

9

Science quests

We live in a time of great change. The future will present us with many challenges and discoveries — some so exciting and absurd

that they may be beyond our wildest hopes and dreams ...

OVERARCHING IDEAS

- Patterns, order and organisation
- Form and function
- Stability and change
- Scale and measurement
- Systems

SCIENCE AS A HUMAN ENDEAVOUR

Scientific understanding, including models and theories, is contestable and is refined over time through a process of review by the scientific community.

Advances in scientific understanding often rely on developments in technology and technological advances are often linked to scientific discoveries.

People can use scientific knowledge to evaluate whether they should accept claims, explanations or predictions.

Advances in science and emerging sciences and technologies can significantly affect people's lives, including generating new career opportunities.

The values and needs of contemporary society can influence the focus of scientific research.

SCIENCE UNDERSTANDING

The transmission of heritable characteristics from one generation to the next involves DNA and genes.

The theory of evolution by natural selection explains the diversity of living things and is supported by a range of scientific evidence.

Global systems, including the carbon cycle, rely on interactions involving the biosphere, lithosphere, hydrosphere and atmosphere.

This is an extract from the Australian Curriculum.
Any elaborations may contain the work of the author.

THINK ABOUT THESE

- Why did Superman's parents send him to Earth?
- What is the relationship between the Incredible Hulk, nanotechnology and gamma radiation?
- Could X-Men interbreed with humans?
- What does Spider-Man have in common with sea slugs?
- What sorts of spiders might be crawling *inside* your body in the future?
- Do you have music in your genes?
- What does the movie *Avatar* have to do with microbes and nanowires?
- How can killer tomatoes protect you from disease?
- Is the junk in your DNA actually a treasure?

Is this a crystal ball? No, but it helps us glimpse the future. This near perfect spherical drop of water is resting on a super water-resistant surface coated with nanoparticles. The surface is self cleaning. What new applications can you think of for this surface?



Towards immortality

Is artificial evolution of our species possible? DNA technology, drugs and implants for existing or experimental therapies could make this a reality. We can already insert new genes into various parts of the adult human body. In the future, this may also include gametes and embryos. We have the technology to cut and paste various genetic sequences, not only within the same species, but between species. How might these modifications affect future generations?

We also have the power to replace body parts with natural organs, mechanical organs or tissues derived from stem cells. We already have drugs such as steroids to enhance physical performance, and psychoactive drugs that can alter our powers of cognition such as memory, mood, appetite, libido and attention. Where will our next discoveries and technologies take us?



INQUIRY: INVESTIGATION 9.1

Life in 2050

KEY INQUIRY SKILL:

- communicating

1 Research and make notes on how current scientific research may affect life in the future. You may wish to consider the following questions.

- What future technologies and applications will change our lives?
- How far may our life spans be extended?
- Will we all be disease-free?
- Will some people be more entitled to medical services than others?
- How much of us will remain organic and how much integration with computers and other synthetic materials can occur before we are no longer considered human?

- 2 (a) Creatively weave your findings from question 1 into a science fiction story about life in 2050.
(b) Design a cover page for your story.
(c) Put together some promotional material for your story and include this on the back cover of your book.
(d) Share your story with your class.

Daring to dream

Why not go on a journey that will take you beyond your wildest dreams?

Creatively critical

A clever scientist realises that science is not just about critical thinking with clarity, accuracy and detail. It is also about thinking flexibly and creatively with an open mind. Reading, writing or watching science fiction can help unlock your mind's doors to take a step outside reality. Science fiction can take you to another universe where anything is possible. It provides you with the opportunity to dream and imagine endless possibilities and creations.

Science fiction authors in the past, such as Aldous Huxley (1894–1963) and Arthur C. Clarke (1917–2008), have had a considerable effect by taking others on a journey beyond their wildest dreams. It is only in our time that some of their dreams are becoming a reality.

In our image

Mary Shelley's novel *Frankenstein*, in which scientist Victor Frankenstein creates a monster who eventually turns on and kills Frankenstein and those he loves, has led to a genre of stories in which the creation destroys the creator. The popularity of such a theme has contributed to technophobia, or the fear of technological advances. These advances may not be only in robotics, but also in other types of creation such as new chemical compounds or transgenic organisms produced by genetic manipulation.

Science fiction tells tales of how humans attempt to outdo nature and are often then confronted by menaces of their own making. The tales also describe how the human spirit, determination and imagination are used to solve and conquer these menaces.

Isaac Asimov has been universally acknowledged as the father of robotics. He has written many stories about the human fear of robots. His story

Evidence (1946) suggests that a well-programmed robot not only could look human but, if programmed with the Three Laws of Robotics, would be more ethical than many politicians.

By using human ova and hormone control, one can grow human flesh and skin over a skeleton of porous silicone plastics ... The eyes, the hair, the skin, would be really human, not humanoid ... if you put a positronic brain and such other gadgets ... inside, you have a humanoid robot.

From *Evidence* by Isaac Asimov

In another of Asimov's stories, *The Bicentennial Man* (1976), he deals with the issues of the ethical responsibility that humans have for their creations, the relationship between organic and inorganic matter and the futuristic line between living and non-living. The novel is about a humanoid robot, Andrew, who, unlike other robots, desperately wants to become human. The story begins with him questioning another robot:

'Have you ever thought you would like to be a man?' Andrew asked. The surgeon hesitated a moment, as though the question fitted nowhere in his allotted positronic pathways. 'But I am a robot, sir.'

From *The Bicentennial Man* by Isaac Asimov



In the 1994 novel *The Ship Who Searched* by Anne McCaffrey and Mercedes Lackey, the benefits of becoming more ‘machine’ were explored. In this story, a paralysing alien virus leaves the heroine unable to live without a mechanical support system and she is transformed into a ‘shell person’ or ‘brain ship’ to adventure throughout the universe.

No amount of simulator training conveyed what it really felt, to have a living, breathing ship wrapped around you...Never mind that her ‘skin’ was duralloy metal, her ‘legs’ were engines, her ‘arms’ the servos she used to maintain herself inside and out...That all of her senses were ship’s sensors linked through brainstem relays. None of that mattered. She had a body again!

From *The Ship Who Searched* by Anne McCaffrey and Mercedes Lackey

New worlds

It is believed that biotechnology promises the greatest revolution in human history. The commercialisation of molecular biology has occurred with astonishing speed and is considered to be the most stunning ethical event in the history of science.

Since the discovery of DNA, science fiction authors have incorporated the new scientific concepts and used them to create futuristic worlds in which humans are forced to cope with their creations.

Problem-solving was his specialty, and he had been selected for it before birth. Gene analysis had chosen the best DNA chain from his parents’ sperm-and-ovum bank. This, and subsequent training, had fitted him perfectly for command.

From *War with the Robots* by Harry Harrison

Aldous Huxley’s *Brave New World* (1931), Harry Harrison’s *War with the Robots* (1962), Michael Crichton’s *Jurassic Park* (1991) and Julian May’s *Jack the Bodiless* (1992) have all addressed the topic of futuristic genetics.

If this insect has any foreign blood cells, we may be able to extract them and obtain paleo-DNA, the DNA of an extinct creature. We won’t know for sure, of course, until we get whatever is in there, replicate it, and test it. That is what we have been doing for five years now. It has been a long, slow process — but it has paid off.

From *Jurassic Park* by Michael Crichton

All four of us children inherit from the Remillard side of the family a dominant polygenic mutant complex: we’re smart, we have extremely high metafunctions, and our bodies age up to a certain point and then persistently rejuvenate. The traits have a reduced penetrance and exhibit variable expressivity. You know what that means?

From *Jack the Bodiless* by Julian May

Of all of these authors, Aldous Huxley gave the most thorough description of the impact that genetic manipulation may have on our society. His book *Brave New World* also described a society in which different human castes were created, produced and brainwashed to happily meet different needs and services. The following text is written from the point of view of a ‘Beta individual’.

Alpha children wear grey. They work much harder than we do, because they’re so frightfully clever. I’m awfully glad I’m a Beta, because I don’t work so hard. And then we are much better than the Gammas and Deltas. And Epsilons are still worse. They’re too stupid to be able ...

From *Brave New World* by Aldous Huxley

In 1976, Robert Swanson, a venture capitalist, and Herbert Boyer, a biochemist, formed a commercial company to exploit Boyer’s gene-splicing techniques. Their company, Genentech, quickly became the largest and most successful of the genetic engineering start-ups. Since this time, many similar companies have sprung up with the purpose of creating genetically modified organisms that can be utilised for financial gain. What will your future hold? How will the new technologies affect you? And what about your children? That is, of course, if the government allows you to have them!

Punk in science fiction

Films such as *Blade Runner* and the *Matrix* trilogy provide examples of cyberpunk. This form of science fiction is a blend of **cybernetics** and punk. The term became widespread in the 1980s, especially to describe novels from authors such as William Gibson and Bruce Sterling. Cyberpunk often explores possible near-futures of Earth that resemble dystopia rather than utopia.

In many cyberpunk stories, there is a conflict between computer hackers, artificial intelligence and big corporations. Characters in these stories are often alienated loners, living on the edge of their society.

Their lives are ravaged by the negative effects of advanced technology, with even their own bodies often having undergone some form of invasive modification. In these possible futures, the advanced technology may be blended with a loss of social order, control and morality.

Over the last few years, offshoots of the cyberpunk genre have resulted in the birth of related genres such as biopunk, steampunk and postcyberpunk. In postcyberpunk, it is heartening that there are characters who act to improve social conditions or

at least try to prevent their further decay. Will your creative science fiction writing produce another science fiction genre?

He'd operated on an almost permanent adrenaline high, a byproduct of youth and proficiency, jacked into a custom cyberspace deck that projected his disembodied consciousness into the consensual hallucination that was the matrix.

From *Neuromancer* by William Gibson

Now showing

Many early science fiction stories are being remade as movies, while new science fiction stories continue to inspire and set your synapses firing. Some science fiction movies explore DNA and genetic engineering (for example, *Gattaca*, *Jurassic Park* and *X-Men*). Other movies take us on journeys through time and space (for example, *Star Trek*, *The Matrix* and *The Time Machine*). The issues and chaos of disease are expressed in *Outbreak* and *The Andromeda Strain* and the potential dangers of robotics are woven into movies such as *I, Robot* and *2001: A Space Odyssey*.



eLesson



Faster computing

Watch a video from the ABC's Catalyst program about nanotechnology and computing.

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UNDERSTANDING AND INQUIRING

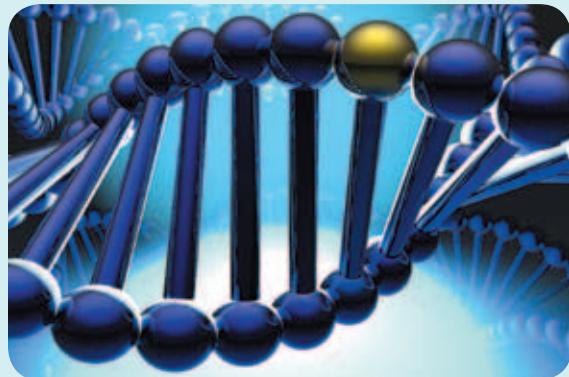
THINK, DISCUSS AND CREATE

- 1 (a) Watch a science fiction movie of your choice. For example: *Gattaca; X-Men; Star Trek; The Time Machine; Outbreak; I, Robot; Frankenstein; 20 000 Leagues Under the Sea*.
(b) Construct a mind map to summarise what the movie was about.
(c) Construct a PMI chart in which the 'P' lists the accurate science in the movie and the 'M' lists the inaccurate, false or misleading science. Under 'I', list things that you found interesting or inspirational about the movie.
(d) Share your PMI chart with others, adding any new ideas that you agree with to your chart.
(e) Suggest changes that you would include if you were to remake the movie.
- 2 On your own or in a team, write your own science fiction story.
 - (a) To start, think about some science concepts, principles or theories that you think would be good in a story. Research these ideas, so that you can give substance to your story and so that its science content is not superficial.
 - (b) Design a cover page for your story that is representative of the plot.
 - (c) Publish a class magazine that contains contributions from all students.
 - (d) Read a different class member's story each night and construct a PMI chart of it.
 - (e) Provide a copy of the story's PMI chart to its author, so that they have some feedback.
- 3 Write a short story that leads on from the following:
I woke up at 2.30 in the afternoon in a hospital bed. Two things were different. My skin had been peeled off my left arm, exposing electronic circuitry, and my right foot was missing.

THINK AND DISCUSS

- 4 Suggest fears that people may have about future robots, computers, chemicals or genetically engineered organisms.
- 5 Will computers become more intelligent than human beings? What implications may this have?
- 6 What is artificial intelligence?
- 7 *Nature never appeals to intelligence until habit and instinct are useless. There is no intelligence where there is no change and no need of change.* Discuss what you think H.G.Wells meant by this in his novel *The Time Machine*.
- 8 Two students observed the figure above right. One student suggested that the golden sphere indicated a mutation in the DNA sequence of a gene; the other

student, however, disagreed. Which student do you think is correct? Justify your response.



INVESTIGATE

- 9 Read and comment on the social implications of any of the novels described in this section.
- 10 What are the rules for the modern robot? Security, safety and sex are considered the big concerns. As robots will be entering homes and workplaces, the need for strict guidelines is hugely important. Discuss this with your team and construct a robot rule book.
- 11 Find out more about the International Human Genome Project, genetic engineering, robotics or other technologies by clicking on the **Future Technologies** weblink in your eBookPLUS.
- 12 How important do you think science fiction is in addressing issues that may affect humanity in the future? Can it help us deal with the ethical dilemmas we may face with increasing progress in biotechnology, genetic modification and computing? If you believe that science fiction authors should not be the ones addressing these concerns for us, who should?

eBookplus

INVESTIGATE AND CREATE

- 13 Imagine that you have created a new gene. Its modified DNA sequence codes for a feature that humans do not currently possess. Use the internet and your own imagination to answer the following.
 - (a) Describe the new feature that this gene codes for.
 - (b) Is the gene going to be inserted into the somatic or the sex cells? Explain why.
 - (c) Outline reasons for the creation of this new gene.
 - (d) Identify how this gene is going to be inserted.
 - (e) Who will have access to this gene technology? Explain why.
 - (f) Write a science fiction story that includes your responses to parts (a)–(e).

work
sheet

→ 9.1 Inventions and innovations

Superheroes to super science

Is there science in the stories of superheroes? Where do the ideas of superpowers come from? Where do scientists get ideas and inspiration for new technologies and products?



