Investigating Science Module 7 – Fact or fallacy

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## 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

Module 7 explores how scientific findings are communicated, both within the scientific community, as well as in the general society. Scientific messages are often, intentionally or unintentionally, misconstrued. This has significant implications for society, as science and technology are woven into the fabric of modern life. The end-products of scientific investigations are a set of claims, which are then developed into scientific knowledge. The testing of claims forms the foundation of this module. All claims should be verified before they are accepted. This is particularly true of claims used in advertising or those used by groups (for example, industry, special-interest and business groups) that pursue specific agendas.

The title of the module reflects the dichotomy of claims: fact or fallacy. Testing claims allows the user to determine if the claims are facts or fallacies. Students will explore the scientific basis of claims (for example, the health claims on food packaging or claims about the efficacy of a product), as well as how cause-and-effect relationships are made between claims and conclusions. The role of confusing vocabulary (for example, terms such as theory and hypothesis) in shifting public perception of scientific concepts is examined. Some groups, such as industry and special-interest groups exploit the reputation of science to spread misinformation that is disguised as scientific fact. Students will study examples of such misuse of science. Finally, students will investigate how a fundamental, self-correcting process of science, peer-review, is instrumental in maintaining the integrity of the scientific process, as well as of the outcomes of scientific investigations.

“But journalists shouldn’t have to resort to hype for a good science story. The turgid, lifeless style of scientific papers belies the creativity, camaraderie, rivalry, tragedy and triumph that make cutting-edge research so exciting.”

[The UK National Archives](https://webarchive.nationalarchives.gov.uk/20170405182745/http%3A/www.ingenious.org.uk/Read/Featuredsubjectscienceculture/Dumbingdown/Themessage/)



## Relationship to other modules

Modules 5 and 6 focus on the production of scientific knowledge. Module 7 looks at how scientific knowledge is used in the general community. Misinterpretation and misrepresentation of scientific knowledge can have profound effects on modern society. Module 7 also form the foundation for the ideas discussed in Module 8, where students explore the mutually beneficial, but sometime turbulent, relationship between science and society. A thorough grasp of the concepts in Module 7 can facilitate students’ understanding of the broad concepts described in Module 8.

This module has substantial links with Module 5, particularly in the analysis of scientific investigations. If Module 7 is taught after Module 5, then it may be relevant to revise key concepts from that module (for example, developing first-hand investigations and looking at second-hand investigations through peer review and science journals) prior to commencing Module 7. On the other hand, if Module 7 is taught before Module 5, then it may be relevant to highlight the connections between the modules that will be addressed later.

## Big ideas

* Scientific knowledge evolves. In its early stages, scientific investigations focus on obtaining data. These may be observations, measurements or calculations. Over time, those data are used to construct models that provide explanations of natural phenomena. As more data is collected, scientific models are refined through fair tests and other data collection efforts. Depending on the outcomes of such investigation, unsupported conclusions are discarded, while those that are supported by the evidence available become consolidated, eventually producing knowledge in the form of scientific laws and hypotheses. Even these continue to be refined as more data accumulates.
* When conducted in accordance with accepted scientific processes, all scientific conclusions are rigorous. Some initial investigations may be small in scope and scale and may be designed to obtain preliminary information. Then, those findings will be used in other investigations which are larger in scope. While trained researchers can identify the limitations of investigations, those limitations may not be evident to non-scientists. Thus, scientific conclusions may be mis-interpreted or incorrectly contextualised.
* Sometimes, entities with vested interests (for example industry, business or special-interest groups) deliberately conduct investigations or fund research that produce outcomes that are favourable to their respective agendas. Such endeavours are designed to use science’s esteem in society to reinforce those entities’ agenda. It is important to note that funding scientific research to develop knowledge of natural phenomena is not the same as funding research in order to obtain some desired outcomes: when funding scientific discovery, the funding agency should be prepared to accept all outcomes of well-conducted inquiries.
* No matter whether it is intentional or not, the misinterpretation of scientific findings has significant implications for our society. Many scientific fallacies abound, making it difficult for the average knowledge consumer to differentiate them from scientific facts.
* One important tool for evaluating scientific knowledge (and all forms of knowledge) is critical thinking. Critical thinking employs evidence-based reasoning to evaluate claims. This equips people with the skills needed to separate fact from fallacy.

## Core concepts

### Evaluating the science behind claims

* The veracity of any claim should be tested using the following criteria (note: these ideas are considered further in Appendix 1):
	+ The **validity** of the experiment: any claim (conclusion) of an investigation should be the product of a fair test. Therefore, the investigators should have conducted controlled experiments, with clearly defined hypotheses, variables, a well-designed experimental procedure, as well as collected and correctly-analysed relevant data.
	+ The **reliability** of the data obtained: the consistency of the data when the experiment is repeated.
	+ The **accuracy** of the procedure: how close the observed value is to the true value or how well repeated measurements of a variable within the same experiment agree with each other.
	+ A consideration of the **random** and **systematic** **errors** of measurement (see Appendix 2 for more information on the errors of measurement).
* In scientific investigations, the **claim** represents the answer to the inquiry question. Claims are **justified** using **evidence** and **reasoning**. Data refer to the measurements and observations collected in experiments, while evidence is the **interpretation** of the data. Once justified, one or more claims will be used to form conclusions. Those conclusions then build explanations for the phenomena being investigated. The explanations form a body of knowledge, generally referred to as scientific knowledge. Scientific knowledge is represented as **theories**, **hypotheses**, **laws, models** and **facts**.

