THE NATURAL ECONOMY

How does nature manufacture materials?

AGE RANGE

12–15

DURATION

Preparation:
Varies (10–20 minutes per activity); Activity 1 requires pre-planning and the purchase of equipment.

Activity:
30–40 minutes per activity (four activities in total).

KEYWORDS

Biofabrication; circular economy; mycelium.

SUMMARY

In the natural world, all materials are made using resources found locally; organisms do this at room temperature and pressure. Once materials are done with, they biodegrade back to their base elements. Humans do things differently. They dig up minerals, using high temperatures and pressures to turn them into useful materials. These are often thrown away after use and cannot easily be reused. We could say that nature produces materials using a circular economy, whereas humans have a linear economy. This module explores how we can learn from nature to produce the materials we need sustainably.

BIOMIMICRY PRINCIPLES

1 – Nature runs on sunlight
2 – Nature uses only the energy it needs
3 – Nature fits form to function
4 – Nature recycles everything
5 – Nature rewards cooperation
6 – Nature banks on diversity
7 – Nature demands local expertise
8 – Nature seeks balance
9 – Nature taps the power of limits

LEARNING OBJECTIVES

- Students can apply biomimicry principles in a design.
- Students are able to rethink how products are made.
- Students understand how nature can be mimicked in human design.
- Students understand how biomimicry principles can be applied.

LEARNING OUTCOMES

- Students investigate the impacts of human designed products.
- Students ask questions and research answers.
- Students explore how nature creates materials.
- Students create a product based on biomimicry principles and evaluate it.
- Students present their results.

SUBJECT(S)

This learning module can be used flexibly within the curriculum to support key knowledge about Biology, Physics, Chemistry, 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 • organisms are interdependent and are adapted to their environment • positive and negative human interactions with ecosystems. KS3 Relationships in an ecosystem • how organisms affect, and are affected by, their environment, including the accumulation of toxic materials. **Physics:** KS3 Energy changes and transfers • heating and thermal equilibrium: temperature difference between two objects leading to energy transfer from the hotter to the cooler one, through contact (conduction) or radiation; such transfers tending to reduce the temperature difference: use of insulators. KS4 Energy • energy changes in a system involving heating, doing work using forces, or doing work using an electric current: calculating the stored energies and energy changes involved. • conservation of energy in a closed system, dissipation. • calculating energy efficiency for any energy transfers. • renewable and non-renewable energy sources used on Earth, changes in how these are used. **Chemistry:** KS4 Chemical and allied industries • life cycle assessment and recycling to assess environmental impacts associated with all the stages of a product's life • the viability of recycling of certain materials. **Design, Technology and Engineering:** KS4 • Technical principles (links with most areas). • Design and making principles (links with most areas). KS3 • Design, Make, Evaluate (links with most areas).	Students successfully completing this module will have had the opportunity to access these statements: **1d, 2a, 2b, 2c, 2d, 2e, 2f, 3ai, 3av, 3avi, 3avii, 3b**. See Annex 1 for full statements.

BIOLEARN COMPETENCES

- 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 assess the consequences of applying biomimicry solutions (values).
- Students are more motivated in learning STEAM and experience that knowledge of STEAM can be widely used.
- Students become more familiar with professions and research topics that relate to nature-inspired sustainability and technological innovation, which can inform their choices in post-secondary education and careers.

SUMMARY OF THE ACTIVITIES

	Activity Name	Description	Method	Duration	Location
1	Grown to be grown again	Students use mycelium to grow a product	• Practical experiment	2 x 40 plus time for mycelium to grow	Indoor
2	Is this the future?	Students research new and emerging applications for biofabrication	• Group work	40	Indoor
3	If nature is the solution, what is the problem?	Students interrogate a short video to understand why change is necessary	• Group work	30	Indoor
4	Changing to a circular economy	Students consider why packaging is a problem and what the root causes might be	• Group discussion	40	Indoor

BACKGROUND FOR TEACHERS

Most environmental programmes start by stating a problem, then leading students towards an answer. This module starts by offering a solution and then asking what is the problem. Our intention in framing the module this way is to offer students more creativity.

It is expected that students will already be familiar with the principles of biomimicry. If you have not introduced the principles to students previously, then use the Introduction to Biomimicry from the BioLearn website to introduce them.