Superman

Superman was created in 1938 by Jerry Siegel and Joe Shuster. The story starts with Superman being sent as a baby from his home planet, Krypton, by his parents as his planet is about to explode.

It would make sense that he was sent to Earth because the lower gravity and high energy from our sun might give him an increased chance of surviving. The gravity difference between Earth and Krypton contributes to some of his superpowers. Superman's energy

is thought to come from the sun. The creators may have taken this idea from the way in which plants use light energy in their process of photosynthesis. If this was the case, did Superman's cells use the light energy to trigger some kind of nuclear reaction (like cold fusion), or did he have some way of storing the massive amount of energy that he would have required for all of his super-activities? When Superman is exposed to kryptonite, some of his symptoms are similar to radiation sickness; does that mean that it is radioactive? Where would kryptonite fit into our periodic table? Would it fit among the very heavy elements?

The Incredible Hulk

Dr Bruce Banner, a nuclear scientist, was accidentally exposed to gamma rays and became the Incredible Hulk, a giant with tremendous strength and green skin. The tales behind how his transformation occurs vary. In the recent movie version, his father had modified DNA in his germline cells, which then passed to Bruce. When Bruce's experiments

in nanotechnology led to his exposure to a massive dose of gamma radiation, the radiation acted as a catalyst to express the modified DNA. The incredibly fast and immense cell replication required for Bruce to become the Incredible Hulk and then somehow lose the extra mass to become the meek Bruce again is difficult to explain.



X-Men

The theory of evolution on Earth suggests that it took billions of years for life to evolve from single-celled organisms to the life that we see today. In the X-Men, however, it took only a couple of generations for significant mutations in hundreds of individuals to give them unique powers and abilities. This burst of mutations that radically changed some of our species into X-Men matches the idea of punctuated evolution suggested by Niles Eldridge and Stephen Jay Gould, rather than Darwin's evolution by a slow process of gradual change.

The X-Men go by the name *Homo sapiens superior* rather than *Homo sapiens*, suggesting that they are a human subspecies. If so, they would be able to interbreed with humans and produce fertile offspring.



Spider-Man

After being accidentally bitten by a radioactive spider, Peter Parker gains incredible powers. He has incredible speed, amazing strength and a knack for climbing walls, and he can fire sticky, silky thread from his wrists. Although at first it seems far-fetched that the venom of this spider has had such an effect, think about it a little more. Did the radiation alter the spider's DNA so that the venom produced (a protein) was able to trigger mutations within the DNA in Peter's cells? If these mutations were then expressed, could they lead to spider proteins being synthesised, resulting in particular characteristics that Peter did not have before?

How does Spider-Man climb up walls? Spiders are covered in tiny hair-like structures called setae. Molecular interactions between these and surfaces such as walls and ceilings enable spiders to climb easily. Peter's webbing is an adhesive polymer that mimics spider silk, which has a tensile strength almost equal to steel.

The melding of Spider-Man's superpowers can inspire scientists to use their imaginations and apply their new thinking to fields such as bionics or **biomimicry**, using inspirations in nature to develop new products and technologies. Already a team of Italian scientists are suggesting that their latest nanotechnology discovery may unlock the secret to a wall-scaling Spider-Man suit.



Biomimicry

Biomimicry is the practice of developing new products and technologies that are based on replicating or imitating designs in nature. The most famous example of biomimicry is the invention of Velcro in 1941 by George de Mestral, a Swiss engineer. He was inspired by burrs that stuck to his dog's hair.



Velcro mimics the action of burrs.

Another example is superhydrophobicity or the **lotus effect**. The surfaces of lotus leaves are bumpy, causing water to bead and roll off. Scientists have developed a way to chemically treat the surface of plastics and metals in a similar way. Imagine all of the applications this process could have.



The lotus effect

Scientists have marvelled at the intricate patterns of **silica** within the cell walls of tiny single-celled algae called **diatoms**. They have also been impressed with the ability of diatoms to manipulate silicon at nanoscale levels (around one billionth of a metre), and they have genetically engineered some diatoms to manufacture working valves of specific shapes and sizes. These valves are then used in silicon-based nanodevices that can deliver drugs to target cells within human bodies. This is an example of **biosilification**.



Silica and diatoms

HOW ABOUT THAT? SCIENCE MIMICS LIFE?

Sangbae Kim is an expert in rapid prototyping methods for biologically inspired robotic systems. He uses ideas of mechanisms used by animals, such as how they move, to create mobile robots. One of his robots is the Stickybot, which has foot pads inspired by the feet of the gecko that allow it to climb walls at a speed of about 1 m/s.

The tiny hairs (setae and spatulae) on the pads of a gecko's feet cling to surfaces using molecular interactions known as the **Van der Waals force**. This helps to support the gecko's weight as it scurries up walls (in the same way that similar structures work for spiders). Kim has covered Stickybot's feet with hairs made of silicone rubber. Later models of this design could be used for repairing underground oil pipelines or cleaning windows in multistorey buildings.

Another of Kim's robots is his cockroach-inspired hexapod, iSprawl, which can run up to 15 body-lengths per second over rough terrain.

Dr Sangbae Kim gets his inspiration for his robots from the animal kingdom. Geckoes have almost half a million setae on each foot, enabling them to climb up even very smooth surfaces.



UNDERSTANDING AND INQUIRING

INVESTIGATE, THINK AND DISCUSS

- 1 Suggest why going to a planet with a lower gravity might give Superman an increased chance of survival.
- 2 What is cold fusion? Comment on related research or experiments.
- 3 Describe the symptoms of radiation sickness and ways to treat it.
- 4 Find out more about Superman's kryptonite. Based on the information you have found, suggest where it would fit into the periodic table.
- 5 What are gamma rays and why are they dangerous to living things?
- 6 If Bruce Banner's father's modified DNA was in somatic cells rather than germline cells, would it still have been passed on to Bruce? Explain.
- 7 What is nanotechnology? Identify four different types of applications, research or products that involve nanotechnology.
- 8 Suggest why the Incredible Hulk would have to have incredibly fast cell replication. Suggest where these cells go when he shrinks back to being Bruce.

- 9 Research theories about gradualism versus punctuated evolution. Which do you think is the best theory? Justify your response.
- 10 What is the scientific name for X-Men? Does this mean that they are a different species to non-mutant humans? What are the implications of this?
- 11 Is it possible for foreign DNA to make its way into the human genome? Justify your response.
- 12 If spider DNA was inserted into Peter Parker's DNA, suggest how that could result in Peter expressing spider characteristics.
- 13 Find out more about the possibility of a Spider-Man suit.
- 14 What is meant by the term *biomimicry*? Provide two examples.
- 15 Find out more about Van der Waals force and how it helps geckoes to climb walls.
- 16 Use the internet to find examples of robots that have been inspired by animals.
- 17 Find at least two products or technologies that are based on mimicking nature.



work
sheets

9.2
9.3

Science under scrutiny
Great ideas and lucky breaks!

Nano news

When we immerse ourselves into the world of nanotechnology, we need to learn to think very, very small. So small that many of nature's laws that work in the big world no longer work in the same way!

Tiny, but packing a powerful punch

When we talk about **nanotechnology**, we need to think in **nanometres** (one billionth of a metre, or $\frac{1}{1\,000\,000\,000}$ m). Although our thinking about nanotechnology needs to be small, the implications and potential applications of nanotechnology are enormous. In fact they are so fantastically enormous, that it is very hard to imagine what they all will be.

Nanotechnology has already enabled us to develop super-smart and super-strong materials and medicines, but what new technologies are yet to come from this technology? Will you be one of the scientists who will be contributing to the creation, development and application of technologies that are currently beyond our wildest dreams?

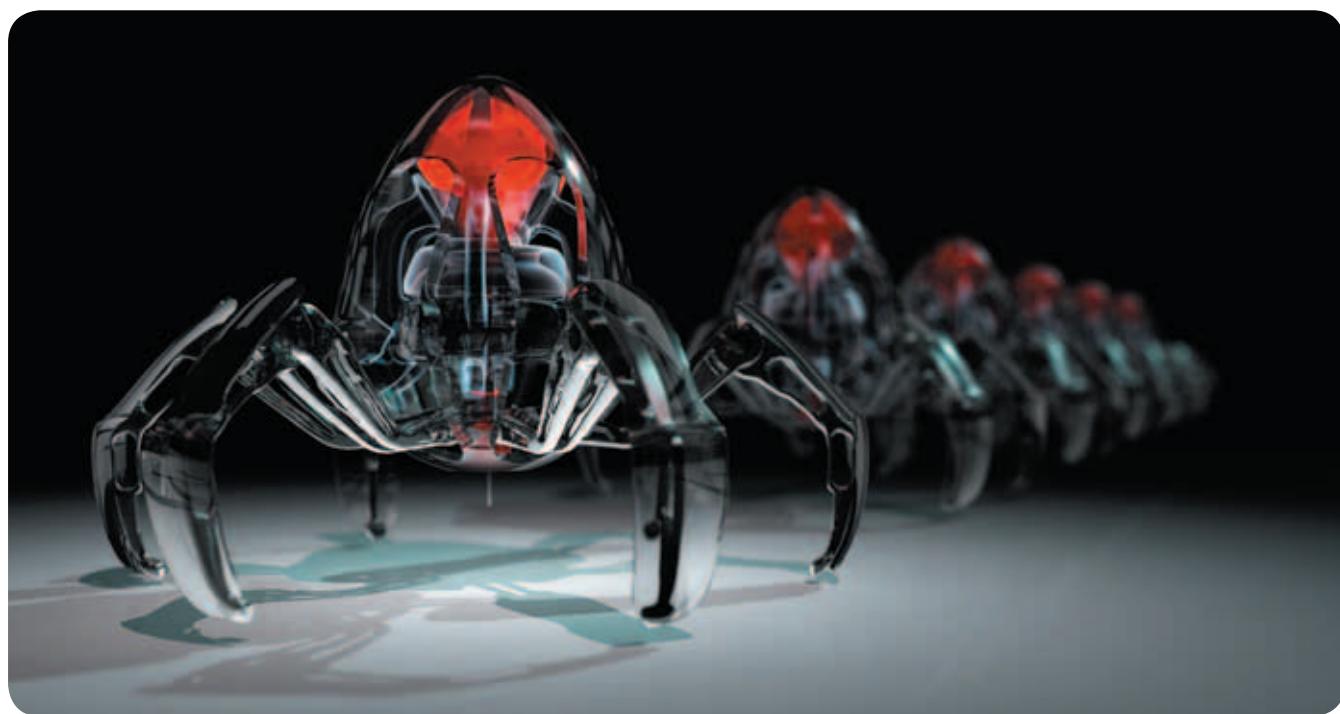
Nanobots to the rescue

Nanotechnology is infecting many other technologies. There are many amazing applications of this technology when it is combined with others. One exciting area is the melding together of nanotechnology, information technology and biotechnology.

Nanotechnology enables us to create and use materials and devices that work at the level of molecules and atoms. Imagine minuscule machinery that could be injected to perform surgery on your cells — from the inside! These nanomachines, or nanobots, could be programmed to seek out and destroy invaders such as bacteria, protozoans or even your own cancerous cells. Heart attacks or strokes caused by blockages in your arteries might also become a thing of the past. These nanobots may be able to cruise through your bloodstream to clear plaque from your artery walls before it has a chance to build up. Could these nanobots also be programmed to repair our telomeres and prevent aging of our cells, act as antioxidants destroying dangerous free radicals, repair DNA mutations — even stop us from growing old? Does nanotechnology hold the secrets of our immortality?

NANO-SPIDERS

Let's hope that you don't have a fear of spiders, because one day one might be crawling through your body as it delivers a drug directly to specific cells or kills cancerous cells. Scientists have created



microscopic robots that look like spiders and are about 100 000 times smaller than the diameter of a human hair. These spider-bots can walk, turn and even create products of their own. Their body is made out of the protein streptavidin; attached to it are three legs of DNA and a fourth leg acting as an anchoring strand.

