**Investigating Science Module 8: science and society**

Contents

[Teaching the Year 12 Modules 2](#_Toc46150382)

[Module summary 3](#_Toc46150383)

[Relationship to other modules 4](#_Toc46150384)

[Big ideas 4](#_Toc46150385)

[Core concepts 5](#_Toc46150386)

[Society’s views of science 5](#_Toc46150387)

[Regulation of scientific research 8](#_Toc46150388)

[Influences on scientific research 14](#_Toc46150389)

[Alternative conceptions and misconceptions 29](#_Toc46150390)

[Conceptual difficulties 29](#_Toc46150391)

[Opportunities for extended concepts 30](#_Toc46150392)

[The cost of scientific research 30](#_Toc46150393)

[Science and society 30](#_Toc46150394)

[Benefits of scientific research 31](#_Toc46150395)

[Research regulations and ethics 32](#_Toc46150396)

[Suggested teaching strategies and investigations (practicals and Depth Studies) 33](#_Toc46150397)

[Resources 34](#_Toc46150398)

[IQ8-1: How do science-related events affect society’s view of science? 34](#_Toc46150399)

[IQ8-2: Why is scientific research regulated? 35](#_Toc46150400)

[IQ8-3: How do economic, social and political influences affect scientific research? 36](#_Toc46150401)

## Teaching the Year 12 Modules

The new Stage 6 Investigating Science course was implemented in NSW schools in 2018-2019. This syllabus incorporates new content and learning activities such as Depth Studies. The syllabus is designed around inquiry questions and formal assessment tasks emphasise the skills for working scientifically.

The Year 12 course builds on the skills and concepts learnt in Year 11 with students conducting their own scientific investigations and communicating their findings in scientific reports. Students are provided with the opportunity to examine the interdependent relationship between science and technology and apply their knowledge, understanding and skills to scientifically examine a claim. The course concludes with students exploring the ethical, social, economic and political influences on science and scientific research in the modern world.

Therefore, pedagogies that promote inquiry and deep learning should be employed in the Investigating Science classroom. The challenge presented by the additional content and the change in pedagogical approach were the catalysts for the preparation of these module guides for Stage 6. These guides are intended to assist teachers deliver Investigating Science effectively by outlining overarching concepts (big ideas), core and extended ideas, strategies for teaching the modules, uncovering of alternative conceptions, and strategies to address them. The guides support the teacher in facilitating the development of deep knowledge structures, such as the relationships between concepts. The module guides do not cover all aspects of the syllabus, as that was not within the scope of the project.

It is essential that teachers note that the module guides do not substitute the syllabus, but only support teachers to teach it. The information contained in these documents are correct at the time of publication. While every effort has been made to eliminate errors, any errors or omission that are identified after the release of these documents will be corrected and released as resource updates. It is recommended that teachers access the [Curriculum website](https://education.nsw.gov.au/teaching-and-learning/curriculum/key-learning-areas/science/stage-6/investigating-science) for the latest version of these documents.

## Module summary

This module explores the following inquiry questions:

* IQ8-1: How do science-related events affect society’s view of science?
* IQ8-2: Why is scientific research regulated?
* IQ8-3: How do economic, social and political influences affect scientific research?

This module explores the complex relationship between science and society. Scientific research is not conducted in isolation, separate from societal, political, ethical or economic influences. Students investigate how scientific research has produced considerable benefits for society, including economic growth, improved health and the quality of life, and they explore the regulation of scientific research by governments and institutions. They consider that, while research aids economic development and human progress, the types of questions investigated and direction of research is often affected by the priorities set by governments and large corporations, as well as personal and cultural factors.

Teaching the content in Module 8 facilitates the development of scientific literacy in students. Students should employ evidence-based reasoning to discuss socio-scientific issues, and learn to frame them in a scientific narrative.

Outline of concepts in module 8



## Relationship to other modules

Module 8 may be considered to the capstone unit of the Year 12 Investigating Science course. In Module 8, the key ideas of Modules 5, 6 and 7 are brought together so that students can explore the dynamic relationship between science and society. When teaching the other modules, teachers should make relevant references to Module 8. This allows students to form the ‘big picture’ about the content in the Year 12 Investigating Science course. While Modules 5 and 6 describe the generation of scientific knowledge, Module 7 explore how that knowledge is transmitted to the general community. Then, in Module 8, students investigate the consequences of scientific messaging in society, such as the regulation of research or influence of various forces on funding research.

It is therefore highly recommended that Module 8 is taught after all other modules as it incorporates the major ideas of the course and allows students to draw links between them. Some of these links include:

* Appropriate and ethical scientific processes and methodologies used in research can be linked to procedures around conducting investigations appropriately as covered in Module 5.
* Benefit-sharing in research using Indigenous intellectual and cultural property can be linked to the potential for the ethical development of new drug treatments and synthetic chemicals through bioharvesting of plants from Country and Place as covered in Module 6.
* Meltdowns of nuclear reactors and the impacts on the public image can be linked to radioactivity and radioactive decay on the development of radiotherapy and nuclear bombs covered in Module 6.
* The impacts that governments and large corporations have on scientific research relates to ideas on how conflicts of interest results in evidence being suppressed, misinterpreted or misrepresented, for example, tobacco industry and lung cancer; fossil fuel industry and climate change as covered in Module 7.

##  Big ideas

* Historically, science-related events and incidents have altered the public’s perception of science, both positively and negatively.
* Scientific research is not immune to societal, political, or economic influences - scientists rely on funding from governments, institutions and industry. This may affect the type of research and investigations that scientists can engage in and can sometimes influence the direction of scientific research.
* In many countries, scientific research is strictly regulated. This is extremely important for ensuring that ethical practices are followed when conducting research and negative public perception is minimised. The regulation of research also ensures that society benefits from scientific discoveries.
* Scientific research has delivered enormous benefits to society, in terms of economic development, improvements to the quality of life, facilitating sustainable living and enhancing human knowledge[[1]](#footnote-1).

## Core concepts

### Society’s views of science

* Science’s pursuit of knowledge (scientific discoveries and technological inventions), as well as human-made disasters, affect society’s view of science. These perceptions may be positive or negative and have the potential to sway public policy. Sometimes, science- and technology-related events result in new laws and regulations to govern existing industries and research. Some examples include:
	+ **Meltdowns of nuclear reactors** – the use of nuclear energy to obtain electricity was a major technological breakthrough in human history. Initially, the peaceful uses of nuclear energy were generally viewed in a positive light. Major nuclear reactor accidents, such as those that occurred at Three Mile Island (1979, USA), Chernobyl (1986, Ukraine) and Fukushima (2013, Japan), have shifted the public’s opinion about the continued use of nuclear power to generate electricity. Surveys of public opinion in the US showed that before the Three Mile Island accident, public approval for nuclear power generation was 60%. Greater awareness of the environmental effects of long-term storage of nuclear wastes, as well as nuclear reactor accidents (Three Mile Island and Chernobyl), has reduced public approval for nuclear power generation to less than 20%[[2]](#footnote-2). The Fukushima nuclear reactor incident[[3]](#footnote-3) in Japan also elicited similar shifts in public opinions about nuclear power generation. A study in Germany indicated that public support for nuclear power generation declined in the wake of the Fukushima incident. The Fukushima accident resulted in a shift in government policy: six months before the accident, the German government was poised to enhance investment in nuclear power generation. After the accident, the government discarded all policies supporting this technology[[4]](#footnote-4). Another issue that garnered public opinion against nuclear power generation is the storage of nuclear waste. Nuclear waste is radioactive and, thus, harmful to living things. The long-term storage of nuclear waste is expensive. Furthermore, such storage areas must be in geologically-stable areas that are far away from highly-populated regions. An accident during the processing of spent nuclear waste in Russia caused a radioactive plume to spread over much of Europe[[5]](#footnote-5).
	+ **Development of the smallpox vaccine** – smallpox was a deadly disease of humans. There are two forms of smallpox (Variola major and Variola minor). The Variola major form of smallpox causes significant morbidity and mortality, while the minor form of smallpox is a mild disease. Edward Jenner demonstrated the efficacy of vaccination against smallpox[[6]](#footnote-6). In 1967, the World Health Organisation (WHO) embarked on an ambitious program to eradicate the disease through vaccination. In 1980, WHO achieved that goal, with smallpox becoming the first human disease to be eradicated through vaccination. Despite the success of the smallpox eradication program, as well as the current efforts to eradicate polio through mass immunisation, public support for vaccination has declined in many parts of the world (or has plateaued). The dichotomy is depicted in the media as ‘pro-vaxers’ versus the anti-vaxers’. Reduced vaccination rates are associated with increased rates of infectious diseases: in the UK, a sharp decline in pertussis vaccination rates in 1974 caused a whooping cough epidemic in 1978, in which more than 100,000 people contracted with the disease[[7]](#footnote-7). In Australia, childhood vaccination rates have remained at 93-94% (average) since 2003 (the Australian government target is 95%)[[8]](#footnote-8). To increase vaccination rates, the Australian government introduced the ‘[No Jab No Play, No Jab No Pay](http://www.ncirs.org.au/public/no-jab-no-play-no-jab-no-pay)’ policy, which reduced Family Tax Benefits to the families of children who are not vaccinated. The discredited and retracted publication[[9]](#footnote-9),[[10]](#footnote-10) that linked MMR (measles, mumps and rubella) vaccination with autism is an essential tool used to sway public opinion against vaccination. Recent research has indicated that parents who do not vaccinate their children against infectious diseases may not be dogmatic about vaccination but require reliable information from trusted sources. Such data has led the Australian government to set up the [National Centre for Immunisation Research and Surveillance](http://www.ncirs.org.au/) to disseminate scientifically-valid information about vaccination to the public.
	+ **Development of flight** – Flight has long been a dream of humans (many cultures have mythologies about flight). Early attempts at flying attempted to mimic the flight of birds (for example, Leonardo da Vinci’s flying machine). The development of powered flight is one of humanity’s most significant technological breakthroughs. While the principles of flight are based on the scientific concepts (for example, Newton’s Third Law of Motion, fluid dynamics, Bernoulli’s principle and the Carnot cycle), technological and engineering developments have used those concepts to produce the type of powered flight that is familiar to all today[[11]](#footnote-11). Transcontinental passenger flights are routine mode of travel today and are arguably the safest mode of transportation. According to the International Air Transport Association, 4.5 billion people travelled on commercials flights in 2019. Powered flight has also enabled humans to leave Earth’s surface and travel to the moon. The history of flight has produced many pioneers (for example, Charles Kingsford Smith and Amelia Earhart) who have become legends of contemporary society. The technological advances brought about by air and space travel have contributed to a positive public image of science. Despite the increased awareness that air travel contributes to carbon and nitrous oxides emissions (see [Flight shame: flying less plays a small but positive part in tackling climate change](https://theconversation.com/flight-shame-flying-less-plays-a-small-but-positive-part-in-tackling-climate-change-125440)), as well as to the world-wide spread of infectious diseases, air travel remains popular (see [Air travel restrictions won’t protect us from the coronavirus](https://theconversation.com/air-travel-restrictions-wont-protect-us-from-the-coronavirus-131237)). The public’s perception of aviation science remains positive.
	+ **Positive and negative aspects of damming rivers** – Rivers are critical components of dynamic ecosystems that provide water, food and energy to human societies. The damming of rivers addresses some of these needs. Worldwide, hydroelectric power represented about 16.1% of total power generation (2015 data), with China leading the world in the use of dam technology (the Three Gorges Dam is the largest in the world)[[12]](#footnote-12). In Australia, 7.5% of total electricity generation was hydroelectric power (this represented 35.2% of clean energy generated in 2018)[[13]](#footnote-13) – Hydro Tasmania and the Snowy Mountains Hydro Scheme were the largest producers of hydroelectric power in Australia. However, the construction of dams (which are a scientific and technological feat) also causes significant damage to downstream ecosystems (for example, deforestation and loss of biodiversity), including the biotic systems that exist within the rivers[[14]](#footnote-14). Altered rainfall patterns caused by climate change is exacerbating these effects. Thus, while 60% of the renewable energy worldwide is produced by hydroelectric power, generated through the damming of rivers, the adverse effects of damming in the Amazon River, the Mekong River and other great river systems have generated considerable public antagonism towards their use. However, as scientists deepen their understanding of complex ecosystems, geology and hydrology, the construction of sustainable dams is now a possibility[[15]](#footnote-15).

