Module Guide: Reproduction

- **Curriculum:** Science
- **Year:** 9*
- **Stream:** Science Understanding
- **Biological Sciences:** *describe the form and function of reproductive cells and organs in animals and plants. Analyse how the processes of sexual and asexual reproduction enable survival of the species.*
- **CD code**: AC9S9U02

- **Additional curriculum links:**
  - Tissue Culture Case Study:
    - **Stream: Nature & Development of Science-** *how advances in technologies enable advances in science; how science has contributed to developments in technologies & engineering* (CD code: AC9S9H02). Advancements of propagation techniques through research and applications for commercial horticulture.

***Year 10 curriculum linkage opportunities:**

- Note: **meiosis & mitosis** are addressed in Curriculum 9.0 Science for year 10 (CD code: AC9S10U01). This may reduce the need to cover specific details of meiosis/mitosis genetic content in this reproduction module. Covering the details of meiosis and mitosis can be applied at the educators' discretion.

- The case studies and examples in this module can be applied in the year 10 meiosis & mitosis learning content, allowing for deeper detail to be added for these illustrated real-world examples. This is particularly relevant for the honey bees case study (part 3).

Module Guide:

This guide provides a suggested sequence of module content with room for elaborations, as well as case study examples that highlight the science of agriculture/ agri-food systems.

1. Sexual & Asexual Reproduction:
   - **Background Themes: Asexual & Sexual Reproduction**
   - **Plant & Fungi-** examples of sexual & asexual reproduction;
2. **Case Study from Horticulture:** Tissue Culture (clonal propagation)
3. **Case Study: Insects –** Honey bee reproduction examples (comparison of European bees & Cape bees)

1. Background Themes: Asexual & Sexual Reproduction

Sexual & Asexual Reproduction

- **Cover initial fundamentals, including:**
  - General features – what, where, how:

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- **Sexual reproduction:** fertilisation or 'inter-gamete contact' is successful, resulting in genetically diverse offspring that combines the parental genetic material. Educator may wish to cover the types of reproductive cells, their form & function. How do these vary across animals, plants and fungi? Consider genetics – e.g., chromosome count & genetic diversity.
- **Asexual reproduction:** production of clones. Division of somatic cells. Educator may wish to cover examples of what parts of an organism may be used to form a new, identical organism. Consider genetics – e.g., chromosome count & genetic diversity.

- **Sources of genetic variation**
  - Sexual: increased diversity from combinations from gametes (N)
  - Asexual: chance/random 'point' mutations as their source of genetic diversity
- **Evolution –** organisms have evolved their reproduction 'strategies' (one form, or both forms available for some organisms).
- **Conditions that may favour a particular form of reproduction strategy** (environmental conditions, resources etc. that may favour/ disadvantage each form of reproduction).
- **Resource for revision:**
  - **Interactive digital activity for sexual and asexual reproduction:** provides examples from diverse phyla (microbes, animals, plants). See this page from the **Genetic Science Learning Centre**. Open students' eyes to the reproductive strategies of a variety of organisms, including those that exhibit both asexual and sexual reproduction strategies.
- **Benefits and limitations/negatives** of each reproduction method (discuss, explore, write)

- Format of Activity Ideas:
  - **Class discussion & prompt questions** (whole class or small groups). Report back to whole class.
  - **Graphical organisers:** side-by-side comparison worksheets (e.g., Tables- columns are reproduction type; rows are the traits/ features/ pros/cons etc.) Can leave blanks for students to suggest their own additions.
  - **Cause/effect or pros/cons worksheet** (graphical organiser template)
  - **Class debate (if content familiar enough for participants)** – e.g., the pros and cons of these reproductive strategies.

Plant & Fungi

Examples: Plants and fungi represent diverse examples of organisms that can reproduce sexually and asexually. These both play a important roles in ecosystems- both in nature and managed ecosystems within agricultural production.