REMOTE-CONTROLLED POWER PISTONS

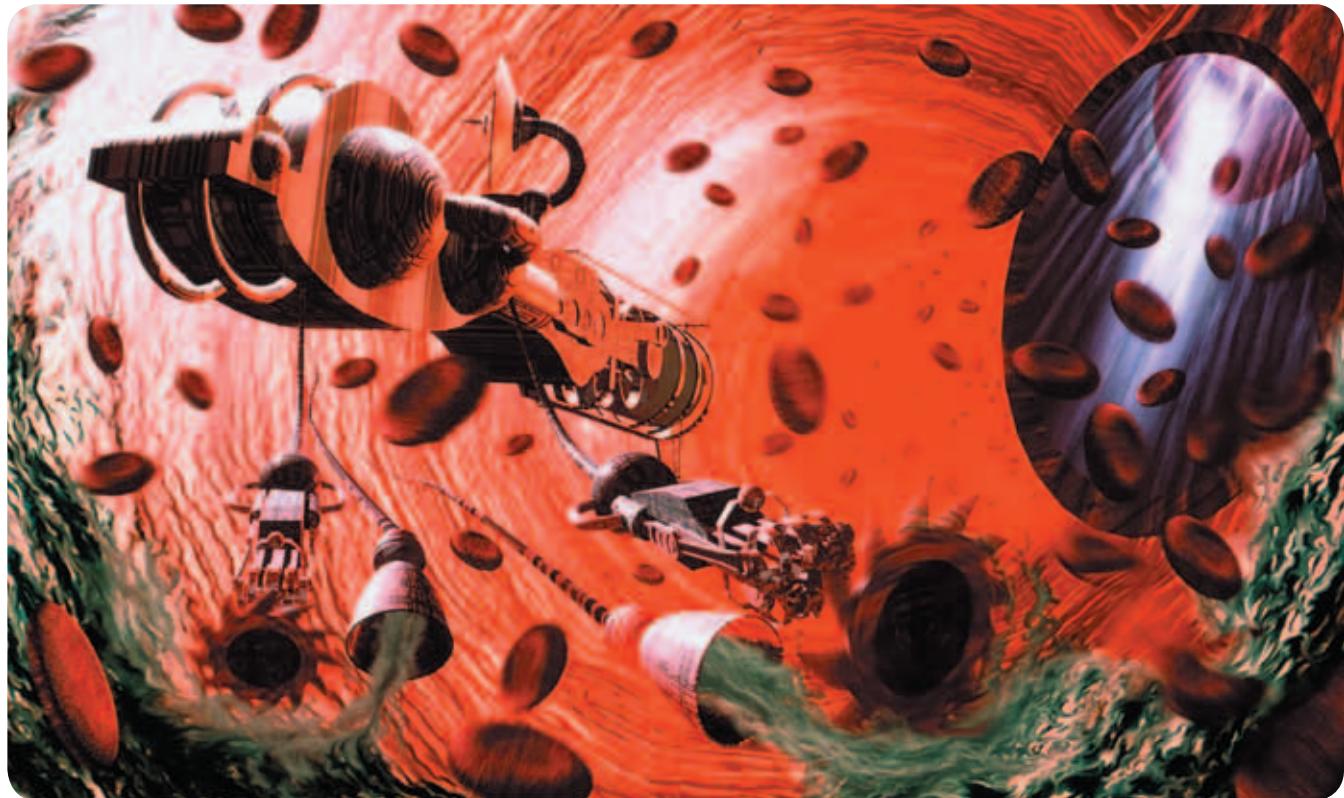
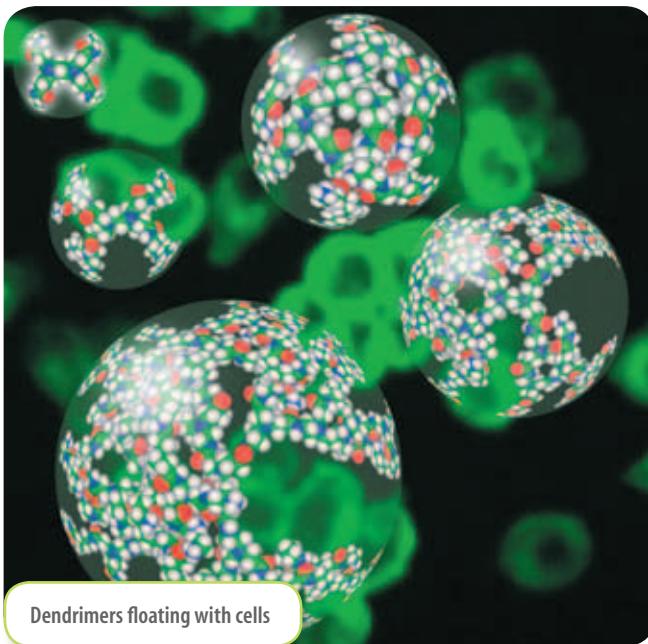
Scientists have built nanoscopic DNA pyramids that respond to different chemicals by changing their shape. They suggest that these structures could be used as motors for nanoscale robots.

Nanocells

Scientists have already designed artificial cells. One of these is an artificial red blood cell. These tiny machines carry stores of oxygen and carbon dioxide with sensors to detect levels of these gases. When levels of oxygen are low they release oxygen, and when carbon dioxide levels are high they absorb carbon dioxide. These artificial cells are around 200 times more efficient than our current red blood cells; this may allow us to swim underwater or sprint for 15 minutes without needing to take a breath. If they were available and you could purchase them, would you use them?

Death-delivering dendrimers

Nanoparticles around the size of 0.1–100 nm — small enough to pass through our cell membranes — are being developed to deliver drugs directly to cancer cells. The basic structure of such nanoparticles is called a **dendrimer**. Scientists have attached folic acid, methotrexate and a fluorescent dye to dendrimers. Folic acid is essential in cell division,



and as cancer cells are actively dividing, they have a high demand for it. The folic acid in the nanoparticle acts as bait to attract the cancer cells. Methotrexate is a drug that kills cancer cells. When the cancer cells accept the nanoparticle, the methotrexate poisons the cell, killing it. The fluorescent dye allows the process to be monitored. The size of these dendrimers allows them to be filtered out of the blood by the kidneys and eventually excreted in urine.

Nano-music

Do you have musical genes? Can you hear your own personal symphony of life? Researchers at Project Evolution have converted the language of DNA and proteins into music. The pattern in the music of Huntington's disease, a triplet repeat disorder, shows up as a repeated musical theme. The tones and rhythms hint at the code behind the code. For example, hydrophilic amino acids have a lower note than hydrophobic amino acids.



Weblink

Gene2Music

Use the [Gene2Music](#) weblink in your eBookPLUS to listen to the music of genes.

Nanoscaffolds

Nanoscaffolds could be implanted into different parts of the body to encourage the regrowth of damaged tissue. An example could be to encourage nerve tissue to regrow optic nerves. Your optic nerve connects your eye to your brain. It can be severed by a traumatic injury (such as in a car crash) or damaged by glaucoma causing excessive pressure in your eyeball. These traumas can lead to vision loss. By using these nanoscaffolds like a garden trellis, the growth of axons of optic nerve cells could be encouraged so that the communication gap can be bridged.

Nanofactories

What will future production factories look like? Imagine millions of tiny robots working together on an invisible, submicroscopic production line. Not only could they assemble almost anything and do it atom by atom, but they could also be programmed to make more of themselves! If you have watched *Star Trek*, maybe this is the technology that they use to generate their clothing and food supplies. Is this yet another example of fiction becoming fact?

Smart stuff

How about wearing clothing that literally reflects your mood? Or how about your wallpaper or lighting changing colour with mood changes or programming? Intelligent fibres, interactive textiles and smart fabrics that have been created with nanotechnology may change colour in a flash.

What if 'one size fits all' really was the case? Imagine shoes that instantly changed shape to mould perfectly around your feet and clothing that changed texture or shape to match your environmental conditions.

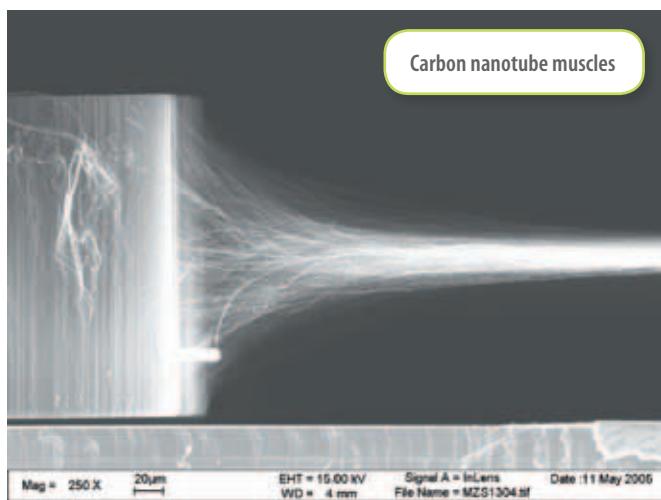
Imagine the effects of paint that has musical nanomachines mixed into it. After putting this paint onto your walls or furniture, you could program it to produce music, tones or vibrations to suit your moods.

Tiny but tough

Imagine a car, train or plane made of diamond and just as strong as current models but 50 times lighter. Nanotechnology may be used to rearrange carbon atoms into an inexpensive workable diamond material. This may lead to the production of a car so light that you could pick it up and carry it!

Nanotubes come on strong

It's not science fiction anymore! Scientists at the University of Texas at Dallas have developed a way to make carbon nanotube 'muscles'. These ribbons of tangled carbon nanotubes can act like artificial fibres in a robot, expanding and contracting to create movement. Not only are they stretchy along



their width, they are extremely stiff and strong along their length. Their ability to maintain these properties in temperatures ranging from about 196 °C to more than 1500 °C would enable robots with these nanotube muscles to function in extreme conditions.

Nanowires

In the movie *Avatar*, the indigenous people of the planet Pandora are connected into a network that links all elements of the biosphere. They are in tune with all other life forms on the planet, from phosphorescent plants to pterodactyl-like birds.



On Earth we have a parallel interconnected ecosystem similar to that in the movie. Some researchers suggest that sulfur-eating bacteria living in the muddy sediments of the sea floor are connected by a network of microbial nanowires. These scientists suggest that these fine protein filaments are involved in shuttling electrons back and forth, allowing these communities of bacteria to function as one super-organism. Lars Peter Nielsen of Aarhus University in Denmark and his team have discovered evidence that may support this controversial theory that he calls electrical symbiosis.

Could this idea inspire the development of another type of communication technology? Will we be connected to each other and possibly other life forms by implanted nanoparticles or nanobots? Could we also be connected to the **abiotic factors** in our environment, being sensitive to their needs and changes? Would such an interconnected ecosystem where we are all in tune with each other and our biosphere help us look after our planet better? Will it save us from extinction?

Tiny size, enormous responsibility

Will nanotechnology be our technological saviour or our exterminator? At the level of atoms and molecules, many of the laws that we accept and use do not necessarily apply. Scientists are still trying to figure out what these laws are, and their implications for the types of technologies that could be — and have been — developed. Have we opened a ‘Pandora’s box’ that will lead to a future of unexpected disasters, or one full of great wonders?

Who is regulating the research, development and application of nanotechnology? Who has ownership of the products of technology and responsibility for any unforeseen dangerous consequences? Are there ethical implications in the types of nanotechnologies that should be allowed? Who decides? Who are the guinea pigs for many of these new nanotechnology products that are largely untested over the long term? What are the implications on future generations of our use of these nanotechnologies?



Will we be able to continue to control nanotechnology, or will it control us?
Who is in whose hands?

UNDERSTANDING AND INQUIRING

REMEMBER

- 1 State how many nanometres are in one metre.
- 2 Suggest why it is difficult to know what all of the potential applications of nanotechnology will be.
- 3 Identify examples of other technologies with which nanotechnology is being combined.
- 4 At what level does nanotechnology allow us to work?
- 5 Describe possible medical applications of nanomachines or nanobots.
- 6 (a) Compared with the diameter of a human hair, how big are the nano-spiders developed by scientists to destroy cancerous cells?
(b) Identify the organic components of these nano-spiders.
- 7 Suggest a use for nanoscopic DNA pyramids that can be triggered to change shape by responding to different chemicals.
- 8 Provide an example of an artificially designed cell and how it could be used.
- 9 Describe how dendrimers can be used to kill cancerous cells.
- 10 Describe a potential application of:
 - (a) nanoscaffolding
 - (b) nanowires
 - (c) nanotubes.
- 11 Suggest why research, development and potential applications of nanotechnology may need to be regulated.
- 12 Suggest why the pattern in the 'music' of Huntington's disease shows up as a repeated musical theme.
- 13 Unscramble the following nano terms.
 - (a) thogaynecolon
 - (b) matonerens
 - (c) renimderd
 - (d) wonairen

INVESTIGATE, THINK AND CREATE

- 14 Research the technology used to make the spider-bots move. Construct your own robot that can move. Your model may be built out of motorised Lego (or similar) or shown in animation style, slowmotion style or any other multimedia format.
- 15 Nano-spiders have drawn huge interest because they are able to sense their environment and react to it. Click on the **Nano-spiders** weblink in your eBookPLUS to find out how this is achieved. Create your own picture book, animation or documentary of this process.

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- 16 (a) Many science fiction stories and shows include ideas based on nanotechnology. Examples include the Borg in *Star Trek: The Next Generation* and the Replicators in *Stargate: SG-1*. Watch a science fiction TV show and evaluate the plausibility of the science within it.
(b) Suggest your own story for another episode in one of these shows.
(c) Use puppets or multimedia to share your story with others.
- 17 (a) Research a possible application of nanotechnology that interests you, including its implications. Possible topics include:
 - spacesuits • clothing
 - nanobots • nanomachinery
 - nanofactories • nanodevices
 - medicines, e.g. drug delivery, biosensors, bioresorbable materials
 - cosmetics, e.g. anti-aging, skin care
 - artificial cells or body parts
 - aeroplanes or spacecraft
 - nanomaterials, e.g. quantum dots, dendrimers, nanotubes, fullerenes.
(b) Share and discuss your findings with other members of your team. Construct a PMI chart to summarise your discussion.
(c) Create a science fiction story that incorporates your findings. Share your story with the class.

INVESTIGATE, THINK AND DISCUSS

- 18 What sorts of research are being performed into the safety of using nanotechnology?
- 19 Who is regulating nanotechnology? Who is determining the safety of this technology? What are their criteria?
- 20 Find out more about the theory of electrical symbiosis. Do you think that such a process really exists? Justify your response.
- 21 If a form of electrical symbiosis or some other type of interconnectedness between individual life forms and the biosphere could exist on Earth, suggest implications of this for survival.
- 22 If dendrimers used to treat diseases are excreted in urine, what happens to them after excretion? Suggest ecological consequences that should be considered.
- 23 (a) Watch the movie *Avatar* and evaluate the accuracy or plausibility of the science within it.
(b) Discuss ideas that the movie inspires for possible scientific research.

work sheet

→ 9.4 Killer-bot

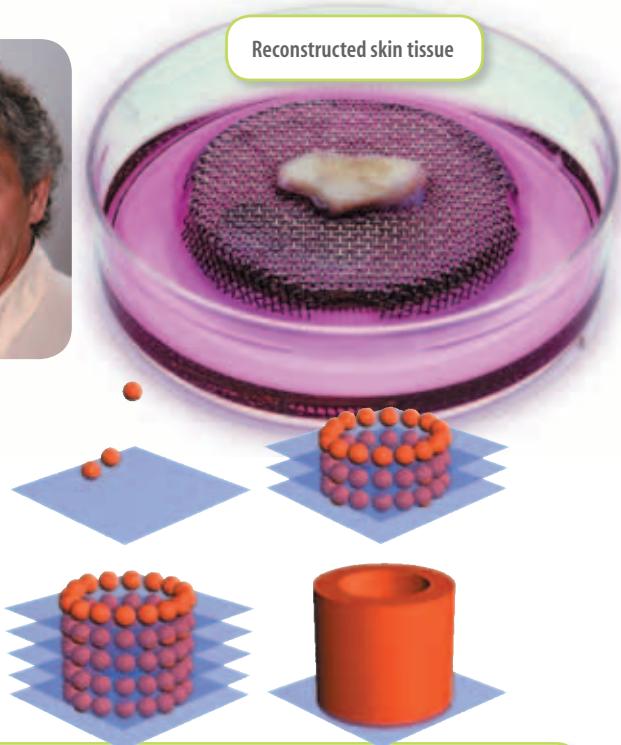
Gardening in the laboratory

Would you like to become a laboratory gardener? Want to grow some new cells, tissues, organs or organisms? Just follow the instructions, plant the seeds and watch them grow!