### **Regulation of scientific research**

* Domestically and internationally, scientific research is regulated, both by governments and by scientific bodies. The regulations are based on **legal** and **ethical** frameworks, which, in turn, are based on available scientific evidence. Those regulations ensure that research is conducted in a manner that conforms to scientific and community standards (refer to Extended Concepts in this document for a summary of the principles of ethical frameworks).
* Some governments pass laws that regulate certain types of research (for example, in Australia, research on human embryos are tightly regulated and breaches of those regulations may result in severe penalties (fines)). The cloning of humans is also prohibited by Australian law.
* Ethics is a set of moral obligations that define right and wrong in peoples’ behaviours, practices and decisions. While most principles of morality are personal (for example - truth-telling, avoidance of injury and harm), ethics refer to moral principles in whole societies. Many professional bodies (for example - medical, legal, engineering) have developed ethical standards that their members adopt. Those institutions may impose sanctions on members who violate those codes of ethics.
* Institutional research ethics committees ensure that research projects conform to established ethical guidelines. For human experimentation, researchers must seek approval from Human Research Ethics Committees (HRECs), while experiments involving vertebrate animals must be approved by Animal Ethics Committees (AEC). These committees are local in every institution where research is conducted. Approval (or exemptions) must also be obtained when conducting research involving genetically-modified organisms.
* Researchers are not allowed to commence their research until all requisite approvals have been obtained. Also, many scientific journals will not publish manuscripts without the necessary ethics approvals.
* Ethics guidelines also apply to biobanks (for example, tissue transplantation), as well as the use of research-generated data.

#### Regulatory issues

* The following discussion explores ethical and regulatory frameworks that apply to some research settings:
	+ **Genetic modification of sex cells and embryos** – the ability to alter the genetic information is a powerful tool in biomedicine. It has the potential to correct disease-causing genetic changes in humans. A new genetic engineering tool known as CRISPR has been used to create malaria-resistance mosquitoes, disease-resistant plants, and correct genetic diseases such as HIV, haemophilia and leukaemia in humans[[16]](#footnote-16). However, changes to the genetic information of sex cells or pre-implantation embryos can affect future generations of the species. To address the concerns of germline gene editing, the US National Academy of Science released a [report](https://www.nap.edu/catalog/24623/human-genome-editing-science-ethics-and-governance) that lays the groundwork for developing guidelines to regulate such research, as described in the [news release on allowing human genome editing](https://www.nationalacademies.org/news/2017/02/with-stringent-oversight-heritable-human-genome-editing-could-be-allowed-for-serious-conditions). Some countries ban research on the editing of embryonic genomes. Most scientists agree that any regulation should strike a balance between achieving the goals of fundamental scientific research, and the unethical use of gene-editing technology.
	+ **Development of biotechnological weaponry** – Substances of biomedical value, such as vaccines, antibodies, gene products and hormones (also known as biologics) are valuable therapeutic agents. However, biotechnological products can also be used to inflict harm. Biological warfare and bioterrorism are two areas of concern for many governments. While scientific research into potentially deadly infectious agents can generate vital information for treatment, prevention and control of infectious diseases, that information may be used by people who are not well-intentioned so to cause harm. For example, in 2001, the bacterium that causes anthrax was used in a bioterrorism incident in the US[[17]](#footnote-17). Sometimes, the data obtained from ‘routine’ research (such as infectious diseases) can be usurped to create bioweapons. For example, in 2012, scientists conducted research[[18]](#footnote-18) to determine if viruses can acquire new characteristics – for example, the ability to infect new hosts or acquire new methods of transmission. In that study, they created a genetically-engineered avian influenza virus which could infect ferrets (but not kill them). While the unmodified virus is usually passed from one animal to the next via physical contact, the scientists observed that the mutated virus could spread via airborne transmission. Thus, the mutated virus acquired a new ability – airborne transmission. From extrapolating these results, the scientists suggested that, although no cases of human-human transmission of the avian influenza virus are currently known, small changes to the viral DNA can convert it into an airborne pathogen (and cause pandemics). After the publication of this paper, some scientists raised concerns about the availability of the data in the public domain[[19]](#footnote-19). The information could be used to created genetically-engineered pathogens that could be weaponised. Currently, many countries are signatories to the [Biological Weapons Convention](https://www.un.org/disarmament/wmd/bio/) (which prohibits the development and stockpiling of biological and toxin weapons). It has been suggested that those countries should also regulate research into the materials that may be used in biotechnological weaponry[[20]](#footnote-20).