- **Plants:** Could further discuss specific elements of sexual reproduction, showing plant reproduction examples from each. Examples:
  - Survival via sexual and sexual reproduction methods. Features, pros & cons.
  - Illustrate linkages to pollination & its importance to horticulture (i.e., formation of seeds & fruit)
  - Discuss the reliance sexual reproduction for food systems (e.g., food production & food security).

- **Fungi:** Fungi sexual and asexual reproduction cycle, with examples from each reproduction cycle.
  - Students will be familiar with store-bought mushrooms, yet they can represent only part of the reproductive cycle of fungi.

- Fungi can reproduce asexually (e.g., by budding), and many also have sexual reproduction and form fruitbodies that produce spores.
- Example – illustrate these differences by showing class generalised fungi lifecycles (showing both forms of reproduction stages).
- Example: see this website for fungi reproduction characteristics. Includes fungi lifecycle reproduction diagram & terminology.

2. <u>Case Study Example from Horticulture: Tissue Culture (via clonal propagation)</u>

Clonal propagation

Cloning refers to the procedure of creating a new multicellular organism, genetically identical to the parental source material. (Fertilization or inter-gamete contact does not take place).

Humans have developed their own techniques for developing cloned organisms (e.g., plants for horticulture) using highly-controlled environments with optimise the growing conditions for specific crop/plant variety.

For example, a small section of a parent plant can be removed, then treated in a tissue culture environment, and over time develop into a new organism of identical genetic make-up to the parent.

Tissue culture

- This is conducted in a highly controlled environment. The below horticulture case study example details some key steps within an example of this method.
- **Tissue culture represents one method of cloning** that ideally requires a sterile environment, healthy plant tissues, sufficient nutrients and light, and several other factors that need to be strictly met.

Case study introduction

- **Agri-food content linkages:** horticulture, plant science, genetics & selective breeding, fragrance & flavour industry, food & fibre.
- The following example highlights current long-term research within the Tasmanian Institute of Agriculture (TIA) in Hobart. This research and methods include close collaboration with Tasmanian industry within the field of essential oil production for the fragrance industry.
- This outlines some fundamental elements of the science of agriculture that underpin tissue culture propagation of the herbaceous Australian native plant *Boronia* used in the essential oils industry, including the ‘what, why & how’ of this technique and industry.

Above: *Boronia* tissue culture for fragrance research at the Tasmanian Institute of Agriculture (TIA).

Background – why *Boronia*, and why Tasmania?

- *Boronia* is a genus of shrubs that belong to the Rutaceae family of aromatic native Australian plants. The most well-known members of the Rutaceae family of plants are citrus (lemons, oranges, limes), all of which are highly fragrant. Due to this, they are used extensively in the fragrance and food industry.
- The genus *Boronia* contains around 160 different plant species, with fragrant flowers and/or leaves. Most species are **endemic** to Australia (endemic = only found to naturally occur within this specific location, no where else in the world).
- *Boronia* flowers and/or leaves are economically grown as a crop throughout Australia, including commercially within Tasmania.
- **Why Tasmania?** Climate and soil conditions - Tasmania's (and mainland Australia's) climate is favourable for the genus (*Boronia* is native to Australia and has adapted to these conditions).
- **Research & industry:** Tasmania is also the centre of considerable ongoing research and the development of commercial production of *Boronia* for the fragrance industry. **Essential Oils of Tasmania (EOT)** have grown *Boronia* in Tasmania for over 35 years, including research collaborations with the Tasmanian Institute of Agriculture (TIA) to enhance their production – see their website for more information.
- **The intensely rich-smelling floral essential oil from *Boronia*** is the main product that growers are seeking. This essential oil is produced from the flowers and/or leaves which are are harvested, then extracted using steam distillation (or other extraction methods in the perfume industry). The resulting intense-smelling is bottled or mixed with other fragrances and sold commercially.
- **Experiential opportunities:**
    - Students could **smell *Boronia* essential oil** to experience the fragrance 'profile' themselves.
    - **Ask students:**
        - what 'fragrance notes' can you notice from smelling this? Describe them, writing these down & drawing upon smells that students are familiar with.
        - Does the scent/s change the longer you leave it in the air (e.g., in 15-30 min), or does it remain strong, floral etc.? (e.g., Could do a t=0 min, 15 min, 30 min check). Note how it changes.
        - Are there similarities to other smells that you're familiar with? (e.g., pleasant, and potentially unpleasant smells)
        - **Source:** obtain essential from chemist, health food shop, online etc. Commonly produced across Australia.
        - **Suggestion: Review & consider whether conducting an allergy and/or risk assessment is required for this activity,** specific to your school requirements. (e.g., contact irritation or exposure to the intense fragrance as an irritant).
        - **Additional questions:** What enables you to smell these molecules in the air? *(volatile organic molecules – they evaporate from a liquid to a gas at low-moderate temperatures, travelling through the air. These molecules*