Grow it back

Want to grow back some missing body parts or create spares? Researchers are racing to create skin, cartilage, heart valves, breasts, ears and other body tissues in tissue-engineering laboratories. Some burns victims have had uninjured skin shaved off their bodies and grown in laboratories, while others have had pre-grown skin grafted onto their bodies.

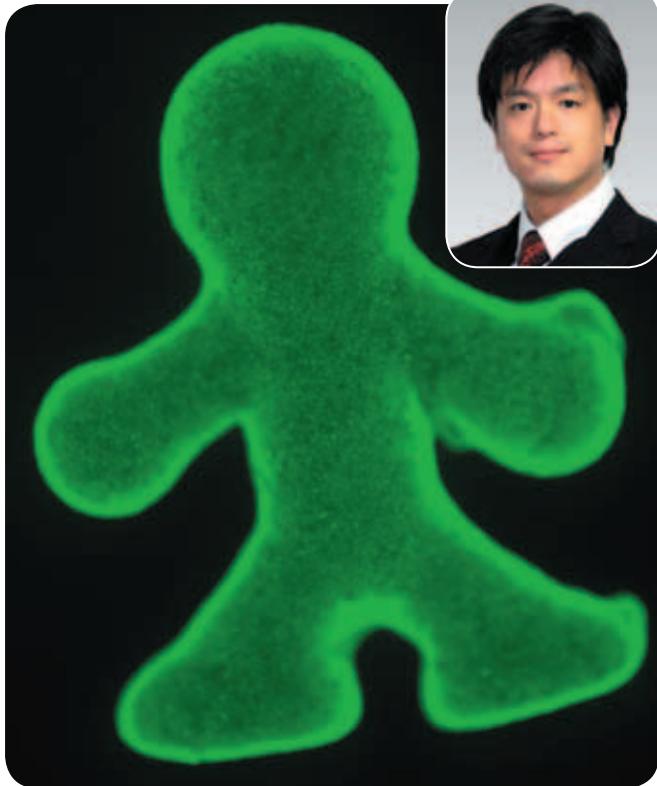
One method used to grow new tissues involves the injection of synthetic proteins that induce tissue to grow and change. These proteins give messages, depending on the combination, to make more fat or bone. Using these methods, spare parts could be grown on-site, or grown elsewhere and transferred later. Some would need surgery for shaping, others would grow using scaffolding (such as freeze-dried joints or cartilage) to give shape.



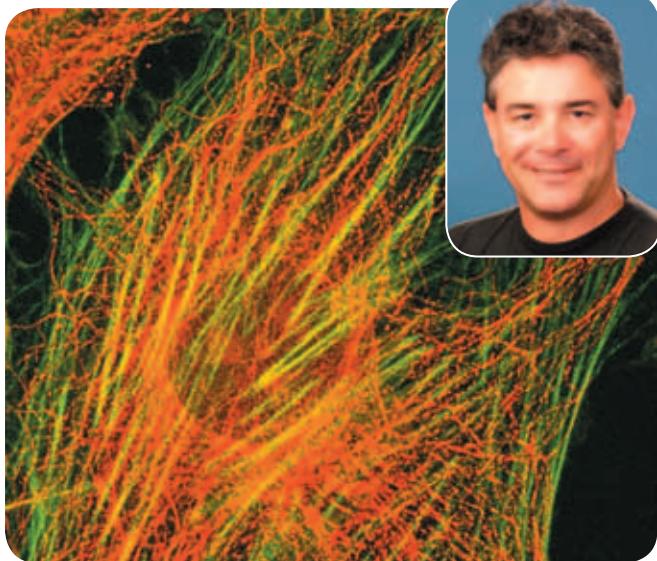
Gabor Forgacs, a tissue engineer at University of Missouri, is making blood vessel networks by using a 3D printer to print them out. He cultures three types of blood vessel cells and then loads them into a fridge-sized bioprinter that has been programmed with the pattern of the vessels to be printed out.



Cardiac researcher Doris Taylor has revived the dead. The process involved rinsing rat hearts with a detergent solution to strip the cells, until all that remained was a protein skeleton of translucent tissue — a 'ghost heart'. She then injected this scaffold with fresh heart cells from newborn rats and waited. Four days later, she saw little areas beginning to beat. After eight days, the whole heart was beating. Could this research lead to new transplant technologies that could be used in humans?



Bearing a resemblance to a jelly baby, a 'living doll' has been created from liver cancer cells. These cells are held in place by 100 000 capsules of collagen. Shoji Takeuchi's team built this figure so that drugs could be tested in conditions closer to those inside the body rather than in a dish.



Keith McLean is a CSIRO scientist whose work involves the development of biomedical materials to replace, repair and regenerate diseases or damaged body parts. His current research is focused on novel biomedical adhesives, ophthalmic biomaterials, bioactive scaffolds for cell therapy and platforms for the propagation of stem cells. The main image here shows mouse fibroblasts (cells of connective tissue) spanning and filling pores in a polymer fibre scaffold.

Imagine a future in which injection of growth proteins into areas where a person is missing a body part would enable bone, joints, fat, tissue, nerves and blood vessels to grow. Imagine being able to grow an ear, joint, nose or finger for immediate use or as a spare!

Mix 'n' match

Transgenic organisms result from combining the genetic information of two different organisms. Genetic information from Arctic fish has been added to tomatoes to make them frost resistant, and genetic information from a bacterium has been added to cotton and potatoes to give them resistance against certain insect pests. Do these altered organisms belong to the same species as those that are not altered? What other changes may result from these new DNA additions?

Recently, the Genetic Manipulation Advisory Committee (GMAC) approved the release of more than 500 transgenic tomato plants into Queensland and Victoria. A gene has been added to these tomatoes so that caterpillars that would normally eat the tomatoes are killed if they eat the plants. It is hoped that this addition will reduce the amount of pesticide that needs to be used.

CSIRO scientists have modified potatoes by switching off the gene that causes cut or bruised potatoes to go brown. They have achieved this by copying the gene, reversing it and then replacing it in the potato plant. This technology could also be applied to other fruit and vegetables.



Killer tomatoes? Scientists are developing genetically modified tomatoes that contain edible vaccines. Diseases that are currently being focused on are Alzheimer's, cholera and hepatitis B. The availability of affordable vaccines for these diseases where they can be easily grown and processed in countries where they are most needed will save many lives.



A healthy glow? Ruppy is the world's first transgenic dog. She and four other cloned beagles have a gene that makes them glow under UV light. Dog fibroblast cells were infected with a virus that inserted the fluorescence gene into their nuclei. These nuclei were transferred into egg cells that had been emptied of their original nuclei; they were then implanted into cloned embryos in surrogate mothers. In the future, the same technique could be used to clone dogs with genes for human diseases or knock certain genes out.

Cloning around

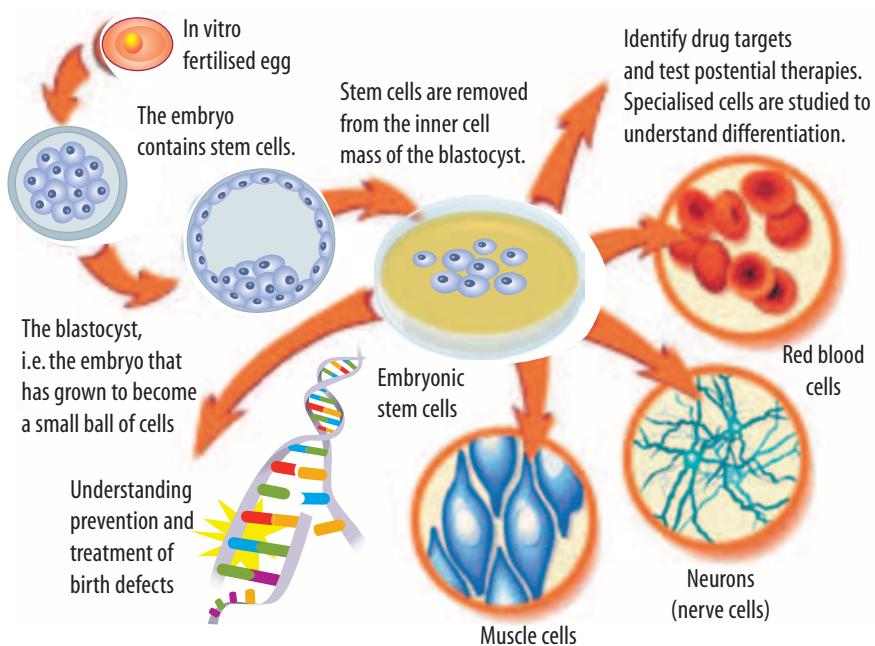
Genetic engineering techniques enable the DNA in organisms to be altered so they can produce proteins and medicines that humans need. These techniques can also produce organs with minimal possibility of rejection for transplants. Cows have been genetically altered to produce more milk or leaner meat, and bacteria have had human genetic information added to them so that they produce insulin for diabetics and blood clotting factors for haemophiliacs. Cloning can then be used to produce these altered organisms in large numbers.

For all of its advantages, cloning may be considered a form of **asexual reproduction** because it does not involve the fusion of two cells. Although it may enable the production of large numbers of identical offspring, their similarities may lead to a decrease in biodiversity and reduce their genetic survival if they are exposed to unfavourable circumstances. The effect of the environment on the cloned individuals also needs to be considered, as genetic inheritance is not the sole factor in determining the phenotype of an organism.

Stem wars

What's the stem of the trouble? What are stem cells and why are people arguing about them?

Stem cells are important because they are so versatile. They have the ability to differentiate into many different and specialised cell types. They may differentiate into blood cells, bone cells, heart cells, liver cells, nerve cells or skin cells. This ability makes them invaluable in the treatment and possible cure



of a variety of diseases where they may replace faulty, diseased or dead cells.

Stem cells can be divided into categories based on their ability to produce different cell types.

- **Totipotent stem cells** are the most powerful as they can give rise to all cell types.
- **Pluripotent stem cells** can give rise to most cell types (e.g. blood cells, skin cells and liver cells).
- **Multipotent stem cells** can give rise to only certain cell types (e.g. various types of blood or skin cells).

HOW ABOUT THAT!

In 1998, it was reported that a researcher from the University of Wisconsin had found a way to isolate cells from the inner mass of an early human embryo and develop the first embryonic stem cell lines. The stem cell issue had entered the public arena.

STEM CELL SOURCES

Stem cells can be described as being **embryonic stem cells** or **somatic stem cells**. Embryonic stem cells are pluripotent and can be obtained from the inner cell mass of a blastocyst (the mass of cells formed at an early stage of an embryo's development). Somatic stem cells are multipotent and can be obtained from bone marrow, skin and umbilical cord blood.

WHAT'S THE PROBLEM?

The source of embryonic stem cells raises many ethical issues. Embryonic stem cells can be taken from spare human embryos that are left over from fertility treatments or from embryos that have been cloned in the laboratory. Some say that this artificial creation of an embryo solely for the purpose of obtaining stem cells is unethical. There has also been concern about the fate of the embryo. In the process of obtaining stem cells, the embryo is destroyed.

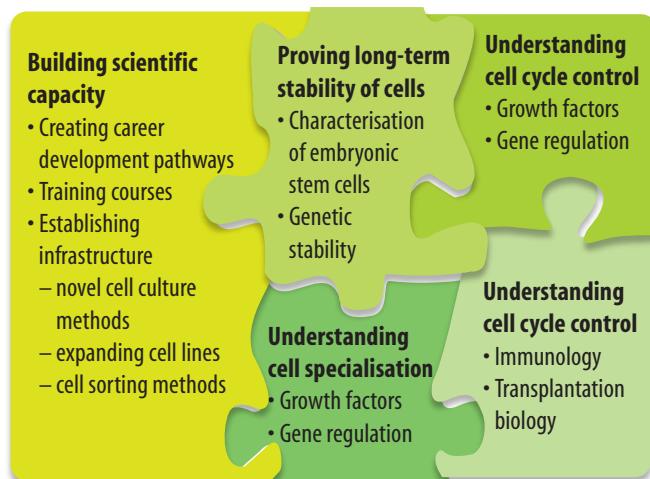
Some parents have decided to have another child for the sole purpose of being able to provide a diseased or ill child with stem cells. In this case, the blood from the umbilical cord or placenta is used as a source of stem cells. Some suggest that this is not the right reason to have a child and that they should not be considered to be a source of spare parts for their siblings.

ENDOGENOUS STEM CELLS

Most research so far has been on creating stem cells from embryos or adult tissues in labs and

The scientific challenges of human stem cells

Basic research phase



Research in human stem cells faces a number of challenges. There is much about these cells that we do not fully understand, such as the mechanisms that drive cell specialisation and the interaction between host and transplanted cells; and the long-term stability of transplanted cells needs to be established.

manipulating their development using chemical growth factors and implanting them where needed. But there could be another way: awakening our bodies' own endogenous stem cells to achieve natural regeneration. Imagine being able to regrow entire lost limbs, as some amphibians can!

HOW ABOUT THAT!

Scientists at CSIRO are studying Australian frogs and their ability to produce a sticky glue-like substance. These frogs, from the genus *Notaden*, produce this substance as a protective measure against predators. The CSIRO scientists want to mimic the design of this glue so that they

can produce a medical adhesive that could be used to repair damaged cartilage, close up wounds and bond cartilage, tendons and

bone. Could their research also provide us with a substance to help us stick in our replacement spare parts?



UNDERSTANDING AND INQUIRING

THINK

- 1 If cloning takes over as the main form of human reproduction, sperm and eggs would no longer be essential.
 - (a) Suggest advantages and disadvantages of this. Give reasons for your suggestions.
 - (b) If 100 clones were made of a single individual, would they all look and act the same? Explain your answer.
 - (c) Suggest the evolutionary consequence that this may have on the human race.
- 2 Should human DNA be inserted into the DNA of other organisms? Give reasons for your opinion.
- 3 Suggest improvements to the human design. List both advantages and disadvantages of these improvements.
- 4 Would you eat genetically modified food? Find out published arguments for and against this issue. Once researched, decide on your viewpoint and present your arguments in a class debate on the issue.