#### Ethical issues

* Some areas of scientific research raise significant ethical concerns. These include:
	+ **Research involving radiation**: Ionising radiation refers to high energy, shortwave electromagnetic energy (for example, X-rays and Gamma radiation). This type of radiation can damage DNA and tissues. Therefore, if a research investigation involves the use of radiation (for example, the development of medical imaging), then the researcher must specify the parameters of exposure (for example, the type, dose, frequency, anatomy). The age medical condition of the participants must also be considered – for example, young children and pregnant women should not be exposed to radiation if possible. Most importantly, if comparable data can be obtained by using other non-radioactive methods, then those methods should be preferably used. Historically, human radiation experiments have been conducted in the pursuit of knowledge[[21]](#footnote-21) (for example, development of therapies and diagnostics, space exploration, weapons research). Presently, in Australia, all research projects involving exposure to radiation must be approved by research ethics committees before that can be conducted. This includes biomedical research, nuclear energy research and nuclear waste disposal. A government body, the [Australian Radiation Protect and Nuclear Safety Agency (ARPANSA)](https://www.arpansa.gov.au/), develops evidence-based guidelines that inform the regulatory and ethical issues regarding research involving radiation exposure.
	+ **Pharmaceutical research**: The pharmaceutical industry undertakes research into the development of new treatments and therapies for human and veterinary diseases. The products of such research have significantly improved the quality of life for people, as well as outcomes for animals (animal husbandry). In many countries, various national authorities regulate the development and use of pharmaceutical products (for example, the [Therapeutic Goods Administration](https://www.tga.gov.au/) in Australia). The term ‘bench-to-bedside’ describes how new pharmaceuticals are developed and tested before use. New laboratory discoveries must be put through a regime of small and large animal testing, followed by human clinical trials, before they can be approved for human use. The testing of pharmaceutical products on animals is a contentious ethical issue. The methods used to test the pharmaceuticals in humans also raises ethical issues. In some countries where strict laws on the conduct of clinical trials exist, the feasibility of conducting human clinical trials becomes limited. Pharmaceutical companies have been known to trial new pharmaceuticals in countries where ethical research standards are lower than in those countries with robust regulatory frameworks[[22]](#footnote-22). Another ethical issue regarding the pharmaceutical industry is that companies may not release all relevant data about the drugs they manufacture to the regulatory authorities and consumers (transparency). In some instances, medical practitioners discover the side effects of some medications after the drugs have been approved for use in the community. This leads to the withdrawal of the drugs from the market (one example is the anti-inflammatory drug, Vioxx[[23]](#footnote-23)). When pharmaceutical companies advertise their products to the public, the risks associated with those products may not be adequately declared. The industry operates on business models that seek to maximise profits for its members. This creates several ethical issues regarding pharmaceutical research (that is, the conflict between profit maximisation and the general good of providing healthcare for all). For example, pharmaceutical companies may incentivise doctors to use their own brands of drugs, even though cheaper alternatives (for example, generic drugs) may be available. Incentives and gifts often have the power to influence medical treatment options that doctors prescribe to their patients[[24]](#footnote-24),[[25]](#footnote-25). Members of the industry may also be on medical boards that set the standards for classifying various conditions (this creates a conflict of interest). Finally, pharmaceutical companies may also fund University researchers to conduct research, but not publish the findings in peer-reviewed journals.
	+ **Gene manipulation technologies**: Gene manipulation technologies, such as recombinant DNA techniques, cloning and gene editing technologies, are powerful methods to alter the genetic information in organisms. These technologies provide scientists with a method to correct genetic errors (genetic medicine), produce biopharmaceuticals, and improve agricultural outcomes. However, there are several ethical issues concerning the use of such technologies in research and development. Gene manipulation technologies can reduce genetic diversity (for example, using monocultures in agriculture). Genetic changes made to reproductive tissues (eggs and sperm), as well as to embryos, can be transmitted to successive generations and be maintained in the population gene pool. Gene editing (for example, CRISPR) are more powerful than other technologies such as pre-implantation genetic diagnosis (PGD) and in-vitro fertilisation (IVF)[[26]](#footnote-26). Despite its power, there are significant dangers associated with the use of CRISPR, such as off-target effects (making changes to the wrong parts of the genome), resulting in conditions such as genetic mosaicism. Non-therapeutic uses of gene manipulation technologies (for example, enhancement of specific traits, or gender selection), are highly controversial. Justice and equity issues also weigh heavily on this discussion, as it genetically engineered genomes can cause class stratification in societies.
	+ **Mining practices**: Mining provides raw materials that are essential for modern living. Petroleum, minerals, coal, rare earth metals and gems are used extensively in manufacturing, energy and other industries. As such, the mining industry is a significant contributor to the Australian economy (about 15% of Australia’s GDP or A$240 billion in 2019[[27]](#footnote-27)). The process of extracting these substances from subterranean and submarine sources is complicated and can be damaging to the environment. Environmental impacts of mining could include physical damage (erosion, sinkholes), chemical damage (acid and heavy metal runoffs), pollution of water tables, as well as damage to ecosystems (biosphere). Mining practices can also cause adverse health effects for miners (skin and respiratory diseases). Therefore, there are significant risks associated with mining practices, which raise ethical issues for societies. In Australia, state and territory authorities issue mining licences only when the mining company can demonstrate compliance with the Mining legislation. The compliance includes work health and safety rules, as well as minimising adverse environmental impact.
	+ **Bioprospecting**: Bioprospecting refers to the systematic search for and development of new sources of chemical compounds, genes, micro-organisms, macro-organisms, and other valuable products from nature[[28]](#footnote-28). Bioprospecting allows scientists to identify and develop new compounds for consumer use, health, energy and the environment. Some ethical issues surrounding bioprospecting are sustainable use of resources, respect for indigenous land use and use of indigenous knowledge, as well as ensuring that all parties can engage in benefit sharing. The unethical use of bioprospecting is referred to as biopiracy[[29]](#footnote-29).

#### Scientific codes of conduct

* The scientific community has established codes of conduct for undertaking research in particular areas of science. These are summarised in Table 1

Table 1 - Outline of the codes of conduct that apply to research involving cloning, stem cells, surrogacy, genetically-modified foods and organ transplantation.

|  |  |
| --- | --- |
| Area of research | Codes of conduct |
| Cloning | * In Australia, genetic engineering processes are regulated by the Office of Gene Technology Regulator (OGTR). For certain types of genetic engineering methods, researchers and research institutions must apply for a licence to undertake that research.
* Whole organism cloning is permitted for agricultural uses (animals and plants), provided that approved methods are used.
* Reproductive cloning of humans is prohibited, although research on cloned human embryos is permitted (under strict conditions).
 |
| Stem cells | * There are three main classes of stem cells (adult, embryonic and induced pluripotent). Adult stem cells are harvest from specific organs and can only form tissues of those organs. Embryonic stem cells can form most tissues in an organism. Induced pluripotent stem cells are adult stem cells that have been induced (in the laboratory) to behave like embryonic stem cells.
* Research involving vertebrate animal stem cells must be approved by animal ethics committees, while those involving human stem cells must be approved human research ethics committees. These committees determine if legislative requirements have been met (for example, human embryonic stem cells can only be obtained from excess embryos from medical approaches that use Assisted Reproductive Technologies).
 |
| Surrogacy | * Surrogacy refers to an arrangement where a woman agrees to bear a child for other people (the parents of the child after birth).
* In Australia, only altruistic surrogacy is permitted (the surrogate mother cannot receive payments for bearing the child, except for medical and related expenses).
* The four guiding principles of surrogacy in Australia include:
	+ that the best interests of the child should be protected (including the child’s safety and well-being and the child’s right to know about their origins),
	+ that the surrogate mother can make a free and informed decision about whether to act as a surrogate,
	+ that sufficient regulatory protections are in place to protect the surrogate mother from exploitation, and
	+ that there is legal clarity about the parent-child relationships that result from the arrangement.
 |
| Genetically Modified Foods | * Genetically Modified foods (GM foods) refer to foods produced from organisms whose genetic material (DNA) has been altered using genetic engineering techniques.
* Examples of GM foods include crops (soy, rice, wheat), fruits (apples, pineapples, papayas) and (apples, pineapples, papayas) and derived substances (modified starch, sugar and vegetable oil).
* In Australia, all foods that contain GM protein or DNA, as well as those with altered characteristics (for example, increased protein or fatty acids) must be labelled as a GM food.
* Since all GM foods are safety-tested by Food Standards Australia New Zealand (FSANZ), labelling of GM foods is not mandatory (except for the previous point).
 |
| Organ transplantations | * Organ transplantation is a life-saving medical procedure for patients with organ failure or damaged organs.
* In Australia, organ transplantation processes comply with human rights, as well as the principles of bioethics (respect, autonomy, justice, equity, solidarity, altruism, reciprocity, care and wellbeing, welfare and security, transparency, effectiveness and efficiency).
* The organs donated for transplantation must be obtained without exploitation or coercion.
* There should not be inequity or bias in the selection of recipients for organ transplantation. The allocation of recipients should be transparent, and the information made publicly available.
* All parties involved should be allowed to make decisions in a free and voluntary manner but ensuring that informed decision-making is facilitated.
 |

### Influences on scientific research

#### The cost of research

* Space exploration is an expensive endeavour. Un-crewed space missions cost millions of dollars, while crewed space mission cost billions. For example, NASA has calculated that it costs about AUD$28,000 to send 1 kg of material into space.
* One argument against investing in space exploration is that the funds can be better spent on addressing issues on Earth itself, such as climate change, poverty or hunger. (Note: this is often framed as an ‘either-or’ argument).
* Space exploration research enables scientists to address fundamental questions about the Universe that cannot be answered by relying on Earth-based facilities and resources.
* The spinoffs of space exploration research have benefitted human society in general. Some examples of such benefits are shown in the Table 2.

Table 2 - This table outlines how the spinoffs of space research has benefitted society

|  |  |
| --- | --- |
| Technology for space exploration and research | Technology for human society |
| Energy for spacecraft and satellites | Photovoltaic cells |
| Food for astronauts | Freeze drying of foods |
| Remote control of space vehicles (for example, the Mars rover) | Autonomous vehicles and mapping software (Google maps) |
| Radioastronomy (the study of signals from black holes) | Wi-Fi and Local Area Networks |
| Satellite and telescopic imaging | Medical imaging systems (including Artificial Intelligence algorithms) |
| Spacesuits | Fire-fighting suits |

* Data from NASA suggest that for US$1 spent on space research, the US economy benefits by about US$8. Another perspective on this discussion: the Rosetta space probe mission to land a satellite on a comet cost the European Space Agency about AUD$20 billion. This works out to be approximately AUD$3.70 per person in the European Union.
* Space exploration research also directly addresses some of the problems that plague human society. For example, satellite data is used to collect data about the climate and weather patterns. Satellite data is also used to improve agriculture and water management. Therefore, space exploration research funding does not divert expenditure from other societal issues.
* There is no guarantee that if space exploration research is shut down, the funds saved from that enterprise will directly flow into systems to address social issues, such as climate change, poverty and hunger.