The module uses mycelium as a focus for rethinking how humans create materials. Humans have been using mycelium for centuries as yeast in brewing and more recently in producing products such as biofuels from corn. Unlike yeast, however, mycelium is multicellular and can grow into macro-sized structures in the same way that cells in our bodies build bones. As mycelium grows it assembles a dense network of long, microscopic fibres that grow through soil like a superhighway system. This 'wood wide web' transports nutrients between plants and electrical and biochemical signals. There is still much to learn; a useful summary can be found at www.bbc.co.uk/earth/story/20141111-plants-have-a-hidden-internet.

Humans can intervene in mycelium networks. Instead of allowing mycelium to produce mushrooms, it can be 'persuaded' to build predictable structures using moulds and dry substrate such as wood chips. This process of biofabrication can be used to literally grow everything from packaging and construction materials to plant-based foods, all replacing harmful plastics from the environment. In this module, students will learn this is not hypothetical as they grow their own mycelium structure.

Activity 1 offers excellent opportunities for Design and Technology. In Physics, students could grow insulation boards using mycelium and test their thermal properties (see www.biohm.co.uk/mycelium). This supports GCSE Required Practical on the effectiveness of different materials as thermal insulators. This could be taken further to evaluate the effectiveness of mycelium insulation in houses through building simple model houses which are fitted with the mycelium insulation boards; links to constructing trial houses are:

- www.designcoalition.org/kids/energyhouse/pdfs/experiments.pdf – simple design;
- www.en.seacs.eu/energy-house-kit-secondary-primary-schools/4 – more complex.

OUTLINE OF THE MODULE

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:

Functions: 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'.

Strategy: 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

LOCATION
Indoor

TOOLS AND MATERIALS

- See weblink for details (https://www.grown.bio/shop/)
- W1.1 evaluation wheel

PREPARATIONS

Pre-purchase mycelium substrate from https://www.grown.bio/shop/. It is possible to cultivate your own mycelium spores or purchase them more cheaply (see below).

1 | GROWN TO BE GROWN AGAIN

» CREATE

This activity is based around using mycelium as a medium for growing structures. In human systems, we tend to create materials and then think about how to deal with waste products. Nature does things differently, it starts with a sustainable material (chitin, cellulose, etc.) and then evolution works out useful things which can be made from it. This activity mimics this process by starting with a sustainable material (mycelium) and asking students what they can make from it. Our intention in framing the module this way is to offer students more creativity.

The following video from Mycoworks provides a good starter for students explaining how mycelium is being used by business to grow structures for commercial products: www.youtube.com/watch?v=VWQznqpy3Ss&feature=emb_logo

Other videos and information to share with students can be found here: www.thegreentemple.net/articles/mycelium-the-future-is-fungi.

This is a very open activity. The purpose is to challenge pupils to create a product based on biomimicry principles. Rather than asking pupils to address a specific challenge, an open question is provided:

"What can you create from mycelium?" This could be a specific product or simple 'something useful'.

The boxed text below provides details of how students can create their own material using mycelium. Growing a material in this way means it can be shaped into a range of different products: pencil case, coaster, cup holder, insulation, etc. A quick image search using the term 'mycelium products' will yield lots of examples to inspire students. And of course lots of helpful videos such as this one: https://www.youtube.com/watch?v=Hn8SwpZiemo&list=PLNtVHW6WqcLmqLsKFfS5KNxbGmJIoHu3q&index=3&t=26s.

Once students have created their product, use the evaluation wheel in W1.1 to assess results and suggest improvements.

Mycelium Kits and Substrate

Kits are easily available from https://www.grown.bio/shop/. You can purchase a kit including moulds, although it is relatively simple for students to make moulds using cardboard and offer more creativity. We suggest the GIY Hemp Kit as the simplest way to start.

A step-by-step instruction manual can be found here: https://www.grown.bio/wp-content/uploads/2020/07/GIY_Manual_GrownBio.pdf. Or try this video: https://www.grown.bio/wp-content/uploads/2020/07/Grow-It-Yourself-GIY-Mycelium-with-Grown.Bio_.mp4.

Once inspired there is much more to research here: https://materiom.org/recipe/200. Mushroom spawn can be purchased here: https://www.annforfungi.co.uk/. This will be less costly but will require sourcing a suitable substrate for the mycelium to populate separately.

As an alternative to using mycelium, producing bioplastics is an option; see for example www.instructables.com/Make-Your-Own-Bioplastics/. This is likely to be less costly than purchasing mycelium kits.