reach receptors in your nose which send signals to your brain as to what perceived smell the molecule has).

- **Breeding: Different plant varieties can have different physical traits** (phenotypes). Different varieties of the species *Boronia megastigma* are bred for fragrance production commercially.
  - **Ask:** What sorts of different physical traits can you think of that may be present across varieties? Why might producers and researchers may breed them for these traits?
  - ***Think****: this is an agricultural plant grown & harvested in fields.*
  - ***Think:*** *what is the 'target market] for this product (fragrance industry, consumers)*
    - E.g., **fragrance profile** differences (presence or absence of different notes – e.g., removal of unpleasant notes)
    - **Growing traits** of the plant – e.g., morphology of the plant (e.g., height of plant, branching, hardiness for conditions – e.g., drought resistance, frost resistance, hardiness against pests such as insects, fungal pathogens, soil pests such as nematode worms etc.).
  - **Ask: Why might these traits matter?** At the end of the day, this is a commercial crop, produced for the fragrance industry so productivity (yield) as well as quality of the resulting oil produced are important.

Background: Growing in gel instead of soil!

In this example, the plant tissue culture clones are grown in an agar gel (a solid jelly-like material that is sourced from seaweed). This holds moisture and many essential nutrients in a controlled, sterile (i.e., minimise microorganisms present), artificial environment created by humans.

- **Ask:** compare and contrast the agar gel growing medium with soil in a field.
- ***Think:*** *nutrient sources, drainage, source of water, open or closed vessel (open to air/ the elements etc.).*
- **Activity format:** could note these differences listed as a side-by-side table, or illustrated etc. This could be conducted in small groups, individually, or whole class discussion.
- **Ask:** What challenges/limitations might each medium have? (soil and agar)

What sorts of conditions & nutrients are required for tissue culture?

Just like plants that grows in a field, tissue cultures require fundamental nutrients and resources to survive. However, when growing in a gel medium in a tissue culture, the plant is under an artificially-designed environment controlled by humans.

Note: can keep this section as light or deep as you wish. Linkages to themes of plant biology and chemistry.

Sunlight, Water, Temperature– all factors are fundamental to plant growth, however in a controlled environment they are solely provided by a human-designed set-up (not nature!)

- **Lighting** can include overhead lights (e.g., LED lights) to promote photosynthesis
- **Water source**: agar gel provides the water in a sealed container

- **Temperature**: controlled temperature (e.g., cool-room/ refrigerator) – having conditions too warm can stress the plants!

Nutrients: In tissue culture gels (in this example), the plants receive its nutrients and supplements from the gel – including a range of that are required for growth. This can also include chemicals that promote growth of plant cells and ultimately new plantlets.

Examples nutrients & supplements that may be found in agar gels are listed below:

- **Specific macronutrients**- e.g., Nitrogen (nitrate form NO_3^-), Calcium (Ca^{2+}), Phosphorus (such as in the form of Phosphate, PO_4^-), Magnesium (Mg^{2+}), Potassium (K^+), Iron (Fe^{3+}).
- **Specific micronutrients** - e.g., Manganese (Mn^{2+}), Zinc (Zn^{2+}), Boron (B^{3+}), iodine in the form of iodide ions (I^-), Molybdenum (Mo ions), Cobalt (Co ions), Copper (Cu^{2+}).
    - **Note on ions:** The macro- and micronutrients are typically present as the charged ion form of the element as this form is more soluble (can be dissolved) into a gel solution when the agar is prepared, as well as ion forms are more easily absorbed by the plants uptake by the plant.
- **Plant growth regulators** can support cell growth and induce metabolic pathways in plant cell and tissue culture protocols. Plant growth regulators include auxins and cytokinins (specific families of molecules that can contain a range of chemicals with similar functions, respectively). Their roles for plants tissue culture include:
    - **Auxins** are used in plant cell culture to promote cell division, cell elongation, and callus formation
    - **Cytokinins** promote cell division and differentiation in plant tissue culture.
- **Vitamins, amino acids, sugars** – e.g., glycine, thiamine, various sugars.
- **Slightly acidic pH gel** – this is commonly used for plant tissue culture, with research showing it can better support plant growth in the gel medium.

- **Leaves & Callus – where are the roots?**

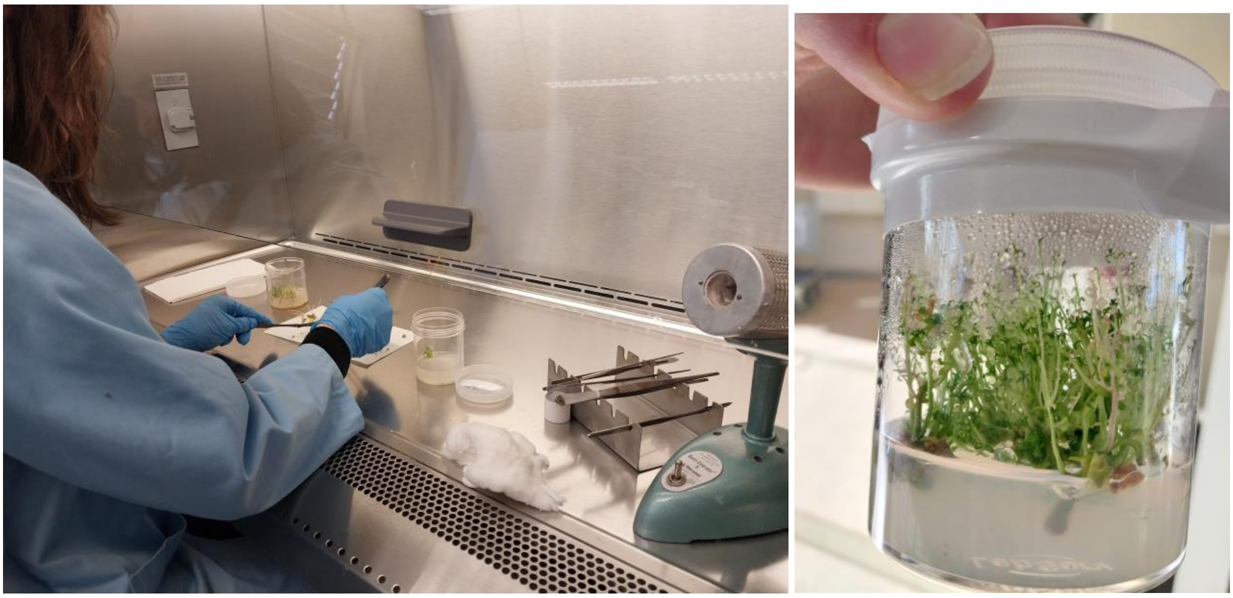
In this case study, the *Boronia* 'plantlets' (yes, tiny plants) growing in the agar gel jars contain the typical green parts expected of a plant – stems and leaves. However, a key difference in these samples is that you often won't see roots!

Callus: This general lack of roots is an interesting difference from traditional propagation methods. Instead, there a compact clump of brownish cells called **callus**. These cells are constantly dividing and growing new tissues and organs (e.g., leaves) attached to the central callus clump. They can absorb the nutrients from the agar medium and harness this for promoting plant growth.