#### Economic benefits of scientific research

* Investment in scientific research often produces positive economic returns. This is one of the main reasons for national governments to invest public monies into Research and Development (R&D)
* Scientific knowledge contributes to technological development. Technologies, in turn, improve the human condition by enhancing health and wellbeing, care for the environment and contributing to economic wellbeing. Some examples include:
	+ **Nuclear power generation**: Research into the structure of atoms revealed that large amounts of energy are stored in atomic nuclei. The nuclei of unstable atoms (radioisotopes) emit energy during decay (nuclear fission and fusion). Much work went into understanding how these processes may be carried out under controlled conditions, so that the energy released may be used to meet the energy requirements of human societies. Until recently, nuclear fusion was an unviable technology (see the [ITER project](https://www.iter.org/), the world’s first nuclear fusion reactor). However, nuclear fission can be harnessed to generate electrical energy, electricity. Scientific discoveries showed that uranium ores could be processed to produce fuel rods. In nuclear reactors, when neutrons bombard the fuel rods under controlled conditions, radioactive decay is initiated, releasing large amounts of heat energy. This energy is used to heat water, which is then used to generate electricity. Unlike the use of fossil fuel generators, atmospheric pollution does not occur during nuclear energy generation. Furthermore, nuclear power generation is more efficient than coal-fired power plants: one kilogram of uranium produces 20,000 times more electricity than an equivalent amount of coal. The IPCC considers nuclear energy generation as a viable low-carbon alternative[[30]](#footnote-30), compared to fossil fuels. Thirty-one countries use nuclear power generation and new reactors are being built in many countries. It remains an essential method of electricity generation and a contributor to those countries’ economies. However, nuclear power is expensive and there are significant risks to its use (nuclear waste disposal, nuclear accidents and terrorism).
	+ **Antimicrobial drugs**: The main classes of antimicrobial drugs are antibiotics and antifungal agents. Scientific research indicated that antimicrobial drugs exploited molecular differences between microbes and non-microbial organisms (and other animals). Those differences are targets for the discovery of new antimicrobial drugs – indeed, after the initial discovery of penicillin by Alexander Fleming, the pharmaceutical industry embarked on a program to discover new antimicrobial drugs, either through the discovery of new natural antimicrobial substances, or the synthesis of new chemical compounds. Currently, several different classes of antibiotics are available, and by carefully managing their use under the direction of health professionals, health outcomes for humans have improved considerably. Antimicrobials have not only reduced the incidence of some infectious diseases but have also allowed doctors to perform complicated medical procedures (for example, hip replacement surgery, organ transplantations and cancer treatments). It is estimated that antibiotic resistance can cost the economy US$4-5 billion dollars annually, indicating the value of these drugs to modern society.
	+ **Genetically modified foods**: Genetic engineering techniques provide scientists with the ability to modify the genetic materials of organisms. Using these techniques, researchers have produced recombinant organisms that contain DNA from other species. The genetically-engineered organisms can possess new traits, such as insect- or pesticide-resistance. These traits are beneficial for farmers, as they can increase the profitability of their business. GM foods can also contribute to global food security and poverty reduction[[31]](#footnote-31), as well as environmental benefits[[32]](#footnote-32). The altered nutrient content of some crops (for example, beta carotene enhanced rice) can help to reduce the morbidities caused by vitamin A deficiency. Farmers who planted insect-resistant corn and cotton saw a 13-17% increase in yield. It has been estimated that if non-GM crops were not planted, then 0.6 – 9 million additional hectares of arable land would be required to keep up with demand[[33]](#footnote-33).
	+ **Petroleum products**: Petroleum is a liquid mixture of hydrocarbons that are extracted from rock strata. In its unrefined state, this mixture is usually referred to as crude oil. When refined, it produces a variety of fuels and other chemicals that are important for modern society. Advances in organic chemistry, as well as technological developments, have allowed scientists to produce fuels such as diesel, oil, kerosene and petrol. About 90% of the products of crude oil refining are those fuels. The remaining 10% of the products of crude oil refining are a variety of chemicals that are collectively called petrochemicals (for example, plastics, synthetic rubber, solvents, fertilisers, pharmaceuticals, additives, explosives and adhesives. Many industries are reliant on the petrochemicals, including automotive, packaging, household goods, medical equipment, paints, clothing and the construction industry[[34]](#footnote-34). Six of the ten largest companies in the world (on the basis of revenue) are oil companies[[35]](#footnote-35).
	+ **Robotics and drones**: Robots are automated programmable machines that can perform a variety of tasks. The development of the field of robotics is closely aligned to developments in science, technology and engineering. Thus, while robots were initially used in manufacturing and production lines (for example, car manufacturing), contemporary robots can perform a broader range of functions and possess high-level processing (decision-making) abilities. Advances in sensor technology provide modern robots to construct detailed images of their environments. For example, LIDAR (Light Detection And Ranging) allows robots to construct 3D maps (similar to Google maps), while micro-sensors embedded into the outer structure of robots allow them to detect temperature and texture[[36]](#footnote-36). Developments in artificial intelligence (AI) are providing robots with the ability to make subjective decisions, as well as enabling them to learn from their experiences. An exciting new area of robotics is drone technology. Drones are pilotless aircraft that are controlled by ground-based operators. Drones that have the latest sensors, actuators and imaging tools have allowed researchers to explore inaccessible environments and obtain data more cheaply than through the use of traditional aircraft and satellites. One recent development in drone technology is the use of drone swarms. Using knowledge developed by biologists who study bird and insect migrations, scientists programmed (using swarm gradient bug algorithm) 30 small autonomous drones to mimic flocking behaviour[[37]](#footnote-37). The ‘flock’ of drones were far more efficient at search-and-rescue missions than an individual drone, as they were able to communicate information about the operations with each other, as well as perform autonomous navigation[[38]](#footnote-38). Drones will significantly enhance our capacity in areas such as search-and-rescue, information about harsh weather systems (cyclones, bushfires), agriculture, infrastructure maintenance, aerial photography and mapping, biodiversity, wildlife and ecosystem maintenance.

#### Health benefits of biomedical research

* Human health and wellbeing have been significantly improved through scientific discoveries. For example, the discoveries of Jenner, Pasteur, Koch and Fleming revolutionised infectious diseases medicine to such an extent that William Stewart, the Surgeon General of the United States of America, said in 1967: “The time has come to close the book on infectious diseases. We have basically wiped out infection in the United States.” While this is not so, science continues to inform and advance medical practice to enhance human health and wellbeing.
* Advances in both scientific knowledge and technological developments have boosted medical practice. Some examples of these include:
	+ **Medical-surgical devices:** Medical devices are designed to diagnose, prevent, treat and monitor medical conditions[[39]](#footnote-39). They include surgical equipment, syringes, gloves, pacemakers, baby incubators and implants (including prosthetics). Data from the US indicate that, in the past 20 years, advances in medical technology have resulted in a 56% reduction in hospital stays, 25% decline in disability rates, 16% decline in annual mortality and increased life expectancy of approximately 3.2 years[[40]](#footnote-40). Innovations in science and engineering have reduced the size of cardiac pacemakers from a large box-like device to one that weighs two grams (this development occurred incrementally over the last 60 years). Another recent innovation is the use of 3D printing, which allowed personalised replacement structures (for example, 3D-printed organs for organ replacement surgery) to be constructed quickly. Combined with advances in materials science, as well as tissue culture and engineering, 3D printing is paving the way for medicine to improve the quality of life for many people. Table 3 lists the invention of some medical-surgical devices.

Table 3: Example of the development of medical-surgical devices that have contributed to the advancement of medical science.

|  |  |  |
| --- | --- | --- |
| Advance | Lead researchers | Country |
| Development of an artificial heart valve | Victor Chang | Australia |
| Development of a multichannel cochlear implant | Graeme Clark | Australia |
| Dialysis machine | Willem J. Kolff | Netherlands |
| Pacemaker | Albert S. Hyman | USA |
| Magnetic Resonance Imaging | Felix Bloch and Edward Mills Purcell | USA |
| Insulin pump | Arnold Kadish | USA |