Students interested to explore this whole area further might wish to explore the "The Materials Experience" Lab (http://materialsexperiencelab.com/) which illustrates some simple ideas; in particular take a look at these projects: http://materialsexperiencelab.com/master-graduation-projects-overview.

ACTIVITY DETAILS

LOCATION
Indoor

TOOLS AND MATERIALS

- access to internet
- W2.1 biofabricated materials

PREPARATIONS

Ensure internet access.

2| IS THIS THE FUTURE?

» DISCOVER

Creating products by growing them using mycelium is one in a range of biofabrication opportunities. This activity asks students to carry out research into biofabrication. You might like to start by offering the following definition of biofabrication (or get students to find one):

"The generation of products using structural organization from living cells, molecules, tissues and other biomaterials." In other words, growing materials using natural processes. You can find a much more detailed definition at the Institute of Physics (https://physicsworld.com/a/how-do-you-define-biofabrication-today/).

Start by asking students to list four common human-made materials they use on a daily basis. Examples will include plastic, cloth, fabric, leather, metal, concrete. A general list is sufficient. Then, using the internet, ask students to search if there are biofabricated examples of these materials. There are lots of websites exploring this topic and searching the term 'biofabrication' and the material type will reveal a good list. Some general websites are listed below:

- www.healthymaterialslab.org/
- www.modernmeadow.com/
- www.dezeen.com (search within the site for lots of examples).

For each of their four examples, ask students to identify the natural process being mimicked to create the biofabricated material. An example is Hempcrete, a building block created from hemp, lime and which actively absorbs CO_2 during manufacture (www.isohemp.com/en/hemp-blocks-naturally-efficient-masonry).

Using a table similar student worksheet W2.1, ask students to research the pros and cons for each biofabricated material. Could a biofabricated material replace current materials?

EXTENSION

Some students might wish to go further in exploring how biomimicry thinking promotes more sustainable fabrication of materials. For each example they have selected, ask students to consider the function that is being mimicked and the strategy for accomplishing this (refer back to 'Background for Teachers') for definitions of function and strategy.

ACTIVITY DETAILS

3| IF NATURE IS THE SOLUTION, WHAT IS THE PROBLEM?

» QUESTION

LOCATION
Indoor

TOOLS AND MATERIALS

- access to internet, projector
- W3.1 De Bono thinking hats

PREPARATIONS

Prepare to show video clip; circular economy presentation.

In the first activity, students experienced that nature can be harnessed to grow materials suitable for human use. In the second activity they discovered that bio-fabrication is a growing industry. A legitimate question from students might be "so what?" The activity below asks students to interrogate a short video about the circular economy using the De Bono thinking hats technique.

You might start this activity by showing an image of how humans are using more and more materials. See www.eea.europa.eu/data-and-maps/figures/global-total-material-use-by.

Then show the following short video which explains the linear and circular economy. Before showing the video, explain that students will use the De Bono thinking hats technique to critic the video.

DE BONO THINKING HATS: Split the students into groups according to a 'thinking hats' perspective in order that they can more deeply analyse the video and the implications for the economy. This is a critical thinking tool developed by Edward De Bono. It involves using a 'hat' (metaphorical or real) to encourage thinking about an issue with a specific focus. There are six thinking hats in total with each hat offering a different focus (see student worksheet W3.1).

Explaining the Circular Economy and How Society Can Re-think Progress (www.youtube.com/watch?v=zCRKvDyyHmI – 3:48 minutes)

Each of the 'hat groups' feeds back their results to the whole group. As an extension or homework task, you might ask students to create a poster based on their thinking hats – students document their thinking hats discussions in the form of a poster. They share this with the rest of their class.

Finish by using the circular economy presentation to review the key difference between a linear and circular economy (see separate file).

ACTIVITY DETAILS

EXTENSION

Some students might wish to explore this whole area further. Here are some starting points:

- The circular economy is being actively pursued in Europe – https://ec.europa.eu/environment/green-growth/index_en.htm
- Create your own action plan (Figure 4 is especially useful) – https://www.eea.europa.eu/themes/waste/resource-efficiency/textiles-in-europe-s-circular-economy

LOCATION
Indoor

TOOLS AND MATERIALS

W4.1 Iceberg Model

PREPARATIONS

Indoor activity.

Print copies of W4.1 as required.

4 | CHANGING TO A CIRCULAR ECONOMY

» QUESTION

Students might ask if some of their ideas are realistic, or why change is not happening fast enough. This requires some deeper digging into what drives and affects change. One useful model for this is the Iceberg Model (see W4.1).