- *In order to grow a callus in plant tissue culture, a piece of the parental plant tissue should be placed on a nutritive medium (i.e. agar gel). To revive a plant, these callus needs to be transferred to a fresh medium with specific nutrients.*

Later development: Importantly, at the right stage of development, these *Boronia* callus clumpy plantlets can be exposed to specific nutrients and plant hormones that prompt the plants to form roots, ready for being transplanted into soils.

From here, the plantlet can develop more fully to be ready for transplanting to an environment beyond the sterile jar it was grown in. (e.g., fields, greenhouse).



Above: A student at the Tasmanian Institute of Agriculture (TIA) prepares new *Boronia* plantlets from existing tissue culture samples by dividing existing calluses (right) and transferring them.

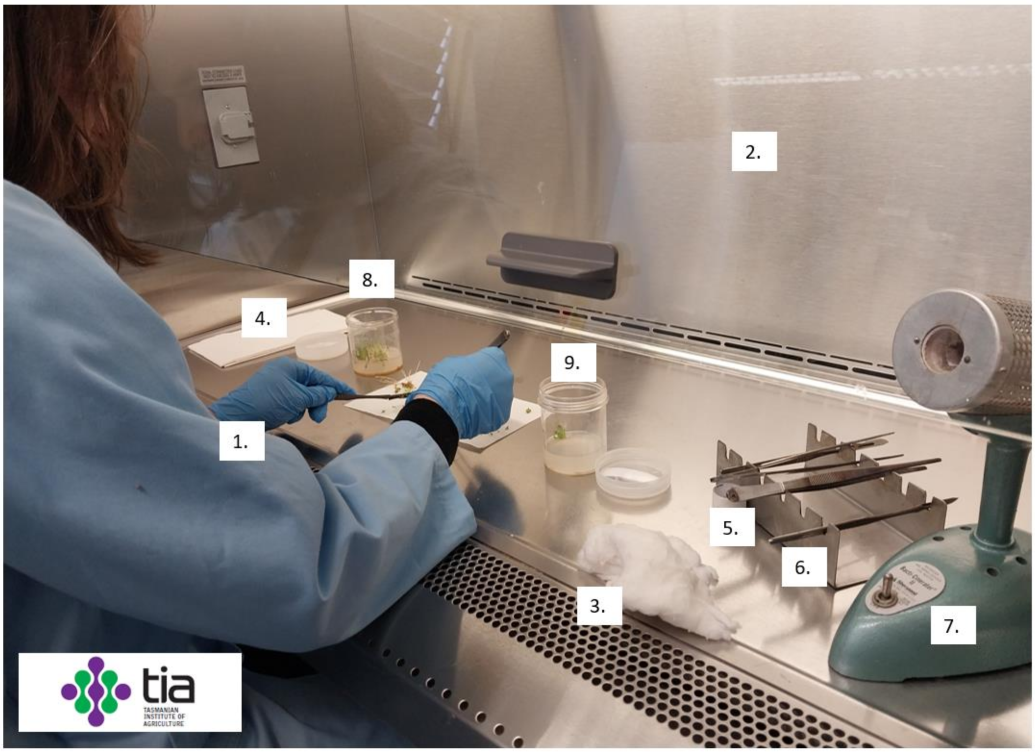
- Example process: from Cells to Callus, the Formation of New Plantlets

The above photo example shows a student dividing a *Boronia* callus (process outlined below) to create new tissue culture clones.

Laboratory technique: A key part of this process is using good laboratory techniques in a methodical manner with consistency and patience. Overall, the process of dividing the calluses is not difficult, however it does involve key processes to ensure the samples are going to have the best chance of growing into new plants. These steps include:

- The **laboratory workspace** is set up to include (see photo of student above):
    - (1) Personal protective equipment (PPE): safety equipment is worn when in the laboratory, including: laboratory coat, gloves, closed toed shoes.
    - (2) a workstation within a hooded ventilated space is set up to perform the dividing process;
    - (3) cleaning of the work surface environment is sterilised (cleaned with ethanol & cotton wool) to reduce the chance of microorganisms contaminating & colonising the samples;
    - Various equipment for the dividing process: sterile paper towel/sheets that are laid in front of the student to divide the plants upon (4); tweezers or forceps for handling the callus/plantlets (5); scalpel for cutting the plant material (6).
    - (7) A hot sterilising tube (hot tube that will sterilise equipment when inserted for short periods – e.g., scalpel and tweezers. A flame (Bunsen burner etc.) can alternatively be used for this process.
- The student collects a jar of *Boronia* plantlets (8) from which multiple *Boronia* callus are maturing, containing stems and leaves. This is the specimen that will be divided to form new plantlets in a new container.