* + **Surgical procedures:** Scientific discoveries have also aided the development of surgery. Surgery before the modern era was dangerous and positive outcomes were doubtful. Scientific advances such as the Germ theory and the development of hygiene and disinfection practices improved patient outcomes. Discoveries in chemistry regarding anaesthetic gases were essential to the development of invasive procedures. Surgery has benefitted from advances in imaging technology (for example, CT scans, PET scans and MRI) and instrumentation (for example, the endoscope and gamma knife). Some surgeries which were previously performed with large incisions are now performed laparoscopically. As a result, hospital admissions and time-off-work have reduced. Furthermore, the reduced morbidity and discomfort experienced by patients (hence, less need for medication and post-surgery care) produce better outcomes. Recent developments in robotic surgery (robot-assisted surgery) may change the way surgeries are conducted in the future. Although surgical robots are not autonomous devices (that is, they must be controlled by surgeons), they may be used to conduct minimally-invasive surgeries. Surgical robots are expensive, which adds to the cost of conducting surgeries. However, this technology is in its infancy, and there are several studies that question the benefits of such surgeries, relative to their costs[[41]](#footnote-41).
	+ **Water purification and wastewater treatment:** Water-borne illnesses can affect a large proportion of a population very quickly. According to the Centre for Diseases Control (CDC, USA), approximately 1.3 million Americans become ill annually from drinking contaminated water[[42]](#footnote-42). Although drinking water may be contaminated by physical (particulates), chemical or radiological substances, the highest risk to the public are caused by water-borne pathogens. Therefore, drinking water must be purified before consumption. Water purification occurs at a community level (for example, Sydney Water purifies water for the Sydney Basin), or at an individual level (for example, household or personal water purifiers). In Australia, the National Health and Medical Research Council (NHMRC) sets the standards of drinking water. They produce a document called the [Australian Drinking Water Guidelines (ADWG)](https://www.nhmrc.gov.au/about-us/publications/australian-drinking-water-guidelines), which is used by all States and Territories to ensure that their drinking water is of acceptable quality (note that bottled water is considered to be a food item and Food Standards Australia New Zealand body prescribes its standards). The NHMRC also guides other aspects of water quality: (a) Fluoridation of drinking water - in some Australian jurisdictions, fluoride is also added to drinking water – this reduces the incidence of tooth decay; (b) Recreational water sources (for example, swimming pools) – these can also be agents of infection and the quality of the water in those sources must be regulated. Surface and groundwater sources can be contaminated by waste (human, animal and chemical), as well as water runoffs from farms and built-up areas. In cities around the world, wastewater is treated before it is discharged. Solid wastes are removed through filtration and settling, and the wastewater is then disinfected by chemical (for example, chlorination or ozone) or UV irradiation[[43]](#footnote-43). Through these measures, the incidence of waterborne infectious diseases in many societies has declined sharply, affording better health and quality of life to the people living in those areas. However, clean water and sanitation are not available in many parts of the world, and people living in those areas suffer from preventable diseases. Advances in science (biology and chemistry), medicine and engineering underpin these improvements in public health.
	+ **Vaccination**: Apart from the use of antibiotics, vaccination is the other medical procedure that has been instrumental in reducing the rates of infectious diseases around the world. Vaccination is the process of generating immunity against an infectious disease by injecting people (and animals) with harmless versions of the pathogens. In doing so, their immune systems will generate protective immunity against the pathogen and provide the immunised people with protection against the disease. Unlike prophylactic medications, which only benefit the consumer, vaccination can benefit other members of the community in which the vaccinated person is located (through herd immunity and pathogen transmission). After Edward Jenner’s discovery of vaccination against smallpox (using cowpox inoculum), and Pasteur’s subsequent demonstration of vaccination against rabies, the science of vaccination (microbiology and immunology) expanded in the 20th century. By the mid-20th century, vaccines against 27 infectious diseases had been developed. By the end of the 20th century, smallpox had been virtually eliminated, while polio and yellow fever are on the verge of being eliminated. Australia’s aspirational target for national vaccination is 95%[[44]](#footnote-44) (studies have indicated that for herd immunity to be effective against highly contagious diseases, between 92-95% of the population should be immunised). Australia is close to achieving this target (In May2020, [94.74%](https://www.health.gov.au/health-topics/immunisation/childhood-immunisation-coverage/current-coverage-data-tables-for-all-children) for all 5-year-old children, and [96.86%](https://www.health.gov.au/health-topics/immunisation/childhood-immunisation-coverage/current-coverage-data-tables-for-aboriginal-and-torres-strait-islander-children) for 5-year-old children of Aboriginal and Torres Strait Islander descent). The [Department of Health](https://www.health.gov.au/health-topics/immunisation/vaccine-preventable-conditions-and-diseases) website provides information on a number of vaccine-preventable conditions. As a result of global vaccination efforts, the incidence of many infectious diseases has been drastically reduced. For example, according to the World Health Organisation, measles vaccination resulted in a 73% drop in measles deaths (equivalent to 23.3 million deaths) between 2000 and 2018 worldwide[[45]](#footnote-45). When the impact of nine other vaccines are considered, approximately 11 million deaths have been averted between 2011 and 2020. Recent developments in science and vaccine technology (for example, nanotechnology) and vaccine delivery (for example, vaccine patches) will increase the [global reach of vaccination](https://www.who.int/immunization/global_vaccine_action_plan/GVAP_doc_2011_2020/en/), ensuring equitable access to healthcare for vaccine-preventable diseases.

#### Impact of governments and corporations on scientific research

* In the 15th - 19th centuries, scientific research was mostly self-funded (for example, Charles Darwin, Henry Cavendish, John Dalton and Antoine Lavoisier) or relied on patronage from the wealthy (for example, Galileo’s work was funded by the Medici family in Florence). They relied on their personal wealth to fund equipment, travel, research assistants, as well as publication costs. However, as the scope of research expanded in the late 19th and early 20th centuries, research was increasingly funded by industry, philanthropy and universities. After World War II, governments also funded scientific research, although the extent and mechanisms of funding varied considerably. Presently, in Australia, the federal government funds research through business industries (businesses with a research and development investment), universities and higher education institutions, government research organisations (for example, the CSIRO, Defense Industry, and the Australian Institute of Marine Science) and non-government research institutions (the Walter and Eliza Hall Institute of Medical Research, and the Garvan Institute of Medical Research).
* The sources of research funds can impact on the type of knowledge that this generated, as well as how that knowledge will be used. Several factors influence knowledge generation and use:
	+ **Corporations and market opportunities**: Industry-sponsored research is an essential component of research funding internationally. Most corporations fund research that is focussed on developing solutions to problems (applied scientific research), as well as fostering innovation. An important driver of such sponsorship is profitability: it is expected that the outcomes of the sponsored research will add to the revenue of the corporations (for example, through increased sales, or generating patents). For example, it is estimated that Google spent 21.4 billion dollars (USD) in 2018 on its various [research projects](https://research.google/) (which is believed to represent about 15% of its revenue), including the development of autonomously driven vehicles and quantum computers. However, according to the American Association for the Advancement of Science (AAAS), this does not convey the full picture of industry-sponsored research: generally, for each dollar spent on research and development (R&D), 80 cents are spent on development, while only 20 cents are spent on research[[46]](#footnote-46). Industry-sponsored research, in general, does not address issues in basic scientific research (note: basic research is carried out for the advancement of knowledge, without seeking economic or social benefits). Market forces can influence the areas of research that are funded by industry groups. For example, in the pharmaceutical industry, there is a lowered emphasis on vaccine development, compared to the development of new drugs. The vaccine market is small compared to prophylactic drugs: the cholesterol-lowering drug alone has a higher market share than the entire pharmaceutical market combined. Consequently, there are fewer pharmaceutical companies that undertake R&D in vaccine manufacture: Of the twelve vaccines routinely recommended for infants and young children, seven vaccines are made by one company, and only one vaccine is made by more than two companies[[47]](#footnote-47).
	+ **University research project budgets**: In Australia, universities undertake about 33% of all R&D conducted in the country. In Australia, university research is substantially funded by the Australian government (0.5% - 0.6% GDP). Government funding of research at universities occurs at two levels: (i) competitive research grants (where research proposals are assessed and funded based on their merit); (ii) research block grants (non-competitive funds given to research universities to support research programs). Competitive research grants are awarded by the [National Health and Medical Research Council](https://www.nhmrc.gov.au/funding) (NHMRC; medical, dental and clinical sciences) and the [Australian Research Council](https://www.arc.gov.au/grants) (ARC; non-medical sciences and other disciplines). Research projects at universities are usually funded for a period of 3 - 5 years. After this period, the researchers must reapply for funding. If unsuccessful, those projects may be abandoned, and the staff involved may lose their jobs. Even research funding initiatives that involve industry collaboration (for example, the ARC Linkage Scheme and the Cooperative Research Centres) for generally funded for similar periods. Therefore, scientific research projects must fit within these timeframes. Consequently, large research projects that require extended time periods for data collection and analyses (for example, longitudinal studies[[48]](#footnote-48)) cannot be easily funded under such funding schemes. The scale and scope of many university research programs are relatively small, so those research outcomes may be achieved within the funding timeframes. This is exacerbated by the fact that for renewed research funding, researchers should be able to demonstrate the ‘successes’ of their previously-funded projects. Therefore, they should have published (or be close to publishing) their findings in peer-reviewed journals to stand a reasonable chance of obtaining further research funds through the competitive grants programs.
	+ **Governmental budgets and limited time priorities**: In 2015-16, Australia spent $31.2 billion on R&D, representing about 1.9% of Australia’s GDP. Internationally, this level of expenditure places Australia 18th on the list of Organisation for Economic Co-operation and Development (OECD) countries (35 countries), ranked by their expenditure on R&D[[49]](#footnote-49). The 2017-2018 Australian budget set aside $10.3 billion for R&D (approximately 0.6% of the GDP). These funds are allocated to research programs at universities, business (corporate entities), government research agencies and non-governmental research institutes. Through its competitive grants schemes, the ARC and NHMRC, specific scientific research priority areas. Experts in science, medicine and industry advise the government about in setting up the research priority areas (Table 4), which are ‘designed to focus Australian Government support for science and research on the most important challenges facing Australia’[[50]](#footnote-50).

Table 4: Research Priority Areas for the ARC and NHMRC competitive grant schemes

|  |  |  |
| --- | --- | --- |
| Research Funding | Priority Areas | Notes |
| [Australian Research Council](https://www.arc.gov.au/grants/grant-application/science-and-research-priorities) | * Food
* Soil and Water
* Transport
* Cybersecurity
* Energy
* Resources
* Advanced Manufacturing
* Environmental Change
* Health
 | Each priority is associated with three to four Practical Research Challenges, which aim to guide investment and activity in areas where the Government considers Australia must maintain strong research and innovation capability. |
| [National Health and Medical Research Council](https://www.nhmrc.gov.au/research-policy/research-priorities) | * NHMRC special initiative in mental health
* Northern Australia Tropical Disease Collaborative Research Program
* Community Research Priorities Portal
* Electromagnetic Energy program
 | These areas define health issues in Australia, as well as internationally. The funding priorities emphasise research that targets prevention, treatment, management and cure of health issues. |

However, the government also supports research that falls outside of the priority areas. In this manner, the Australian government supports different types of research activities nationally, especially those that are strategically important to the country. Research priority areas can change from time to time, resulting in changes to the types of research activities that may be funded. Researchers working non-priority areas may find it difficult to secure funding, even if their work may be significant to the field. However, researchers who work in the research priority areas may find it easier to secure funding. For example, the Australian government redefined the 2018-2023 research priority areas to include fields such as ‘decarbonising the energy system’ and ‘Robotics, Artificial Intelligence (including Machine Learning), Augmented Reality and Virtual Reality’. Some government initiatives are designed to support research for more extended periods (compared to funding schemes such as the competitive research grants). For example, the [Medical Research Future Fund (MRFF)](https://www.health.gov.au/initiatives-and-programs/medical-research-future-fund/about-the-mrff)  is an innovative research funding model which uses the interest gained from government investments to provide grants for medical research. It is estimated to be worth $20 billion by 2021. The Australian government also encourages business and industry groups to engage in R&D. One competitive research grant category (called the [ARC Linkage grant scheme](https://www.arc.gov.au/grants/linkage-program/linkage-projects)) funds collaborative research projects between academic researchers and industry partners. Another scheme that encourages partnerships between industry and academia is the [Cooperative Research Centres (CRC)](https://www.industry.gov.au/funding-and-incentives/cooperative-research-centres) program. Business and industry groups that invest in R&D also receive tax concession incentives. However, government policies, national budgets and economic conditions (national and international) significantly influence industry’s participation in research. Australian government data indicates that private industry involvement in R&D in Australia is declining (Figure 1).