IMAGINE

- 5 Design a futuristic human. Give reasons for your changes to the original human design and present your information in a poster.
- 6 Imagine you are living in the future and your partner has asked you to have his or her children. You think that this is wonderful until you realise that he or she means clones. What would you say?
- 7 Imagine that you have just woken up in a laboratory and have been told that you are a clone. Write a story about your life.

INVESTIGATE, SHARE AND DISCUSS

- 8 Find out about the relationship between cloning and biotechnology.
- 9 For one of the following transgenic organisms, find out the following and present your findings in a report and as a class presentation: tomatoes, potatoes, pigs, cows, fish, tobacco, cotton, bacteria.
 - (a) How and why they were made
 - (b) Any biological, social, economic or ethical issues that may result from the change to the organism
 - (c) Your own comments on what you think and feel about these changes
- 10 Debate issues related to:
 - (a) the development of transgenic organisms
 - (b) the cloning of human tissues and organs.
- 11 Find out the requirements for space travel. Suggest how a human could be genetically engineered to be well suited to travelling in space.

- 12 Investigate some of the following questions.

- (a) Which inherited genetic diseases are potentially treatable with stem cells?
- (b) How many different kinds of adult stem cells exist and in which tissues can they be found?
- (c) Why have the adult stem cells remained undifferentiated?
- (d) What are the factors that stimulate adult stem cells to move to sites of injury or damage?

- 13 View an animation about stem cells by clicking on the **Genetic Science**

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Learning Centre weblink in your eBookPLUS. Use these ideas to construct your own story, cartoon, PowerPoint presentation or animation on stem cells.

- 14 In your team, discuss the following questions to suggest a variety of perspectives.

- (a) Is it morally acceptable to produce and/or use living human embryos to obtain stem cells?
- (b) Each stem cell line comes from a single embryo. A single cell line allows hundreds of researchers to work on stem cells. Suggest and discuss the advantages and disadvantages of this.
- (c) If the use of human multipotent stem cells provides the ability to heal humans without having to kill another, how can this technology be bad?
- (d) Parents of a child with a genetic disease plan a sibling whose cells can be used to help the diseased child. Is it wrong for them to have another child for this reason?

- 15 Find out how stem cell research is regulated in Australia and one other country. What are the similarities and differences of the regulations? Discuss the implications of this with your team-mates.

- 16 Research aspects of stem cell research and put together an argument for or against the research and its applications. Find a class member with the opposing view and present your key points to each other. Ask questions to probe any statements that you do not understand or would like to clarify. Construct a PMI chart to summarise your discussion.

- 17 Snuppy, the world's first cloned dog, was created by Woo Suk Hwang's team at Seoul University in South Korea.

- (a) Find out more about Hwang's scientific achievements.
- (b) Find out more about Hwang's research and a reason for his arrest and jail sentence. Were his actions justified? Justify your response.

- 18 Use the **Organ printing** weblink in your eBookPLUS to watch interviews and animations of examples of the technologies outlined in this section.

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Tapestries within our biosphere

Throughout history, life on Earth has been linked to global climate change. The evolution of species has been linked not only to their environments but also to each other. Like threads in a three-dimensional tapestry, the components that make up our Earth's biosphere are interwoven on many different levels.

Prokaryotic cells change our planet

When the first signs of life appeared on Earth, its atmosphere was not as it is today. There was no oxygen for cellular respiration and no ozone layer to protect organisms from the sun's harmful ultraviolet radiation.

The first cellular organisms to appear were prokaryotes, such as bacteria. Fossils of prokaryotes have been found in 3.5-billion-year-old rocks, and fossil records suggest that mounds of these bacteria once covered the Earth.

MUTATIONS, BIODIVERSITY AND OXYGEN

Various types of mutations occurred in these prokaryotes. This resulted in an increasingly diverse range of new life forms. The selection of a sequence of these mutations enabled some of these bacteria to harvest energy from the sun and use carbon dioxide in the atmosphere to make their own food. Using this process of photosynthesis, they released oxygen back into the atmosphere. Over time, this was to change the composition of Earth's atmosphere, with some of the oxygen also being converted into ozone, which was later to form the ozone layer.

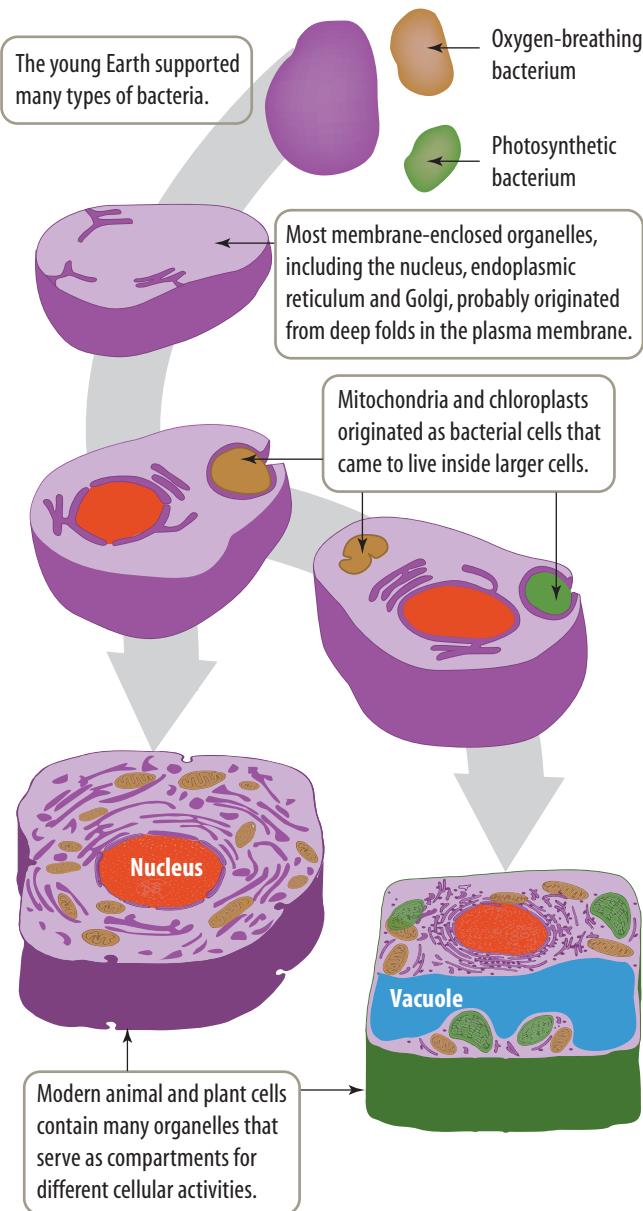
Eukaryotic cells finally appear

Eukaryotic cells finally made their entrance on Earth around 1.8 billion years ago. These cells differed from **prokaryotic cells** in that they contained a variety of membrane-bound **organelles**. These included a nucleus, endoplasmic reticulum and Golgi bodies. Some scientists have suggested that these may have originated from deep folding of the plasma membrane.

The fossil record suggests that organisms made up of many eukaryotic cells appeared about one billion years ago. Cells within these multicellular organisms became specialised for particular functions.

Endosymbiotic theory of evolution

Symbiosis describes a relationship between two different species in which they both benefit



from living and working together. When one of these organisms lives within the other it is called **endosymbiosis**. The **endosymbiotic theory** describes how an ingested bacteria and its larger host cell could become so dependent on each other that after many years of evolution they could not live without each other.

CHLOROPLASTS AND MITOCHONDRIA CONTAIN THEIR OWN DNA

Chloroplasts and **mitochondria** are membrane-bound organelles that are found in eukaryotic cells. They possess striking similarities to prokaryotic cells. They are surrounded by a double membrane and contain their own DNA, which is different and separate from the DNA located within the nucleus. Their DNA is used to produce many of the proteins (such as enzymes) that are essential for their function. These organelles also reproduce like bacteria and coordinate their own DNA replication and division.

It is thought that animals and plants shared a common ancestor that had acquired mitochondria by the process of endosymbiosis. Later, plants also acquired chloroplasts, and their evolutionary path diverged from that of animals.

With increased numbers of photosynthetic organisms, there was an increase in the amount of oxygen in the atmosphere. This provided an environment with conditions suitable for the evolution of a variety of organisms that could use this oxygen in the process of cellular respiration. This process removed oxygen from the atmosphere and released carbon dioxide back into it.

Parasitic superpowers

In various science fiction and superhero stories there are numerous characters (usually the nemesis or



Sea slugs of the species *Elysia chlorotica* (left) steal chloroplasts from algae (right) and gain the ability to photosynthesise.

enemy of a superhero) that can steal superpowers from others. Did you know that there are organisms that can actually do this?

Maybe the Spider-Man stories aren't so far-fetched. Amid the diversity of life currently on our planet, some animals have evolved mechanisms to be able to incorporate organelles (such as chloroplasts) or specialised cells from other species into their own bodies and then use the functions of what they have stolen.

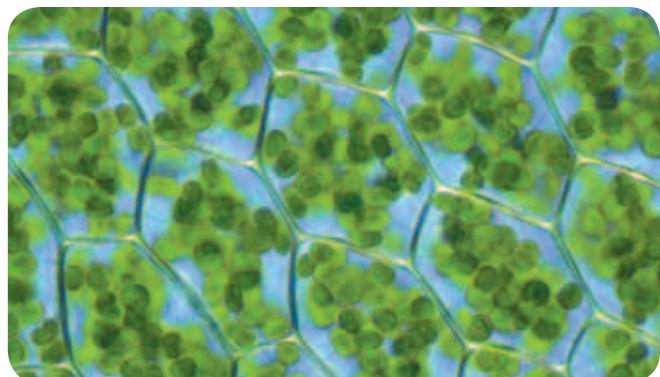
One recent discovery is a type of sea slug, *Elysia chlorotica*. These nudibranch sea slugs steal chloroplasts from algae and then start photosynthesising themselves. Some scientists view this as a type of symbiosis at a genetic level, with partners sharing genes.

STEALING STINGING POWERS

Another type of nudibranch, *Phidiana crassicornis*, can extract the stinging organelles (cnidocytes) from jellyfish and coral and insert them into their own tissue, giving them a weapon that they didn't have before! Once they use these cells, however, they need to find a fresh supply. This is not the case with *Elysia chlorotica*.



The nudibranch *Phidiana crassicornis* can extract stinging cells from jellyfish and coral to use as a weapon.



SOLAR-POWERED ANIMALS

After just one single meal of algae (*Vaucheria litorea*), *Elysia chlorotica* possesses the ability to photosynthesise for life. Scientists have found that the slug actually cuts open the algal filaments and sucks out the contents. It then transfers the living chloroplasts into cells lining its gut. This phenomenon is sometimes referred to as **kleptoplasty** and the captured plastids as **kleptoplasts**.

As these chloroplasts are in the somatic cells and not the gametes of the sea slugs, they are not inherited when the slugs reproduce. Their offspring need to have their own meal of algae to gain the ability to photosynthesise.

We can't survive without you!

Scientists have also discovered that not only is the association between *Elysia chlorotica* and *Vaucheria litorea* specific, it is also obligate. This means that the algae are essential to the life cycle of the sea slug. *Elysia chlorotica* will not complete metamorphosis and develop into an adult in the absence of its algal prey.

UNDERSTANDING AND INQUIRING

REMEMBER

- 1 Identify the first type of cellular organisms to appear on Earth.
- 2 How long ago does the fossil record suggest that cellular organisms on Earth appeared?
- 3 Suggest an environmental effect caused by photosynthesis.
- 4 Approximately how long ago did eukaryotic cells first appear on Earth?
- 5 Identify a way in which prokaryotic and eukaryotic cells differ from each other.
- 6 Outline the difference between symbiosis and endosymbiosis.
- 7 Describe features that mitochondria and chloroplasts have in common.
- 8 Explain how *Elysia chlorotica* adults can contain plastids when their sex cells (eggs) do not.
- 9 The relationship between *Elysia chlorotica* and *Vaucheria litorea* is specific and obligate. What does this mean?
- 10 State the types of scientific approaches that scientists may need to use to solve the mysteries of the evolutionary relationship between *Elysia chlorotica* and *Vaucheria litorea*.

A mystery yet to solve

Scientists are currently exploring questions about how these chloroplasts can continue to function without the algal nucleus on which they were previously dependent. Some scientists suggest that the slug's genome may contain genes transferred from the alga without which the chloroplasts could not function, making it a **holobiont** (combined genome) of slug genes and algal genes.

Other scientists consider that the survival of the chloroplasts is a result of multiple endosymbiotic events, gene transfer and the evolution of modern-day chloroplasts and mitochondria. Scientists are still asking questions and will hopefully be able to use genomic, biochemical, molecular and cellular approaches to unravel the mystery. Will you be the one to solve it?

Looking at the past

There are many scientific careers involved in exploring Earth's history, unlocking mysteries of life from the past and relating it to the present and future. These include palaeogeology, palaeobiology, geology and archaeology.

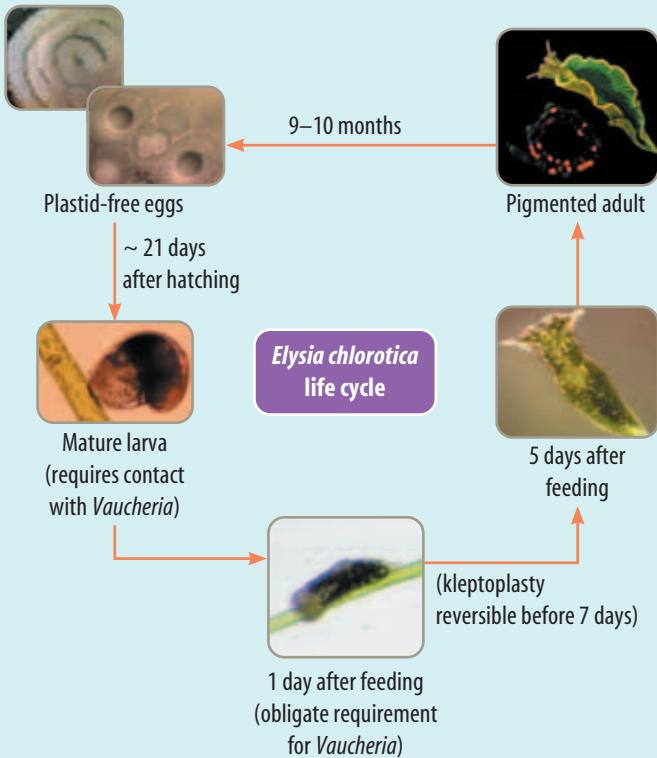
INVESTIGATE, THINK AND DISCUSS

- 11 Find out more about the evolution of:
 - (a) chloroplasts and mitochondria
 - (b) *Elysia chlorotica* and *Vaucheria litorea*
 - (c) prokaryotic cells and eukaryotic cells.
- 12 A 268-million-year-old fossil found on the southern coast of NSW by Professor Guang Shi of Deakin University is considered to contain two species of fossilised bacteria that had lived in symbiosis with a burrowing animal. Shi suspects that the animal acted like a gardener, cultivating the bacterial species best suited to changing climatic conditions. Find out more about this research and other research related to palaeobiology, palaeobiology and global change.