- A freshly sterilised jar (9) that has been prepared with the appropriate nutrient agar medium is also placed in the workspace. (*Note: photo has the student mid-way through a dividing process, so the jar contains a fresh callus sample already)*



Resource: See the digital resource '*TIA Cloning in Horticulture'* from the TIA professional learning pack for a larger version of the above diagrams. This includes the steps involved in dividing the plantlets and propagation diagram.

Dividing plantlet – example process:

- Firstly, the student sterilises the tweezers and scalpel in the hot tube (cleans this from any lingering microorganisms that can colonise the jar & potentially spoil the propagation conditions).
- Working from left to right, the student gently removes an established *Boronia* plantlet (8) using tweezers, then places this upon the paper towel in front of them.
- They then carefully divide the plantlets at the callus, ideally including some callus cell bundles in the next plant, whilst leaving some remaining.
- The new plantlet is placed in the new sterile jar of agar medium (9), placing this on the surface, contacting the gel for its nutrients.
- Continue this process of dividing the same individual (steps 3-4) if you wish to add more freshly cut individuals. Once complete, the jar is closed & sealed. The scalpels/forceps are sterilised with the hot tube and placed on the rack.
- This process is continued with a fresh batch, repeated accordingly.
- All individuals are returned to the controlled environment (refrigerator storage), to be stored for weeks, months or even years until needed or new nutrients are to be provided.
- The student has successfully created tissue culture clones!

Above: *Boronia* plantlets can get quite crowded over time & are good candidates for dividing to form more clones – calluses are visible as brownish clumps in the tissue culture.

- Why can tissue cultures be effective ways to reproduce clones of a plant species?
  - **It's a quick and reliable method** for producing masses of identical genetic clones of a specific plant variety;
  - **Cost-efficiency & Longevity of Storage:** Under the correct storage conditions in sealed sterile containers (cooled in fridge with sufficient lighting), plantlets in the tissue culture gel medium can last for years without needing refreshing of nutrients. Do not need constant watering or repotting. *(Eventually will need care, as the nutrients become depleted and usually are replaced ~12 months*). However, costs associated with creating infrastructure to store the samples, and providing the controlled environment (lighting and cooling) are key cost considerations.
  - **Space efficiency:** In the sealed sterile conditions, you can store hundreds or even thousands of individual organisms in a small space. This is efficient for a 'library' situation of storing plants.

- Why a library of plants can be useful for agriculture applications
  - **Storage of a 'library' of plants with a variety of desirable traits.** This could serve as a back-up population of plants that are separate to those in the field/greenhouse, stored over many years. These plants themselves could form new varieties from cross-breeding when established as mature adults as well, forming more genetically-diverse individuals.
  - **Space efficiency** (see above)
  - **Cost-efficiency** (see above)

- Question: What sorts of precautions need to be used when preparing the tissue cultures, and dividing the plantlets?
  - **Cleanliness – sterile working conditions and equipment.** Ensure that microorganisms do not contaminate the tissue cultures, possibly resulting in mould (fungi), bacteria etc. This can spoil the tissue culture plants and prevent the plants from developing.

- **Working methodically** with a set process & patiently. See laboratory process above.
- **Dividing plants** – cutting up the plants to form new plantlets will often have better success with **small amounts of callus attached**. (i.e., not just leaves & stems). The calluses are dense cell bundles that can divide and grow into different tissues, so without this, the plant may be stunted or not be able to develop as strongly in the tissue medium.