Figure 1. Australian Government investment in R&D by sector and/or subsector, 1978-79 to 2019-20[[51]](#footnote-51). This graph shows, in dollar amounts, that the government’s investment in R&D (total) has increased over the period indicated. However, as shown by the grey line, investment in the business enterprise sector has declined since 2012.

* + **Benefit-sharing in research using Indigenous intellectual and cultural property**: Australia has been populated by indigenous peoples for a long time, during which they synthesised considerable knowledge about many natural systems[[52]](#footnote-52)[[53]](#footnote-53). While some of that knowledge is known to us, others are only now coming to light. Universities and research institutions are actively discovering indigenous knowledge through a number of research investigations. For example, [CSIRO](https://www.csiro.au/en/Research/LWF/Areas/Pathways/Indigenous-futures/Indigenous-NRM/GBR-ecosystem-services) scientists are working with indigenous communities in a variety of projects, such as tracking green turtle populations in Western Australia, development of resins (glues) and on land care and fire management strategies[[54]](#footnote-54). One area of research that has captured international headlines is bioprospecting – identifying new bioactives and pharmaceutical compounds. The harnessing of indigenous knowledge is attractive for this endeavour, as Aboriginal communities possess considerable knowledge base on the medicinal uses of plants[[55]](#footnote-55). However, any commercial benefits realised from such collaborations between researchers and indigenous communities should be shared equitably between all parties. One example of a mutually beneficial arrangement is the commercialisation of the wild plum (a fruit that has a very high level of vitamin C) in Western Australia – this involves a [business partnership](https://www.kimberleywildgubinge.com.au/) between the Kimberley College of TAFE and the local Aboriginal community). Similar consideration must also be given for any patents or other intellectual property rights that may arise from the use of indigenous knowledge.

#### Personal, cultural and social influences on scientific research

* Although scientific, economic, environmental and social factors are significant drivers of research, personal and societal (cultural) factors can also influence the direction of scientific research. In this respect, scientific research is responsive to the changing needs of society. Some areas where such influences are evident include:
	+ **Perceptions about diet in a multicultural society**: diet and health outcomes follow a social gradient: non-Indigenous Australians with high incomes have good quality diets, healthy weights and better health outcomes, compared Australians from Indigenous and minority cultural groups. Furthermore, in multicultural societies such as Australia, perceptions about diet and health can vary considerably. Cultural norms associated with diets (for example, food choices and preferences, food preparation and culinary rules) vary between ethnic groups, even though they may be located in the same geographical area[[56]](#footnote-56). In Australia, the plethora of cuisines (including Indigenous foods) that is available significantly impacts the health of communities. This is exacerbated by messages of health and wellbeing that permeates contemporary society through television, print magazines and online sources. For example, body shape is viewed differently in different societies. In some societies (or sections of societies), being overweight is not considered to be dangerous to health[[57]](#footnote-57). Religious beliefs also inform dietary choices (for example, vegetarianism and non-beef-eating among Hindus, abstinence from pork eating among Jews and Muslims). Other diets have become fashionable in some sections of the community (for example, Atkins diet, Paleo diet, Ketogenic diet). Some diets, such as the Mediterranean diet, have been investigated in controlled, double-blind studies (and shown to improve cardiovascular disease indicators)[[58]](#footnote-58). There are currently several clinical trials that seek to establish the efficacy of the Mediterranean diet. Scientific studies are also underway to explore the relationship between diet and health, such as the effect of caloric restriction on aging[[59]](#footnote-59), and the effect of nutrition and probiotics on immune function in different age groups[[60]](#footnote-60). Consequently, the Australian government, through the NHMRC, undertakes scientific research on the effects of diets and nutrition on health and wellbeing. These are published as [guidelines](https://www.nhmrc.gov.au/health-advice/nutrition), which are used by health professionals, as well as for the education of the general public. The NHMRC also hosts the ‘[Eat For Health](https://www.eatforhealth.gov.au/)’ website, which serves as a single repository of scientific knowledge about diet and nutrition. The CSIRO also undertakes research in diet and health. Using a scientific/technological approach, scientists at the [CSIRO](https://www.csiro.au/en/Research/BF/Areas/Nutrition-and-health/Nutrition-and-health-science/Case-studies) have developed resistant starch, BARLEYmax (a high fibre cereal). They are exploring the health benefits of wasabi, as well as exploring the use of carrot powder to boost the nutritional content of other foods.
	+ **Investigating traditional medical treatments**: Conventional medicine refers to the type of medical practice that is learnt in the medical faculties at universities around the world (medicine, dentistry, nursing, pharmacy). All other types of medical practices are referred to as non-conventional medicine. The World Health Organisation refers to non-conventional medicine as traditional medicine, as it is closely associated with the cultural practices of their countries of origin. Non-conventional medicine is referred to as ‘complementary medicine’ if it is used together with conventional medicine. Otherwise, non-conventional medical practices are referred to as alternative medicine. Traditional/complementary medical practices generally fall into two categories: natural products (for example, herbs and dietary supplements), and mind-body practices (for example, acupuncture, tai chi and yoga). Traditional/complementary medicine is popular in Australia (and in many countries around the world)[[61]](#footnote-61): a population-based study[[62]](#footnote-62) on the use of traditional/complementary medicines in Australia revealed at approximately 70% of 1067 people surveyed had used at least one form of traditional/complementary medical modality. According to the authors, the number of people who had visited a traditional/complementary medical practitioner was the same as that who had visited a conventional medical practitioner. They estimated that the users had spent about AUD$4 billion on traditional/complementary medical treatments. Consequently, government health regulators have begun to explore traditional/complementary medicines. The goals of such exploration are to determine the efficacy of those treatments using controlled scientific experiments, as well as to provide evidence-based information to consumers. Since 2006, the [NHMRC](https://www.nhmrc.gov.au/health-advice/all-topics/complementary-medicines#download) has been evaluating the effectiveness of traditional/complementary medicines. It also advises the Department of Health on the inclusion or exclusion of various traditional/complementary medicines as health insurance products. In the US, the National Institutes of Health set up the [National Center for Complementary and Integrative Health (NCCIH)](https://nccih.nih.gov/), which undertakes and funds research into traditional/complementary medicine, including clinical trials. It also has a comprehensive bibliographic database of research publications on the topic.
	+ **Mining practices**: Mining practices are a polarising issue for contemporary society. Increased public awareness of the environmental consequences of mining practices has caused the mining industry to reflect on the impact of its practices[[63]](#footnote-63). Modern mining operations requires companies to comply with environmental standards, corporate social responsibility and stakeholder engagement guidelines[[64]](#footnote-64). The CSIRO conducted a [study](https://blog.csiro.au/what-mining-means-to-australians-a-national-survey/) on Australian attitudes towards mining. The researchers concluded that mining companies must acquire a ‘social licence’ to operate (a process to take into account the voices of the people). Four specific areas of concern were the impact on mining on the environment (including climate change), agriculture, the health of communities and the cost of living. Participants in the study also highlighted that strong governance is needed to ensure faith and trust in the industry (for example, the fair distribution of benefits). In Australia, the federal government set in place several initiatives (for example, the Leading Practice Sustainable Development Program for the Mining Industry initiative) to ensure that mining processes are conducted following engineering and community standards. Some of the engineering standards were developed through scientific investigations of the impact of mining practices on the environment, as well as on the community (both mining and the general communities). These standards include:
* Airborne Contaminants, Noise and Vibration
* Biodiversity Management
* Community Engagement and Development
* Cyanide Management
* Evaluating Performance: Monitoring and Auditing
* Hazardous Materials Management
* Managing Acid and Metalliferous Drainage
* Mine Closure and Completion
* Mine Rehabilitation
* Risk Management
* Stewardship
* Tailings Management
* Water Management
* Working with Indigenous Communities

Concerns about groundwater contamination by mining practices are being addressed by a [team of Australian researchers](https://www.engineering.unsw.edu.au/minerals-energy-resources/research/research-strengths/sustainable-mining-practices/groundwater-arc-success), who have received funding from the ARC and industry bodies to develop suitable solutions to the problem.

## Alternative conceptions and misconceptions

The following misconceptions/alternative conceptions focus on the relationship between science and society. The [Understanding Science](https://undsci.berkeley.edu/teaching/misconceptions.php#b18) website contains more information on these concepts.