Professor Guang Shi, a geologist and palaeontologist is involved in research on palaeobiology and global change.

- 13** Examine the figure below and read the relevant information in this section.
- At what age do these sea slugs reproduce?
 - Do the eggs of *Elysia chlorotica* contain chloroplasts?
 - Describe what happens five days after the larva feed on algae.
 - Suggest an evolutionary advantage of the relationship being selected for.
 - Suggest a future application of this knowledge.
 - Suggest a hypothesis about this process that could be investigated.



- Dr Trinajstic is now working with Kliti Grice, professor of chemistry at Curtin University and Director of the Western Australia Organic and Isotope Geochemistry Centre, to identify biomarkers in fossils that will reveal what the fish were made of and what they ate. Research and report on:
 - the use of biomarkers to find out more about fossils
 - organic and isotope geochemistry.
 - In 2010, Dr Trinajstic won the Malcolm McIntosh Prize for Physical Scientist of the Year.
- To listen to her speak about her work, click on the **Prime Minister's Prize for Science** weblink in your eBookPLUS.

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(a) The 'mother fish' fossil
(b) Dr Kate Trinajstic



- 14** Research and report on scientific contributions or research from one of the following eminent Australian palaeontologists: Geoffrey Archer, Malcolm Walter, Neil Archbold, Neil Marshall, Alan Partridge, David Haig, John Laurie, Dana Milder, John Mortimer.

- 15** In 2008, palaeontologist Kate Trinajstic from Curtin University in Perth made one of Australia's most significant fossil discoveries. The famous 'mother fish' fossil, *Materpiscis attenboroughi* (named after the well-known science presenter David Attenborough) pushed back the earliest known live birth an astonishing 200 million years. The analysis of her discovery brought together scientists from different science disciplines and showed the need to develop new techniques for further investigations.

- Find out more about Dr Trinajstic's 'mother fish' fossil and how it changed our evolutionary theories.
- Find out examples of science disciplines that are involved in analysing fossils.

INVESTIGATE, IMAGINE AND CREATE

- Construct models to link the endosymbiotic evolution theory to either mitochondria or chloroplasts.
- Find out more about organisms that steal functions from other species. Create a science fiction story that links what you have found to your imagination.
- Imagine that you are a palaeobiologist or palaeogeologist. Click on the **Australian Museum Palaeontology Collection** weblink in your eBookPLUS to do some research.
 - Write a story describing an exciting week in your life.
 - Suggest three research questions that you may be involved in investigating.

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DNA — interwoven stories?

Do you think you are special? Of course you are! Your DNA contains a wonderful tapestry of not just your human ancestry but also that of other genomes.

Hologenome theory of evolution

Although we see ourselves as being purely human, we are not. Like other plants and animals, we contain DNA from a variety of sources. The **hologenome theory of evolution** emphasises the role that micro-organisms have within our evolution.

Micro-organisms (microbiota) within their hosts (such as plants or animals) can be described as being **symbionts**. The term holobiont is used to describe the host and all of their symbiont microbiota collectively. This has been suggested by some scientists to be a unit of selection in evolution.

The hologenome is made up of the combined genomes of the host and the microbes within it. Genetic variation within the holobiont may occur in both the host and the microbial symbiont genomes, and the variation can be inherited by the offspring. Some of this variation may occur within existing microbes; other variation may be due to microbes newly acquired from the environment. Some scientists consider this view as being Lamarckian, as the inheritance of variation via microbes follows Lamarck's idea that traits acquired within the lifetime of the parent can be transmitted to the next generation.

From 'junk' to treasure?

Did you know that our genome contains viral DNA? Our DNA is made up of coding and non-coding sections. It was long thought that the non-coding DNA served no purpose. As this DNA contained highly repetitive sections and did not code for amino acids, it was often referred to as 'junk' DNA. New technologies and discoveries, however, are fast changing our views of this. Scientists have discovered that some of these non-coding regions contain genes that regulate many activities, and without them, protein synthesis using the coding DNA sections would not occur.

IDENTIFIED BY YOUR 'JUNK'?

Scientists have found that the complexity of an organism is not matched to the total amount of DNA that it contains. What they have discovered is that there is a relationship between the proportion of non-coding and coding DNA. When testing people's tissue types, Malcolm Simons, a New Zealand-born immunologist, discovered that the pattern of the 'junk' DNA surrounding MHC genes was a very good predictor of tissue type. Some scientists suggest that this 'junk' DNA has played a key role in making us human, as it distinguishes primates from other mammals. It has been suggested that this 'junk' DNA is due to the invasion of a million copies of jumping genes!

Jumping genes

Barbara McClintock (1902–1992) was a cytogeneticist whose scientific theories (and possibly her gender) clashed with the scientific community of her early research years. McClintock investigated how chromosomes change during reproduction in maize (*Zea mays*). Maize proved to be the perfect organism for the study of transposable elements (TE) or 'jumping genes'. She contributed to our understanding of the mechanism of crossing over during meiosis and produced the first genetic map for maize. She linked regions of the chromosome with physical traits and demonstrated the roles of telomeres and centromeres. She also discovered **transposition** and outlined how it could be involved in turning on and off the expression of genes.

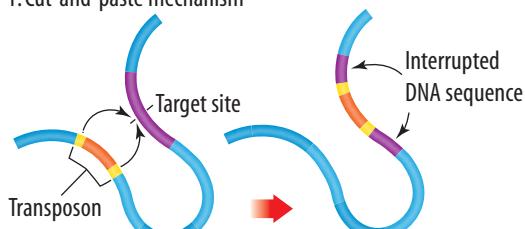
McClintock pioneered the study of **cytogenetics** in the 1930s. Before the structure of DNA was even discovered, McClintock was the first scientist to outline the basic concept of **epigenetics**, recognising that genes could be expressed and silenced. McClintock's theories were revolutionary because they suggested that an organism's genome was not a stationary entity, but something that could be altered and rearranged. This view was highly criticised by the scientific community at the time. She was eventually awarded the Nobel Prize in Physiology or Medicine in 1983, when she was over 80, for research that she had done many years before.

YOUR JUMPING GENES

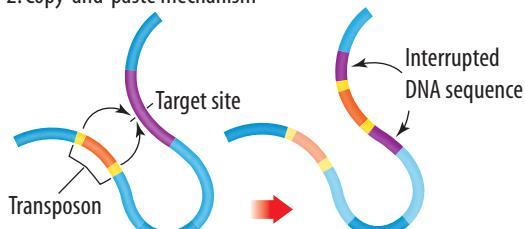
Some of the repeating sequences within our non-coding DNA are known as **transposons** or 'jumping genes'. They may have originated from invading viruses. These sections have the ability to copy themselves independently of the rest of the genome and then randomly insert themselves in other sections of the genome. There have been suggestions that our evolution has been shaped by these transposons.

Two methods of transposition:

1. Cut-and-paste mechanism



2. Copy-and-paste mechanism



DNA sequences known as transposons or 'jumping genes' can copy themselves into other sections of the genome.

Genetic invasion

The human immunodeficiency virus (HIV) is an example of a retrovirus. Retroviruses convert their RNA genome into DNA before implanting it into host chromosomes. This process is called **endogenisation**. If the viral genome is incorporated into the chromosomes in the host's germline, it can become a part of the genome of future generations.

Are you aware that such germline endogenisation has happened repeatedly in our own lineage? This mechanism may help explain the varied sources of the DNA in your own genome. It provides an explanation as to why our genome may contain thousands of **human endogenous retroviruses (HERVs)**. Are these the legacies of viral invasions throughout our evolutionary history?

Viruses have an amazing ability to unite, genome to genome, with their hosts. This has a powerful

evolutionary significance; it supplies the host with a new source of variation for evolution. If a virus happens to introduce a useful gene, natural selection will act on it. Like any other beneficial mutation, it will spread through that population and the next.

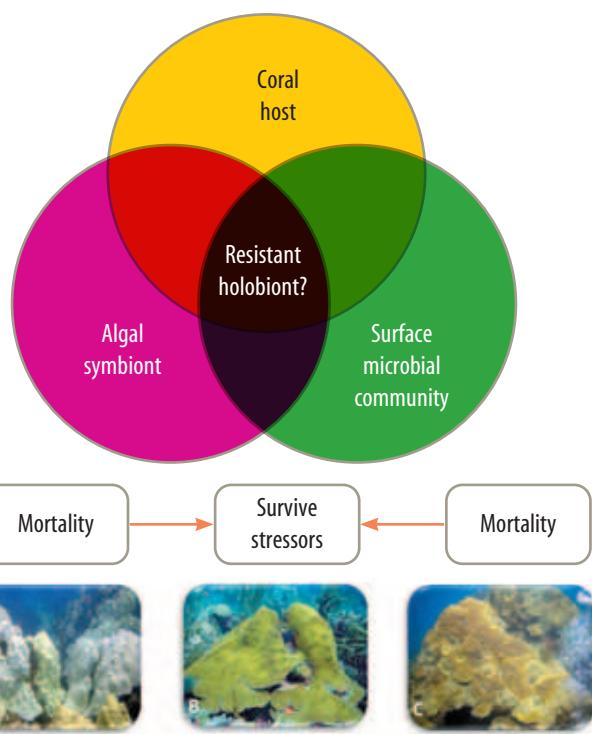
If the human genome has evolved as a holobiontic union of vertebrate and virus, could plagues be considered a vital evolutionary survival tool for our descendants? What are the implications of this theory in terms of how we treat diseases and think about viral infections? Do viruses have a place not just in our present, but in shaping our future evolution?

COPING WITH CLIMATE CHANGE

Some scientists have suggested that reef corals and possibly some other multicellular organisms may alter the microbial communities within their bodies to cope with environmental stresses such as those caused by climate change. More studies on this may provide us with some strategies we can use to help reduce the loss of biodiversity in ecosystems threatened by environmental changes related to climate change.

A career in Caribbean coral holobionts

Emmanuel Buschiazzo began his academic career as a scientist studying applied marine biology in Edinburgh, Scotland. He worked at the Marine





(a) Dr Emmanuel Buschiazza (b) *Montastraea faveolata* coral (c) *Acropora palmata* coral

Environment Laboratory in Monaco in marine ecotoxicology, then did his PhD in New Zealand studying the evolution of microsatellite DNA. His next adventure sent him to Canada for a postdoctoral fellowship in conifer genomics. He is currently involved in blending genomic approaches and population genetics to unravel the biology of two Caribbean coral holobionts, *Montastraea faveolata* and *Acropora palmata*.

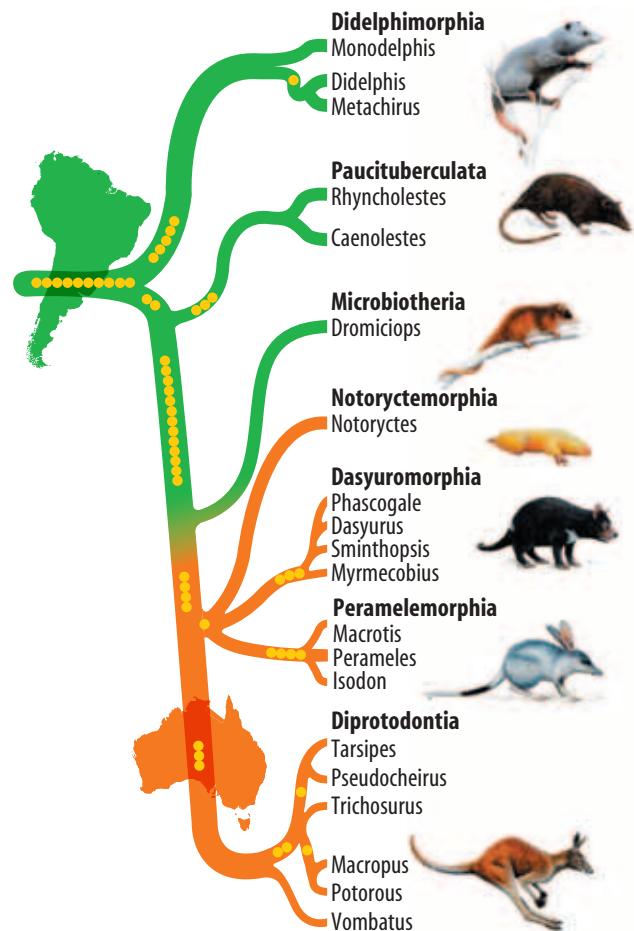
Australian marsupials and jumping genes

Scientists have argued about how marsupials such as kangaroos, opossums and Tasmanian devils evolved in South America and Australia. DNA sequencing and the fossil record tell two different stories. Do ‘jumping genes’ hold the answer to the mystery?

A German evolutionary biologist, Maria Nilsson, has been investigating this mystery by looking at strange bits of DNA called **retroposons**. Retroposons have the ability to break off chromosomal DNA and then copy and paste themselves elsewhere in the genome. Once they copy and paste themselves their locations are stable, making them a reliable marker for determining evolutionary relationships.