- School engagement opportunities
  - Example experiences for schools linking tissue culture to horticulture research & applications:
  - **Field-visits:** (e.g., local industry engaging with horticulture for agri-food or ornamental horticulture such as nurseries). See local example below.
  - **TIA:** Enquire through the Tasmanian Institute of Agriculture in Hobart for a classroom visit, or in-field experience.

Local example of tissue culture propagation:

- **Potato tubers**- seed potatoes can be propagated via tissue culture. A local Tasmanian example is **Agronico** based in the North West- see their website, which also includes a video of their propagation method – from tissue cultures to hydroponic growing processes following tissue culture.

Above: Potato plants in tissue culture, and the resulting seed potatoes grown in hydroponic systems (Source: Agronico)

Insects: Examples of Sexual & Asexual Reproduction

Honey bees as examples of displaying both asexual and sexual reproduction

Insects have diverse examples of reproduction strategies. Below are examples of reproduction that occur with two different types of honey bees – one local example, one from South Africa.

Example 1: European Honey Bee (Traditionally used in beekeeping)

Background: sourced from BeeAware article. Note: you can use this resource to compare and contrast the reproduction seen in the traditional European honey bee (locally used for honey production in Australia), and compare this to the Cape honey bee (South Africa, second example in case study).

In a **typical European honey bee colony**, the following reproduction steps outlined below occur:

- When a **queen bee** lays an egg, she can control whether the egg is fertilised or not fertilised.
  - If the queen lays a **fertilised egg**, this egg will become a worker bee or queen bee (both are **female)**.
  - If she lays an **unfertilised egg**, this egg will become a **drone** (a **male bee**).
- **This type of reproduction is called haplo-diploid** because the queen bee can lay either unfertilised male eggs (haploid, N) or fertilised female eggs (diploid, 2N).
- Worker bees also have ovaries but they are unable to mate. However, worker bees are still able to lay eggs, but since their eggs cannot be fertilised, the worker bee eggs can only become drone bees (males).
- **Queen affects the egg laying in hive:** The presence of healthy and laying queen in a colony suppresses egg laying by worker bees.

In other words, the number of sets of chromosomes (N or 2N) can determine the sex in European honey bees. The term **haplo-diploid sex determination system** reflects the number of chromosome sets (N = haploid, and 2N = diploid).

Recap of honey bee content: Recapping the above European honey bee reproduction points, with the addition of our understanding of sets of chromosomes:

- **Female bees are produced sexually from fertilised, diploid eggs (2N**). They receive half of their chromosomes from each parent (2 full sets of chromosomes = 2N, diploid offspring).
- **Male bees develop asexually from unfertilised, haploid eggs (N).** They receive their entire genome from their mothers – they do not have fathers. They are therefore genetically identical to their mothers (clones).
- Any female honey bee is technically capable of producing male eggs, even ‘worker’ bees (who are incapable of mating).
- The ability of female honey bees to lay haploid eggs (N) that develop into fully functional males is known as **arrhenotokous parthenogenesis, and all male honey bees are produced this way**.
- However, since **only queens can mate, they are the only individuals that can produce female offspring** (2N, diploid offspring).
- <u>Example discussion questions for classes:</u>
  - **Problem solving brain-break questions** (biology & mathematics):

- *Queen bees share a fascinating relationship with the other bees in the hive. Male bees hatch from eggs that have not been fertilized, meaning that their mother is a Queen bee and they do not have a father. Female bees, on the other hand, have both a mother and a father.*
- ***Question:** If you trace a **male bee's** family tree back for **12 generations**:*
  - *how many other bees will be part of that family tree?*
  - *How many of these bees will be male? Exclude siblings, aunts and uncles, cousins and second cousins, etc.*
- Encourage students to work in pairs/ small groups, or unpack problem live as a class.
- Use visual diagrams to work back generations from the bee to the original Queen bee.

- **Ask:** What would these different reproduction strategies mean for the genetics of a honey bee hive? Benefits and potential disadvantages? Think about the impacts on their ability to adapt to changing conditions etc., and the survival of the hive.
- **General inquiry/ discussions:** Investigate the hierarchy of interactions, structure of hive, and relations in a general hive. **For example**: mating with the queen – can all bees do this? who can do it? What does that mean for genetic diversity?