* **Students may believe that science research is independent of social, political, and economic forces.**
	+ Although research in the pure sciences is focussed on knowledge generation, the conduct of research is influenced by social, political and economic factors. Research is sometimes directed to address societal issues (for example, research in infectious diseases or variations in climate induced by anthropogenic activities). Indeed, science influences and is influenced by society.
* **Science is a solitary endeavour.**
	+ Modern scientific research involves collaborations between teams of scientists from different institutions nationally and internationally. Scientific discoveries are peer-reviewed to ensure credibility of the information generated.
* **Science can provide solutions to all of the problems that affect contemporary society.**
	+ While science and technology research address issues that affect contemporary society, there is no guarantee that they will generate practical solutions to those issues.

## Conceptual difficulties

Some concepts, such as the regulation of scientific research, as well as the varied influences on research are very board and may pose difficulties for students. It is important that students employ evidence-based reasoning when evaluating such ideas. Some of the content in this module may provoke emotional responses in students, teachers should maintain the scientific narratives behind those content. For example, to discuss ethical issues in science, teachers should emphasise the fact that current ethical norms in research are based on internationally recognised ethical frameworks. This then allows students to apply relevant principles when evaluating ethical issues in science.

## Opportunities for extended concepts

### The cost of scientific research

* Modern scientific research is an expensive endeavour. Typical research projects not only require funds for scientists’ salary, reagents and equipment, but also fees for laboratory space, fieldwork expenses and (sometimes) publication costs. The project to discover the Higgs boson at CERN (the Large Hadron Collider) was one of the largest scientific projects in history. The [paper describing its discovery](https://www.sciencemag.org/news/2015/05/physics-paper-sets-record-more-5000-authors) (the estimated mass of the Higgs boson) had 5154 authors (24 of the 33 pages of the article were devoted to listing the authors’ names and affiliations!). The ARC Discovery Project (a premier competitive grant scheme) provides research grants from AUD$30,000 to AUD$500,000 for periods of up to five years. In 2020, the average grant in Biosciences category was $519,295, while that in Mathematics, Physics, Chemist and Earth Sciences category was $444,662. The [ARC website](https://www.arc.gov.au/grants/grant-outcomes/selection-outcome-reports/selection-report-discovery-projects-2020) provides statistical information on the grants that were successfully funded under various schemes. Without this government funding, science cannot progress. This has two implications:
	+ Any discoveries or innovation arising from this research should benefit the Australian society;
	+ The Australian government, on behalf of its citizens, can emphasise specific areas of research that are in the best interest of the country (for example, research that boosts the economy and infrastructure, and ensures its security and environment for all).

### Science and society

* When conceiving of scientific research projects, researchers not only consider the design of their investigations in order to answer inquiry questions, but also contemplate on the implications of their work for society itself. For example, in the ARC Discovery Project grant scheme, researchers have to produce a ‘National Interest Test Statement (NITS)’, in which they indicate how their research will benefit science itself, as well as society in general. Some examples of NITS can be viewed at the [ARC website](https://www.arc.gov.au/national-interest-test-statements).
* A scientist’s personal, cultural and social views can influence the type of research that he/she engages in. For example, the Polish nuclear physicist, [Joseph Robtlat](https://undsci.berkeley.edu/article/0_0_0/scienceandsociety_04), resigned from the Manhattan Project (to develop the atomic bomb) because of his objections to the destructive use of nuclear energy. Robtlat received the 1995 Nobel Peace Prize for his work. Indeed, after the Second World War, many of the scientists who worked on atomic and nuclear weapons programs resigned their involvement in such research and advocated for peace.
* While scientific discoveries develop and enhance knowledge, society must determine how to use that knowledge. For example, scientific discoveries in the field of atomic physics described the large energy stores in the nuclei of atoms and how that energy may be harnessed. However, society must determine if that knowledge should be put to use – the use of nuclear power generation or the development of nuclear armaments. Scientific discoveries about the [effect of chlorofluorocarbons (CFCs) on the ozone layer](https://undsci.berkeley.edu/article/ozone_depletion_01) in the atmosphere led to the introduction of new environmental regulations and, eventually, changes to business practices to reduce the use of CFCs. Similarly, scientific discoveries about the [carcinogenic properties of tobacco smoke](https://www.visionlearning.com/en/library/Hidden/59/Comparison-in-practice%3A-The-case-of-cigarettes/166) led to the introduction of health and other policies to improve public awareness of the dangers posed by cigarette smoking.

### Benefits of scientific research

* Even primary (pure) scientific research can lead to developments that may lead to technological developments or knowledge that informs public issues. They may also lead to commercial ventures. Figure 2 shows an outline of technological developments (including commercial outcomes) that have resulted from research in the basic sciences. Note to teachers: [Understanding Science](https://undsci.berkeley.edu/article/cellphone) has an activity which explains how some of the features of modern mobiles phones have developed from discoveries in basic science.
* However, the benefits of scientific research may not be tangibly realised for some time after the research is completed. For example, the median length of time for a registered drug to be approved for general use by the US Food and Drug Administration is 6.4 years[[65]](#footnote-65), while the translation of research in cardiovascular research to clinical practice and patient benefits is 17 years[[66]](#footnote-66).



Figure 2: An overview of technological outcomes and commercial benefits arising from discoveries in basic scientific research. Adapted from [Understanding Science](https://undsci.berkeley.edu/article/%3C?%20echo%20$baseURL;%20?%3E_0_0/whathassciencedone_03).

### Research regulations and ethics

* In many countries, research ethics frameworks are used to develop standards of professional scientific conduct. The following is a list of the core principles on which research ethics frameworks are based:
	+ The principle of **autonomy**: making voluntary and informed decisions (that is capacity to act intentionally, with understanding, and without controlling influences)
	+ The principle of **non-maleficence**: No subject in a study is intentionally harmed or injured, either through acts of commission or omission
	+ The principle of **beneficence**: Produce beneficial outcomes & positive steps are taken to prevent and to remove harm from the patient
	+ The principle of **justice**: Equal access to care, benefits, compensation
	+ The principle of **confidentiality**: maintaining anonymity and privacy.
	+ The principle of n**on-deception**: maintaining open and truthful communications

The Australian Research Council has developed a list of regulations, ethical guidelines and codes of conduct for undertaking research. These policies may be viewed at the ARC [Codes and Guidelines](https://www.arc.gov.au/policies-strategies/policy/codes-and-guidelines) website.

## Suggested teaching strategies and investigations (practicals and Depth Studies)

Due to the nature of the content in this module, student-led investigations will involve non-laboratory exploration of the key concepts. Therefore, the following activities may be used for small-scale investigations or be expanded into Depth Studies. It must be emphasised that relevant Working Scientifically skills be incorporated in all investigations.

* In regard to the need for regulation of scientific research, students could explore the protection of Indigenous cultural and intellectual property in Australia. This [website](https://www.artslaw.com.au/info-sheets/info-sheet/indigenous-cultural-and-intellectual-property-icip-aitb/) could provide some useful background information. Aboriginal people consider that the mining sites they have used in prehistory have significant cultural and spiritual value. Students could research the legislation regarding mineral exploration and extraction and reflect on the different value systems regarding the protection of a culturally significant heritage site versus environmental remediation of mining land.
* Students could be asked to research and develop an advertisement (for example, a poster or pamphlet) that supports or rejects Australia using nuclear energy as an alternative to coal-powered electricity, using scientific data and emotive language as appropriate. [Nuclear power in Australia: A comparative analysis of public opinion regarding climate change and the Fukushima disaster](https://www.sciencedirect.com/science/article/pii/S0301421513009713) could provide a useful starting point. It analyses the results of an online survey in 2010 and follow up survey in 2012 (after the 2011 Fukushima Daiichi disaster) that examined the public's perspective about the acceptability of nuclear power as an option to help tackle climate change.
* Students could be engaged in an activity that enables a debate between those in favour and those against the damming of a local river when investigating public perception on science-related events. They could be asked to research, role play and/or pose arguments based on their research. [To dam or not to dam?](https://www.australiangeographic.com.au/topics/science-environment/2011/01/to-dam-or-not-to-dam/) provides some excellent information on this idea.
* Students could pose their own inquiry questions regarding research into a specific form of genetic technology, for example, “Should we be allowed to have designer babies?” The question could then be investigated using secondary sources, with a presentation made to the class. [It’s time to discuss GM babies](https://cosmosmagazine.com/biology/it-s-time-to-discuss-gm-babies) by Cosmos Magazine provides some background on the concept of designer babies.
* Students could predict Australia’s expenditure in relation to science-related activities as a proportion of its total budget, then conduct research into the data as released by the [Australian Government](https://www.industry.gov.au/topic/data-and-publications-0). They could make a comparison between different areas of research (for example health, environment, energy, space exploration) and produce graphical information. The Conversation [Infographic: Budget 2018 at a glance](https://theconversation.com/infographic-budget-2018-at-a-glance-95649) shows the spending and cuts for the 2018 budget as an example, with reference to space exploration.
* Students could be engaged in a task that allows them to consider both the need for the regulation of scientific practice and the preservation and protection of Indigenous cultural and intellectual property. For example, the Parliament of Australia [Biological Diversity and Indigenous Knowledge](https://www.aph.gov.au/About_Parliament/Parliamentary_Departments/Parliamentary_Library/pubs/rp/RP9798/98rp17#MAJOR) webpage provides some excellent information that includes ideas around bioprospecting and benefit-sharing.
* Students could research the question “Is space exploration worth the cost?” and make an informed opinion or argument after considering all of the pros and cons. [Inside Story - Is space exploration worth the cost?](https://www.youtube.com/watch?v=h01fdhs_zoQ) (duration 25:06) and the Al Jazeera supporting article [Is space exploration worth the cost?](https://www.aljazeera.com/programmes/insidestory/2012/12/2012121472916725918.html) provide some useful information.
* Students could be asked the question: “Would Edward Jenner’s methods that allowed the development of vaccinations be acceptable today?” They could then be asked to perform research to make arguments for and against. [How we conquered the deadly smallpox virus - Simona Zompi](https://www.youtube.com/watch?v=yqUFy-t4MlQ) (duration 4:33) provides some excellent background on the discovery.
* Students could be engaged in activities that ask them to produce and analyse graphical data in rates of vaccination per country and the incidence of certain infectious diseases.
* Scientists’ values and beliefs are influenced by the broader culture in which they live. Such personal views can, in turn, influence the questions they choose to pursue and how they investigate those questions. Students could conduct a case study into relevant examples that demonstrate this idea. [Shaping scientists](https://undsci.berkeley.edu/article/0_0_0/scienceandsociety_04) article provides a good starting point.