Nilsson’s retroposon data suggests that the Australian and South American marsupials could be divided into two distinct groups that had little contact as they evolved. This supports the DNA sequencing data that they share a single South American ancestor who travelled to Australia before

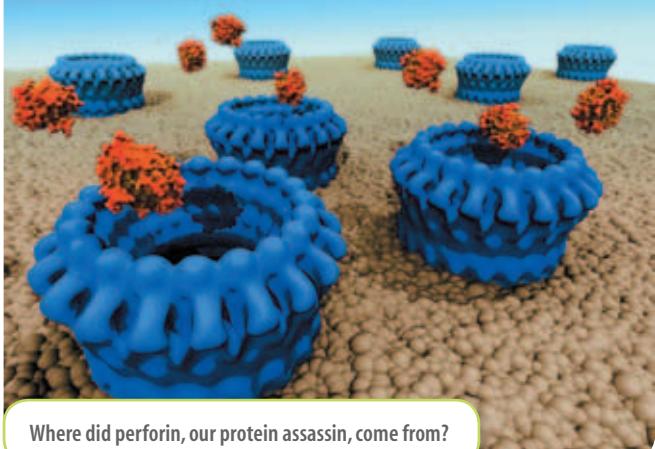
the continents drifted apart, and that they evolved separately afterwards.



Our protein assassin

Australian and British scientists have identified the process through which our natural killer cells

(part of our immune system) puncture and destroy virus-infected or cancerous cells. A protein called **perforin** is responsible for forming a pore in the diseased cell. The natural killer cells can then inject toxins into the diseased cell to kill it from within. By using the Australian Synchrotron and cryo-electron microscopy, scientists have determined the structure of perforin and how it creates pores. This protein resembles cellular weaponry used by bacteria, and it is possible that our immune system may have incorporated the genetic information from bacteria within our evolutionary past.



Where did perforin, our protein assassin, come from?

UNDERSTANDING AND INQUIRING

REMEMBER

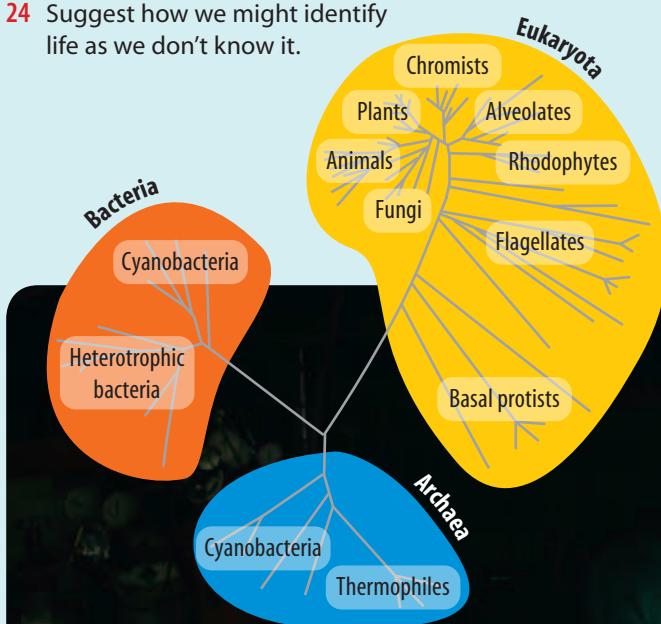
- 1 Suggest why we should not think of ourselves as purely human.
- 2 Suggest what the hologenome theory of evolution emphasises.
- 3 Suggest what is meant by the following terms.
 - (a) Symbiont
 - (b) Holobiont
 - (c) Hologenome
 - (d) Endogenisation
 - (e) Transposon
 - (f) Retroposon
- 4 Suggest why we no longer call regions in our DNA that do not code for proteins 'junk' DNA.
- 5 Who was Barbara McClintock? List examples of ways in which she contributed to our understanding of genetics.
- 6 State another name for 'jumping genes'.
- 7 Provide an example of a retrovirus.
- 8 Suggest how we know that germline endogenisation has occurred within our own lineage.
- 9 Suggest how research on retroposons has contributed to our knowledge about the evolution of Australian marsupials.

INVESTIGATE, THINK, DISCUSS AND REPORT

- 10 Research and report on one of the following.
 - (a) The hologenome theory of evolution
 - (b) Symbionts
 - (c) Holobionts
 - (d) Hologenome
 - (e) Barbara McClintock
 - (f) Transposons (or 'jumping genes')
 - (g) Endogenisation
 - (h) Microbiota and climate change
 - (i) Caribbean coral holobionts
 - (j) Australian marsupials and jumping genes

- (k) Retroposons
 - (l) Epigenetics
 - (m) Perforin
 - (n) Astrobiologists
 - (o) Artificial life
 - (p) Mitochondrial DNA
 - (q) Chromosome painting
- 11 If viruses kill about 20 per cent of all living material in the oceans every day, releasing their contents for other organisms to grow, does that mean that they drive ocean ecosystems?
 - 12 Yellowstone Park in America is a place that attracts scientists. Suggest why many scientists view this park as a voyage back in time.
 - 13 Discuss the following statement: *If it weren't for viruses, ocean ecosystems would stop.*
 - 14 How do you feel about the possibility of having viral DNA in your DNA? Construct a PMI chart for a discussion on this question with your peers.
 - 15 If you had a question to ask about the human genome, what would it be?
 - 16 If you could investigate an aspect of human evolution, what would your research question or hypothesis be?
 - 17 Some people suggest that there was a second genesis on Earth and that it is living among us undetected. It could even be extraterrestrial in its origin. Discuss this possibility and propose a number of questions that could be investigated.
 - 18 Do you think that life (as we know it) could have occurred on planets other than Earth? Justify your response and discuss it with your peers.
 - 19 Do you think that all life on Earth descended from a common origin? Discuss this and justify your opinion.
 - 20 Suggest how astrobiologists could detect a life form on Mars.

- 21** The genetic code consists of 64 possible triplet DNA combinations that code for one or more of the 20 different amino acids; all species on Earth use the same code. Suggest why this might be used as evidence that there has only been one genesis on Earth.
- 22** Due to research by Carl Woese in the 1970s, many scientists now accept that prokaryotes can be divided into two distinct groups and that those in the Archaea group are older than bacteria. These ancient ancestors of life on our planet were riddled with viruses. Does that mean that life on Earth originated from viruses? Discuss this question in groups and record comments made during your discussion.
- 23** If living things did not share an ancestor that shared ribosomes, ATP and the triplet code, then why are these found universally among all living things? Discuss and justify your reasons.
- 24** Suggest how we might identify life as we don't know it.

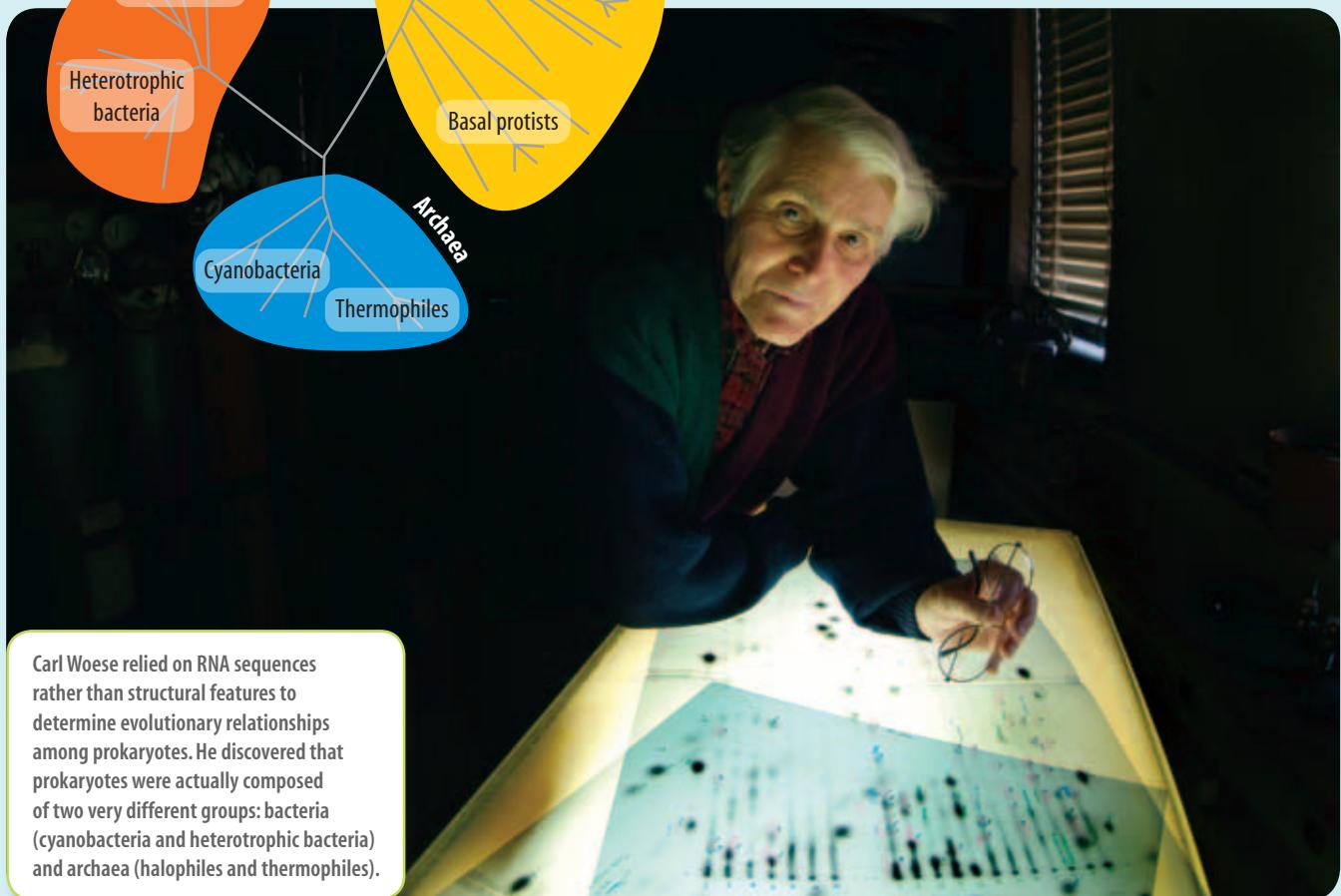


Carl Woese relied on RNA sequences rather than structural features to determine evolutionary relationships among prokaryotes. He discovered that prokaryotes were actually composed of two very different groups: bacteria (cyanobacteria and heterotrophic bacteria) and archaea (halophiles and thermophiles).

- 25** Given that chance plays a large part in the evolution of life, it is unlikely that life from a very separate origin would have the same biochemistry. Discuss this statement. Do you agree with it? Justify your response.
- 26** If you were an astrobiologist, you might refer to known organisms as 'standard' life and alternative forms as 'weird' life. You might not know what you are looking for, or where to look to find it. But how weird is 'weird'? Which criteria do you assign to life, and how will you know when you have found it?
- 27** *Deinococcus radiodurans* is a halophile and an example of an extremophile that can survive high doses of radiation. It can be found living in waste pools of nuclear reactors. Find out more about this microbe and others that can survive high levels of radiation.
- 28** The unusual Murchison meteorite fell north of Melbourne just two months after the lunar landing in 1969. It belonged to a rare class of carbonaceous chondrites. Find out more about this meteorite and its evolutionary implications.

work
sheet

→ 9.5 BIG picture science



Space trekking

Will humans one day venture out into space and colonise other planets? What new technologies will we need, not just to get there, but to be able to survive and thrive?



H. G. Wells (1866–1946) was an extraordinarily powerful and imaginative storyteller. *The Time Machine* (1895), *The Island of Dr Moreau* (1896), *The Invisible Man* (1897), *The War of the Worlds* (1898) and *The First Men in the Moon* (1901) are some of his powerfully imaginative stories. H. G. Wells had his own ideas on what life on Mars would look like and he incorporated these into his writings.

No life has yet been discovered on Mars. This does not mean that it does not or has not existed. In 1997, new technologies enabled a data-collecting mission to begin to send large amounts of information back to Earth as to what Mars is really like — and if creatures similar to those from H. G. Wells's imagination really do glide across its surface!

The red planet

Throughout history, sky watchers have observed the bright red dot in the sky. Some believed that it carried war or pestilence or, for some cultures, even the need for human sacrifice. Perhaps as a consequence of this, the Romans named Mars after their god of war. Other observers theorised that

Mars held intelligent life, which had created canals to channel water to cities. H. G. Wells's *The War of the Worlds*, in which Martians attack the Earth, and Tim Burton's 1996 comedy *Mars Attacks* are two stories that utilise imagination and the science of their times.

Almost 30 Earth missions have failed to get to Mars, the next planet beyond Earth. In 1965, *Mariner 4* made the first successful attempt when it flew within 10 000 kilometres of Mars, transmitted back photographs of Martian meteor craters and revealed that the planet did not have a measurable magnetic field. About seven years later, the first soft landing was made by the Soviet probe *Mars 3*. This landing allowed the first television pictures to be sent from the surface of the red planet.

Spectacular 3-D colour images of the Martian surface were taken by the European Space Agency's probe *Mars Express* in 2004. These images showed gullies that appear to have been carved by water. Also in 2004, NASA landed two rovers, *Spirit* and *Opportunity*, on the Martian surface with the task of examining the chemical composition of rocks. In 2011, these rovers are still exploring the frigid wasteland of Mars. Already they have survived almost 30 times longer and driven 50 times further than they were designed for. But the rovers may be in for some stiff competition in the future — space scientists are increasingly considering using balloons to explore planets, especially those with hostile environments like Mars.

Move over, red rover

If we ever make it to Mars ourselves, we will need to come up with new strategies and technologies to survive the Martian environment. We will need to be able to leave our spacecraft and land vehicles. Specially designed spacesuits will need to provide us with a personal environment that supplies our nutrients, recycles our wastes, protects us from the outside and enables us to do what we want or need to do.

