nature is powered by sunshine. Humans use fossil fuels, these sources are not renewable, and burning them creates CO_2 which is one of the gases causing climate change. Why don’t we do the same and prevent the climate crisis? A wise person would mimic nature and rely on renewable power.

<u>Nature uses only the energy it needs:</u>
Nature takes only what it needs. Why do we not do the same? Our economy is focused on maximizing output and is a big energy consumer. We transport food around the world because that is economically cheaper. Only money seems to count in a lot of decisions, not energy consumption and impact on the natural world. How can we learn to optimize the performance of goods and services to sip energy rather than gulp it?

<u>Nature fits form to function:</u>
A tree is rooted in the ground to draw water and nutrients from the soil; it spreads its branches and leaves wide to increase surface area and absorb sunlight to produce energy and grow. Seeds are lightweight and some even come equipped with a sort of umbrella so they can float in the air. Nature creates designs for the function they provide, so should our buildings, transportation systems and schools.

<u>Nature recycles everything:</u>
There is no ‘away’ to throw things. Everything produced in nature is biodegradable, there is no waste. There can still be abundance, look at all the blossom on a cherry tree; but that all serves a purpose and will be food and nutrients for others. Once the natural life of a pinecone has come and gone, it breaks down into essential elements that are repurposed into new life.

<u>Nature rewards cooperation:</u>
We see competition in nature, but only when it is impossible to avoid; in general competition costs too much energy. On the other hand, very little in nature exists in isolation. Plants cooperate with pollinators to disperse seeds, and the pollinators feed on nectar. Ladybirds feed on aphids and help plants to stay healthy. Nature favours cooperation because it maintains the health of the whole system.

<u>Nature banks on diversity:</u>
Diversity is one of nature’s best insurance policies. When one food source is unavailable, others can be found. Plants use several different strategies to spread seed or defend against predators. We know that species with limited genetic diversity have more difficulty adapting to environmental change, and that ecosystems rich with diversity are more stable.

<u>Nature demands local expertise:</u>
Nature’s systems are inherently local. Certain species thrive under specific conditions; local and regional weather patterns matter, as do other conditions such as soil, air quality and water temperature. Relationships are created locally and local resources are used. Of course, some birds travel long distances but have you seen them take their food with them?

<u>Nature seeks balance:</u>
Ecosystems try to keep in balance. More mice? Then you will see more owls to feed on the mice and keep the population in balance. Forest fires are a great example of a natural phenomenon that renews and refreshes, reducing excessive growth and allowing for regeneration. Every natural system has a tipping point, a carrying capacity or a state of disequilibrium that triggers a change to a different state.

<u>Nature taps the power of limits:</u>
Unlimited growth on a finite earth is not a good idea. All living things are governed by limitations; age, climate, population density and many other factors determine how species and systems develop. Nature has found ingenious ways to work within these limits to be as productive as possible over the long run.

Annex 1 – Key Stage 4 Working Scientifically Statements

Through the content across all three disciplines, students should be taught so that they develop understanding and first-hand experience of:

1. **The development of scientific thinking**
   a. the ways in which scientific methods and theories develop over time
   b. using a variety of concepts and models to develop scientific explanations and understanding
   c. appreciating the power and limitations of science and considering ethical issues which may arise
   d. explaining everyday and technological applications of science; evaluating associated personal, social, economic and environmental implications; and making decisions based on the evaluation of evidence and arguments
   e. evaluating risks both in practical science and the wider societal context, including perception of risk
   f. recognising the importance of peer review of results and of communication of results to a range of audiences

2. **Experimental skills and strategies**
   a. using scientific theories and explanations to develop hypotheses
   b. planning experiments to make observations, test hypotheses or explore phenomena
   c. applying a knowledge of a range of techniques, apparatus, and materials to select those appropriate both for fieldwork and for experiments
   d. carrying out experiments appropriately, having due regard to the correct manipulation of apparatus, the accuracy of measurements and health and safety considerations
   e. recognising when to apply a knowledge of sampling techniques to ensure any samples collected are representative
   f. making and recording observations and measurements using a range of apparatus and methods
   g. evaluating methods and suggesting possible improvements and further investigations

3. **Analysis and evaluation**
   a. applying the cycle of collecting, presenting and analysing data, including:
      i. presenting observations and other data using appropriate methods
      ii. translating data from one form to another
      iii. carrying out and representing mathematical and statistical analysis
      iv. representing distributions of results and making estimations of uncertainty
      v. interpreting observations and other data, including identifying patterns and trends, making inferences and drawing conclusions
      vi. presenting reasoned explanations, including relating data to hypotheses
      vii. being objective, evaluating data in terms of accuracy, precision, repeatability and reproducibility and identifying potential sources of random and systematic error
   b. communicating the scientific rationale for investigations, including the methods used, the findings and reasoned conclusions, using paper-based and electronic reports and presentations

4. **Vocabulary, units, symbols and nomenclature**
   a. developing their use of scientific vocabulary and nomenclature

b. recognising the importance of scientific quantities and understanding how they are determined
c. using SI units and IUPAC chemical nomenclature unless inappropriate
d. using prefixes and powers of ten for orders of magnitude (e.g. tera, giga, mega, kilo, centi, milli, micro and nano)
e. interconverting units
f. using an appropriate number of significant figures in calculations