## Resources

### **IQ8-1: How do science-related events affect society’s view of science?**

* [Six years after Fukushima, much of Japan has lost faith in nuclear power](https://theconversation.com/six-years-after-fukushima-much-of-japan-has-lost-faith-in-nuclear-power-73042) by The Conversation that discusses public opinion and concerns around nuclear reactors in Japan since the Fukushima accident.
* [Public attitudes to Nuclear Power](https://www.oecd-nea.org/ndd/pubs/2010/6859-public-attitudes.pdf) report by the OECD provides a detailed account of the issues that influence the public’s views on the use of nuclear energy for power generation[[67]](#footnote-67).
* [Why don’t Australians see nuclear as a climate change solution?](https://theconversation.com/why-dont-australians-see-nuclear-as-a-climate-change-solution-19099) by The Conversation relates to a 2010 and 2012 follow up survey about the Australian public’s opinion about whether nuclear is a suitable option to tackle climate change.
* [History of Smallpox](https://www.cdc.gov/smallpox/history/history.html) by the Centre for Disease Control and Prevention provides useful highlights around the history of smallpox.
* [Six common misconceptions about immunization](https://www.who.int/vaccine_safety/initiative/detection/immunization_misconceptions/en/) by the World Health Organisation discusses six commonly-held myths about vaccination and infectious diseases.
* [Wright-brothers.org/History](http://www.wright-brothers.org/History_Wing/History_of_the_Airplane/Decade_After/Decade_After_Intro/Decade_After_Intro.htm) covers the first 10 years after successful aviation assesses the impacts on society and technological developments. This provides a useful link to Module 7.
* [To dam or not to dam?](https://www.australiangeographic.com.au/topics/science-environment/2011/01/to-dam-or-not-to-dam/) An article from the Australian Geographic explores the issues surrounding dams in Australia.
* [What the public thinks it knows about science](https://www.ncbi.nlm.nih.gov/pmc/articles/PMC1326427/) examines popular culture and how it may affect public opinion of science. [Through Biased Lenses: The Public Perception of Science Has Changed, but the New View Is No Better](https://www.ascb.org/compass/compass-points/through-biased-lenses-the-public-perception-of-science-has-changed-but-the-new-view-is-no-better/) examines how public opinion has changed, but not necessarily to become more positive.

### **IQ8-2: Why is scientific research regulated?**

* The [Georgia Clinical and Translational Science Alliance](http://georgiactsa.org/discovery/ethics-center.html) hosts numerous resources on Ethical Dilemmas in Scientific Research and Professional Integrity
* [Office of the Gene Technology Regulator](http://www.ogtr.gov.au/internet/ogtr/publishing.nsf/Content/science-plan13-18-htm) - this Australian Government website provides information on its roles and proposed outcomes to regulate genetically based therapies.
* [How do we control dangerous biological research?](https://thebulletin.org/2018/04/how-do-we-control-dangerous-biological-research/) examines the controlling of dangerous biological research to reduce the likelihood of developing dangerous weapons.
* [How therapeutic goods are regulated in Australia](https://www.tga.gov.au/how-therapeutic-goods-are-regulated-australia) - this Australian Government website provides information on how therapeutic goods are regulated in Australia.
* [What are the Ethical Concerns of Genome Editing?](https://www.genome.gov/27569225/what-are-the-ethical-concerns-about-genome-editing/) by the National Human Genome Research Institute about ethical issues including germline editing, safety (off-target edits), informed consent, justice and equity, and genome editing research involving embryos. This resource also contains useful links, including an overview of how genome editing works.
* [CRISPR Ethics: Moral Considerations for Applications of a Powerful Tool](https://www.sciencedirect.com/science/article/pii/S0022283618305862) provides information about the ethics of using CRISPR technologies. [Are scientists’ reactions to ‘CRISPR babies’ about ethics or self-governance?](https://www.statnews.com/2019/01/28/scientists-reactions-crispr-babies-ethics-self-governance/) discusses the controversy surrounding the use of CRISPR to edit the germline, and raises the question: Can Scientists responsible for maintaining and deciding the ethics surrounding editing of human life?
* [Indigenous Cultural and Intellectual Property (ICIP) (AITB)](https://www.artslaw.com.au/info-sheets/info-sheet/indigenous-cultural-and-intellectual-property-icip-aitb/) provides information from the Arts Law Association of Australia about protecting Indigenous intellectual and cultural property.
* Australian Minerals [Legislation, regulations and guidelines](http://www.australiaminerals.gov.au/legislation-regulations-and-guidelines) contains links to relevant guidelines for states and territories around mining legislation.
* [International Atomic Energy Agency and Codes of Conduct](https://www.iaea.org/topics/codes-of-conduct) provides research on international codes of conduct relating to nuclear industry and products.

* [A new way to regulate surrogacy to give more certainty to all involved](https://theconversation.com/a-new-way-to-regulate-surrogacy-to-give-more-certainty-to-all-involved-83868) by The Conversation which briefly outlines different types of surrogacy, and problems with the current model. The Guardian article [International surrogacy laws in the spotlight amid row over baby Gammy](https://www.theguardian.com/world/2014/aug/04/global-surrogacy-laws-debate-baby-gammy-thailand) discusses the case of Baby Gammy as an example.

### **IQ8-3: How do economic, social and political influences affect scientific research?**

* [What Is Space Exploration Doing For You?](https://www.youtube.com/watch?v=KZBjrwqxfnk) (duration 4:28)
* [Budget 2018: 'Seed funding' for Australian space agency to be unveiled](https://www.abc.net.au/news/2018-05-03/australia-space-agency-funding-in-federal-budget-2018/9720370) - ABC News article about new funding for an Australian Space Agency.
* [Five Ways Drones Are Going To Change Our Lives](https://toa.life/five-ways-drones-are-going-to-change-our-lives-e1e8d3e7bc46) is an opinion piece and conversation starter on 5 ways drones are going to change our lives.
* ABC news (USA) article [10 Health Advances That Changed the World](https://abcnews.go.com/Health/TenWays/story?id=3605442&page=1) outlines different technologies and procedures.
* [Medical advances could soon spare patients surgery, say experts](https://www.theguardian.com/science/2018/dec/07/medical-advances-could-soon-spare-patients-surgery-say-experts) by The Guardian on how medical advances could soon make surgical operations obsolete.
* [Clean water and sanitation: the keys to breaking free from poverty](https://www.worldvision.com.au/global-issues/work-we-do/climate-change/clean-water-sanitation) from World Vision. [Health and water](https://thewaterproject.org/why-water/health) published by The Water Project discusses the link between contaminated water and lack of sanitation to poverty and disease in Africa.
* [Pet owners refusing to vaccinate animals over fears it will cause autism](https://www.news.com.au/technology/science/animals/pet-owners-refusing-to-vaccinate-animals-over-fears-it-will-cause-autism/news-story/b25a5e3f04a888ad7eacacfbf3500d10) is suitable for initiating discussion around how misinformation can affect public perception of science as discussed in Module 7.
* [Infographic: how much does Australia spend on science and research?](https://theconversation.com/infographic-how-much-does-australia-spend-on-science-and-research-61094) Is an opinion piece by The Conversation that compares Australia’s spending on science research with other OECD countries.
* [Does Funding Influence the Results of Science?](https://www.theepochtimes.com/does-funding-influence-the-results-of-science_2199994.html) discusses the conflict of interest that can exist between funding and research.
* This ABC science article, [Bioprospecting gets a boost](https://www.abc.net.au/science/articles/2001/09/25/374597.htm) is about a 2001 report tabled in Parliament that recommended funding and a framework to develop the potentially lucrative business of bioprospecting in Australia.
* [Traditional Aboriginal healers should work alongside doctors to help close the gap](https://theconversation.com/traditional-aboriginal-healers-should-work-alongside-doctors-to-help-close-the-gap-93660) by The Conversation explains how Australian society is not supportive of Aboriginal Healers to provide alternative medicinal treatments. It suggests that traditional Aboriginal Healers should work alongside doctors to help to “Close the Gap”. [10 bush medicines that have been curing people for generations](https://www.sbs.com.au/nitv/article/2017/05/25/10-bush-medicines-have-been-curing-people-generations) by NITV explains how bush medicines have been used to treat people successfully for generations. [Project to grow bush medicine business](https://www.katherinetimes.com.au/story/5740159/project-to-grow-bush-medicine-business/) describes a research and commercial partnership to explore developing sustainable agribusiness models for traditional Australian medicinal plants growing in Northern Australia.
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