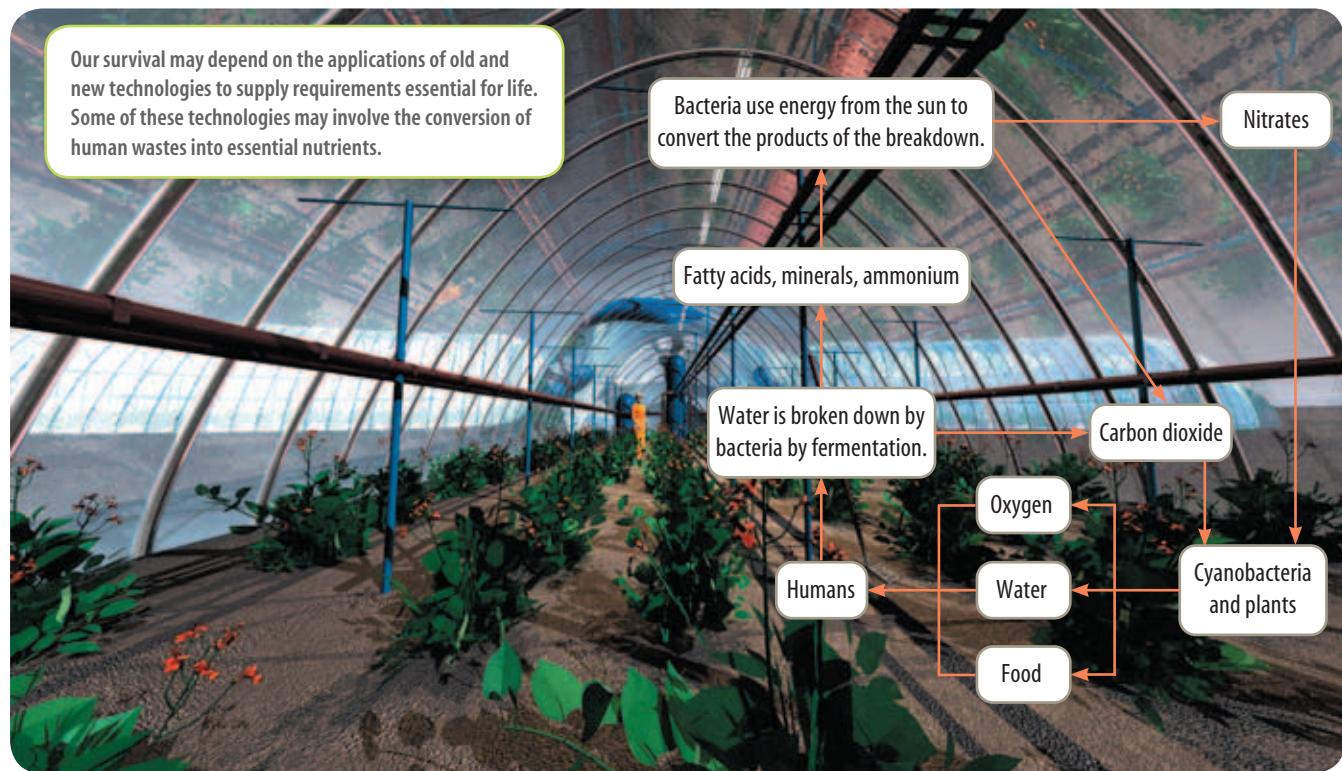
Australian aerospace engineers are involved in the development of futuristic Martian spacesuits such as MarsSkin and mechanical counter-pressure (MCP) suits. MarsSkin suits are tight and elastic and contain

an inner layer of lycra microfibres that transports heat and moisture away from the body and includes sensors to monitor hydration, heart rate and body temperature. Their tough outer layer provides protection against harsh environments. MCP suits have electronic polymer fibres within tight-fitting elastic material and use electricity to mould the suit to the human body. The extra pressure this suit provides reduces the chance of the wearer losing consciousness in the much lower Martian atmospheric pressure.



Red planet greenhouses

In 2010, the United States President Barack Obama announced his intention to send humans to Mars by the mid 2030s. Scientists have already begun



experiments to simulate Martian conditions on Earth. Their experiments are investigating the possible use of micro-organisms to convert Martian rocks into soil, generate oxygen, purify oxygen and recycle waste. These microbial colonies will be our first gardens on Mars.

The future challenge

If we travel to another planet, what other challenges do we need to plan for? Should we be altering our DNA by introducing genes that may give us an increased chance of survival in the different environmental conditions that we are likely to encounter on other planets such as Mars? Should we be genetically engineering specific organisms to take with us? If so, what features should they possess? Maybe we should be cloning ourselves or making replacement parts just in case something goes wrong. Should we be developing new technologies that will help keep us alive in environments that we have not evolved to exist in?

STOCKING UP ON REPLACEMENTS

Maybe we should be cloning ourselves so that we have spare body parts. If the journey takes a number of generations, then we can still be there at the end. Or maybe we should develop a range of bionic replacement parts and just insert them when the old ones wear out.

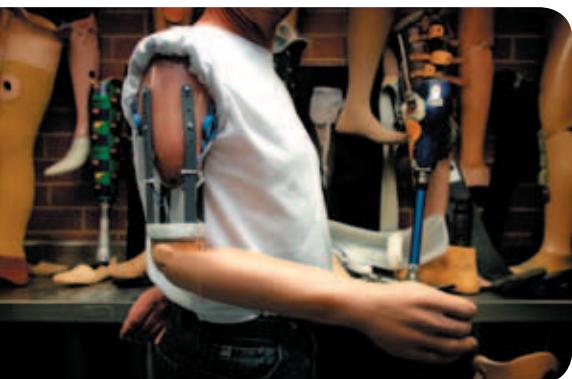
CAN WE FIGHT ALIEN DISEASES?

Should we develop our applications of nanotechnology to defend us against alien disease? If we haven't evolved with these alien pathogens, will they be able to infect us? What will their biology be?

If they do invade us, perhaps we could use nanobots or artificial defences. There have already been designs of these types of defence systems put forward; should we develop these ideas further?

Plastic antibodies

Antibodies made entirely from plastic have already been used



to save the lives of mice injected with bee venom. These artificial antibodies contain cavities moulded to match the shapes of their target molecules. In the future, these could be used in humans to combat toxins or even against proteins that cause allergic reactions to pollen and some foods.

These plastic antibodies were made by a process called **molecular imprinting** — a process similar to making a plaster cast of your hand but at a nanoscale. It involves taking a plastic cast of the target molecule (such as a toxin) by mixing it with monomers (small molecules) that mould themselves around it. When the original target molecule is dissolved, these casts have the specific shape for trapping the target molecule.

It is anticipated that after these plastic antibodies have been injected into the body and have captured their target molecule (the venom or toxin), they would be engulfed by white blood cells and removed from the bloodstream to

be destroyed by the liver. If these artificial antibodies are made of biodegradable materials, then their destruction will be less risky.

Nanobots to the rescue

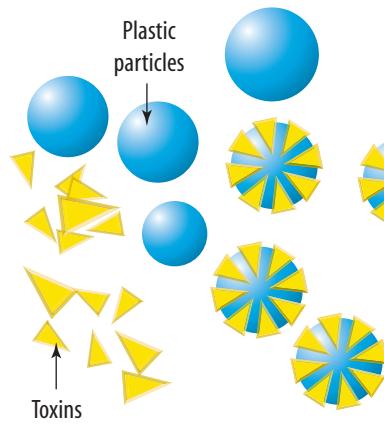
Will nanotechnology take us to the stars? If we come across invasive alien life forms, just their physical intrusion into our bodies may cause us harm. We will not have evolved strategies to defend ourselves. This is where nanobots may come to our rescue.

WHO ARE YOU AND WHERE ARE YOU GOING?

Do we need to develop a separate set of ethics to live by while we travel in space and when we get to our destination? If so, what should they be? Are you interested in going on a journey that will take you further from Earth than anyone has been before? If so, what do you have to contribute to this new world? Now is the time to begin dreaming and planning who you will become and where you want to go.

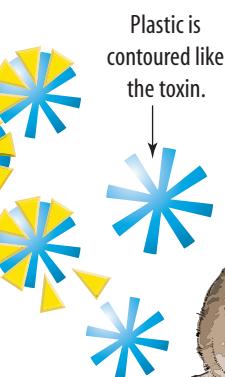
1 Mix toxins and plastic

Mix bee venom toxin with plastic nanoparticles. The plastic envelops the bee venom toxins.



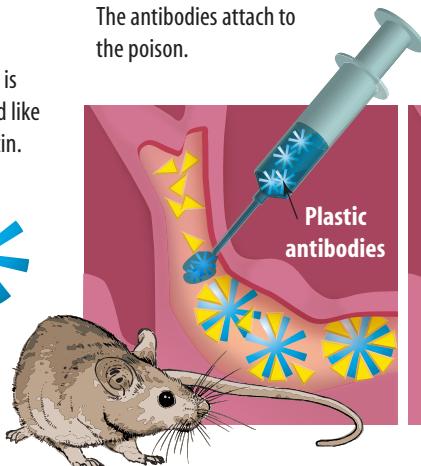
2 Create antibodies

After the mixture binds together the venom is removed, leaving behind its imprint on the plastic.



3 Inject into mouse

Engineered plastic antibodies are injected into the bloodstream of a mouse dosed with bee toxin. The antibodies attach to the poison.

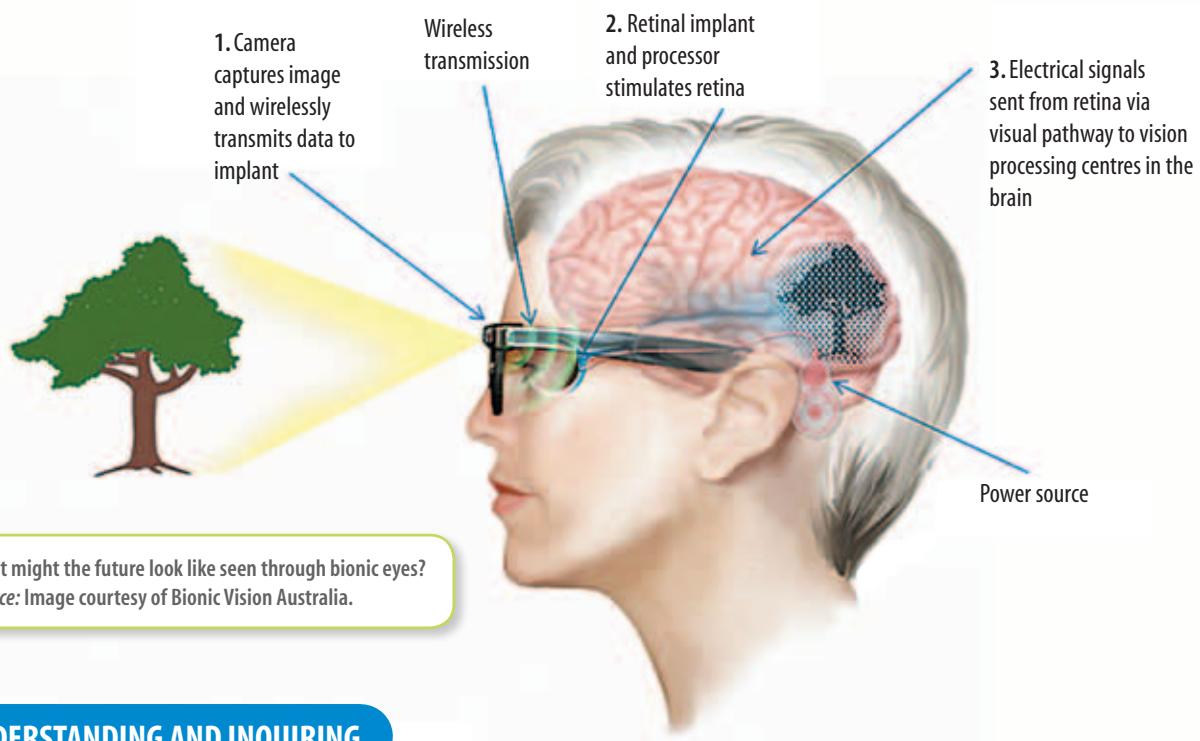


4 Antibodies remove toxins

The mouse's metabolism then removes the plastic antibodies from the bloodstream and into its liver. The mice did not show signs of side effects from the plastic injected into them.



The immune system creates antibodies to fight off invading microbes or toxins. Plastic antibodies, developed by UC Irvine researchers, imitate this same behaviour — in this case attacking toxins of bee venom in the bodies of mice.



UNDERSTANDING AND INQUIRING

INVESTIGATE, IMAGINE, DISCUSS AND CREATE

- 1 Locate, read and summarise the similarities and differences between science fiction novels about life on Mars or Martians. Try reading Brian Aldiss's *The Forgotten Life*, Ray Bradbury's *Martian Chronicles*, Arthur C. Clarke's *The Snows of Mount Olympus* and *Sands of Mars*, and H.G. Wells's *The War of the Worlds*.
- 2 What sorts of projects and research are aerospace engineers involved in?
- 3 (a) Research the differences between current conventional spacesuits and possible future spacesuits.
(b) Research the possible effects of the Martian atmosphere on the human body.
(c) Suggest spacesuit modifications on the basis of your findings. What sorts of science technologies need to be developed to allow this?
(d) Use your findings to design, sketch and label your future Martian spacesuit.
- 4 Find out about organisations that are focused on research about travel to and colonisation of Mars. Report your findings in a *Mars Mania* field guide brochure, PowerPoint presentation, web page or creative story.
- 5 Research and creatively report on:
 - (a) the NASA Haughton–Mars Project (HMP)
 - (b) the MELiSSA loop-life support system
 - (c) NASA research on the feasibility of living in space
 - (d) research and development of artificial life.
- 6 (a) If you found a self-replicating organism living within your computer, what would you do? Discuss and justify your response.
- (b) What defines life? Explain.
- (c) If you were to travel to another planet, what protocols would you have with regards to how you were to treat any life you encountered on that planet?
- 7 Design your own nanobots that will help us to survive venturing out into space.
 - (a) Research and report on examples of current research into humans and space travel.
 - (b) Use the internet and your research to identify three questions that could be investigated further.
 - (c) Write your own science fiction story that is packed with challenges, new technologies and excitement.
- 8 The first inhabited outpost on Mars will possibly depend on microbes for its essential functions. The MELiSSA loop life-support system may use micro-organisms to convert crew waste into resources that can be recycled. Find out more about this system and use the information to design your own system to support human life on Mars.
- 9 Use the **EOS Mars program** weblink in your eBookPLUS to explore what a future on Mars could possibly look like.

eBookplus

INDIVIDUAL PATHWAYS

eBookplus

Activity 9.1
Revising science
quests

Activity 9.2
Investigating science
quests

Activity 9.3
Analysing science
quests