The future of the hive: In a European honey bee colony, the queen may die for a variety of reasons. To counter the loss of the queen, workers may begin to nurture a young larva that was laid by the now deceased queen, and hopefully raise her as a replacement queen by feeding her royal jelly. However, this sometimes is not able to happen and the colony is not able to re-queen itself, and then collapses. Before the colony perishes, and without the queen to restrict laying worker bees, worker bees begin to lay haploid offspring which become drones. These drones are viable and act as the last chance for the colony to pass on its genes.

Example 2: An Unusual Example of Reproduction- Cape Honey Bees

Cape bees- an example where honey bees can produce fertilised, clone female offspring!

- **Case study location:** South Africa
- **Species distribution:** South Africa (an exotic pest in other locations globally)
- **Pest status:** Outside of South Africa- Australia currently considers this sub-species of honey bee as a pest that can threaten our existing honey bee populations.
- **Resources**:
  - **Introduction to Cape honey bee sub-species & its lifecycle**: See BeeAware's article on exotic pests (for Australia)
  - **Fact Sheet** – Cape Honey Bee fact sheet (University of Florida)
  - **Additional article** –**Cape bees** (University of Sydney research article)

- **Introduction:** The Cape honey bee (*Apis mellifera capensis*) is a **subspecie**s of the European honey bee (Apis mellifera) and is native to the Eastern and Western Cape provinces of South Africa. In its natural environment (the Fynbos region of South Africa), the Cape honey bee can be readily managed for the purposes of honey production and pollination, just like other races and strains of the European honey bee.
- However, the Cape honey bee has a distinct reproductive system which makes it unique amongst other races of Apis species. This unique reproductive system causes major problems for beekeepers in its natural environment of South Africa where it acts as a 'social parasite'.

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- **Inquiry & background:** See [BeeAware's article]() lifecycle section for further detail on how this subspecies differs from the traditional European honey bee, and its impacts.
- The **Cape honey bee does reproduction slightly differently**: this subspecies has evolved the ability to reproduce via the formation of diploid (2N) daughters from unfertilised eggs (known as **thelytokous parthenogenesis –** fairly uncommon in the animal kingdom).
- **Sex cells are produced via meiosis**, which usually results in haploid daughter cells (sperm or eggs, N) that can then fuse with another meiotically produced cell from another individual (fertilisation) to produce viable offspring (i.e., sex!)
- **In the Cape honey bee however, the meiotic products fuse together** as if one was a sperm. The eggs they produce **effectively fertilise themselves** and develop into fully functional females that are **genetically identical to their mother**. Female Cape honey bees can clone themselves (Goudie and Oldroyd 2014).
- This results in competition from clones (females!) against the Queen for breeding in the hive.

  - Pros and Cons – see article **& "Attack of the Clones"** section of the University of Sydney article:
    - Social dynamics are different (hierarchy structure – there is competition amongst females for breeding!)
    - There have been examples of clones of Cape bees **colonising other hives**; **producing billions of clones** in some hives (1990's examples in South Africa), uses resources within the hives (hosted by the invading colony), and then the bees **causing the collapse of hives** (negative outcome).
    - These clone cape bees can then move onto other hives and infiltrated again. Devastation of the bee industry ensued.
    - Australia considers Cape honey bees as an exotic pest (see BeeAware's article on exotic pests).

- Case Study Inquiry Activity Suggestion:
  - Students could compare and contrast the European and Cape honey bees' reproductive strategies. Including:
    - Highlight the types of asexual and sexual reproduction that occur & their genetics.
    - Mention these strategies are beneficial for each species
    - Explain any aspects that make them out-compete or threaten another species (see exotic pest notes).
    - Biosecurity links: what are the geographic locations of each species? / varieties.
    - What threats does Australia face with Cape Bees?
  - Can use guiding questions from each case study (1&2 bee types) to prompt the project.
  - **Format:** Project, science communication presentation (e.g., poster), or graphical organiser-based activity.