The Iceberg Model has many applications and can use challenging language. For more background on the Iceberg Model read here: https://ecochallenge.org/iceberg-model/. In W4.1 we have used the original language to describe the model, but we have also included some simpler language below which might be more appropriate depending on the age of students you are teaching.

Trends and patterns:

- Can you see any positive trends towards nature-inspired materials?
- How about more materials which can decompose naturally after use?
- What about new types of materials and products that nobody talked about 5 years ago?
- Do you feel that there are positive trends taking place? Are policy makers and politicians talking about these things too?

Underlying structures / ways of doing things:

- Is the impact of materials and production waste starting to affect how we act and take decisions?
- Are consumption habits changing the way we buy goods and the way they are made?

Mental models / values:

- Are we prepared to change the way with think about our freedom to use and throw away products as we wish?

W1.1 GROWN TO BE GROWN AGAIN

Biomimicry evaluation wheel

DESIGN OR PROJECT NAME:. . . . .

DESIRED FUNCTION / CONCEPT: . . . .

Q1: Based on the nine principles of biomimicry, this is close to how nature would design this product/project.

STRONGLY AGREE	AGREE	NEITHER AGREE NOR DISAGREE	DISAGREE	STRONGLY DISAGREE

Q2: Looking at your design and comparing it to the nine principles of biomimicry, which areas are the strongest? **Why is this the case?**

. . . .

Q3: Which areas are the weakest? **Why is this the case?**

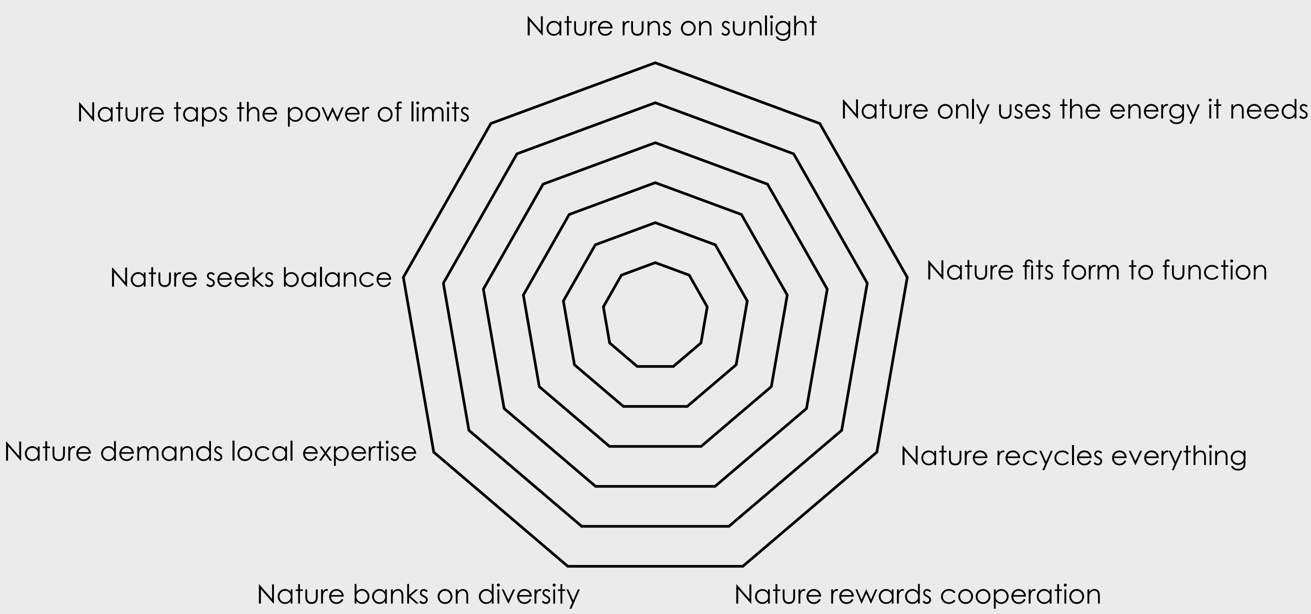
. . . .

Q4: Think of one practical way you can improve your design.

. . . .

Improving your design
Consider how you might use the nine principles of biomimicry to improve your design. How might nature go about designing the product or function you are trying to produce?

TASK: Use the diagram below to plot how your product achieves in relation to each biomimicry principle of design. Use this to consider the strengths and weaknesses of your design.



W2.1 IS THIS THE FUTURE?

Pros and cons of biofabricated material

Biofabricated material	What natural process is being mimicked?	Pros and Cons for... health	environment	economy

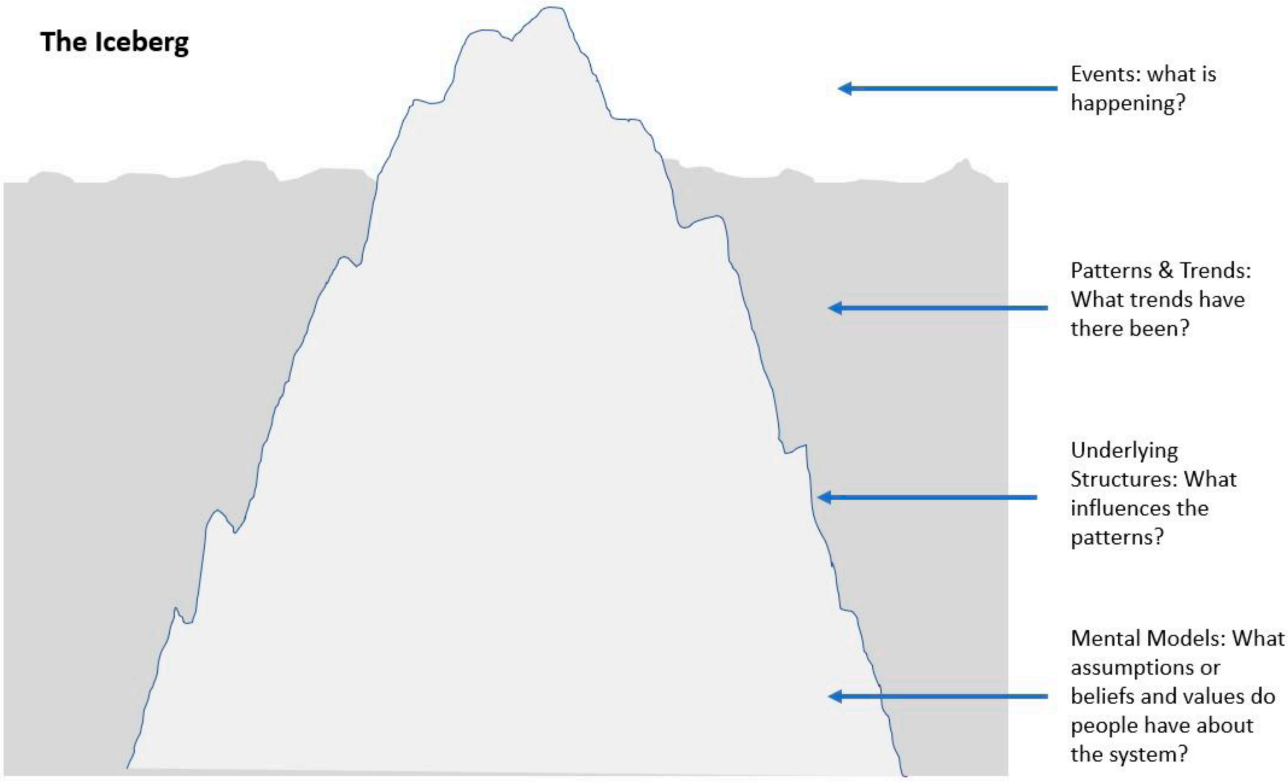
W3.1 IF NATURE IS THE SOLUTION, WHAT IS THE PROBLEM?

De Bono Thinking Hat Questions

RED HAT **Feelings and emotions**	• Based upon my emotions, do I think this is a good idea? • How do I feel about these approach/these ideas?
WHITE HAT **Information and facts**	• What facts, data, and information do we have? • What facts, data, and information do we need? • What information is missing?
YELLOW HAT **Positives and strengths in relation to the issue being considered**	• What are the strengths of these ideas? • What are the positive benefits?
BLACK HAT **Problems in relation to the issue being considered**	• What are the weaknesses? • What may go wrong if we implement these ideas? • What are the potential problems?
GREEN HAT **Creativity and new ideas**	• What alternative solutions are possible? • Could a recommendation be done in another way? • What is a unique way of looking at the issue?
BLUE HAT **Planning and organising ideas**	• Where do we start? • What things should we do first? • What could be the 'action plan' and next steps for these ideas?

W4.1 CHANGING TO A CIRCULAR ECONOMY

Iceberg Model



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