### Sample sizes and sample selection

* In scientific research, experiments are conducted on **samples** of targets (for example, people, animals, plants, objects, or substances). Samples are small proportions of a larger population.
* The samples used in any scientific investigation have a significant impact on the outcome. Samples must be chosen so that the investigators can reasonably obtain relevant answers to their inquiry questions. Factors such as convenience, cost and availability, can affect the selection of samples for investigations.
* Variability in the samples used in an investigation can affect the accuracy and reliability of its outcomes. For example, biological systems often demonstrate a high degree of variability. In order to reduce such variability, larger sample sizes should be used.
* Small sample sizes increase the variability of the measurement: this results in a larger standard deviation[[1]](#footnote-2) of the mean. As a result, the outcomes of such investigations are less precise (statistically insignificant). Conversely, larger sample sizes produce data with a smaller standard deviation, making the outcomes more precise (statistically significant).
* An example of the effect of small sample sizes on the outcomes of investigations are those that involve complex measuring equipment. A review of fMRI (functional magnetic resonance imaging – a technique that measures blood flow to the brain) studies[[2]](#footnote-3) indicated that most studies involved about 30 subjects (median = 30). The researchers found that this number is too small to produce statistically valid conclusions. The authors recommended that such studies should involve 100 or more subjects to produce valid outcomes. However, even a modest fMRI investigation costs many tens of thousands of dollars to conduct.
* Sample selection is an important aspect of experimental design. For the results of an investigation to be valid, the samples used in the investigation must be made up of individuals experiencing the disease
	+ Representative of the target population
	+ Randomly selected and assigned to groups
* Incorrect sampling results in sampling error (bias). There are two main types of such errors:
	+ **Selection bias**: Individuals in a study are not randomly assigned to groups (for example, self-selection, where participants self-enrol into particular groups).
	+ **Sampling bias**: All of different individual in a diverse population are not equally represented in the samples (for example, the racial profile of a human study sample does not reflect the population’s racial profile). Other examples of sampling bias include convenience sampling (using only whatever resources are available), non-response bias (where data is not collected from all members of the study groups), uncontrolled data collection (for example, open surveys).
* A paper[[3]](#footnote-4) published in the New England Journal of Medicine, describes the health benefits of a Mediterranean diet (7447 participants; the study was conducted over five years). The authors reported that people on a Mediterranean diet had a lowered incidence of cardiovascular events, compared to those in the control group. However, the researchers placed members of the same family in the same group. This type of group assignment can introduce a **bias in the sampling process**: it would artificially inflate the characteristics of those groups. After retracting the paper, the authors reanalysed their data by removing the invalid measurements. They published a revised paper[[4]](#footnote-5), with a modified conclusion about the efficacy of the Mediterranean diet in reducing the incidence of cardiovascular events.

### Emotive advertising versus evidence-based claims

* Claims about the value of products may be designed to provoke emotive responses in users. Some of these claims may be express in such a manner as to convey the notion that they are scientifically validated (for example, ‘scientifically tested’ or ‘clinically tested’).
* Claims may also be based on evidence that is produced from fair scientific tests.
* Advertisement claims on food packaging generally fall into one of three categories[[5]](#footnote-6):
	+ **health claims**: food items improve a physical or disease condition (for example, ‘calcium for healthy bones and teeth’)
	+ **nutrient content claims**: where the level of specific nutrients is described (for example ‘low in salt’) or compared with other similar food items (for example, ‘reduced fat milk).
	+ **structure/function claims:** (for example, ‘calcium builds strong bones’).
* Where possible, all claims should be tested through first-hand investigations (as described above) or through secondary source investigations.

### Data analysis and interpretation

* To minimise the impact of bias in the design, conduct and analysis of scientific investigations, researchers employ several techniques to ensure the validity of the investigation, including
	+ The use of **placebos**: A placebo is a substance that lacks the active ingredient being tested in an investigation. Placebos also include procedures and therapies. Usually, placebos are used in conjunction with randomised sampling techniques. An example of an investigation that employed placebos in randomised trials in a large cohort-study[[6]](#footnote-7) evaluated the effectiveness of the herb Ginko biloba to prevent dementia in the elderly. The findings of the study indicated that there were no differences in the incidence of the condition between the two groups (the experimental group that received the herb, and the control group that received the placebo). Some studies have revealed a phenomenon known as the ‘placebo effect’, wherein patients receiving placebos have reported improvements or recoveries from their disease conditions. This may occur because of their beliefs in the benefits of the treatments or the reassurances of their doctors. However, some placebos may have biological effects themselves as referenced in [Placebos: what they’re made of matters](https://theconversation.com/placebos-what-theyre-made-of-matters-124189?utm_medium=email&utm_campaign=Latest%20from%20The%20Conversation%20for%20October%202%202019%20-%201423513454&utm_content=Latest%20from%20The%20Conversation%20for%20October%202%202019%20-%201423513454+CID_8a1aa982b9180f358e8ceef4b28b8217&utm_source=campaign_monitor_uk&utm_term=Placebos%20what%20theyre%20made%20of%20matters). It is important to report on such effects, so that the conclusions of investigations are correctly evaluated.
	+ The use of **double-blind trials**: In blind studies, the participants in the study are unaware of which group (control or experimental) they are assigned to. In double-blind studies, neither the researchers nor the participants know the group assignments. These processes minimise bias (for example, observer bias and confirmation bias). Blinded studies may be ethically controversial if the study denies treatment to patients. Thus, such studies are often performed with the constraints of acceptable ethical practices.
	+ The use of **control** groups: All valid scientific investigations and clinical trials involve the use of control groups. Controlled studies are used to determine if an intervention (for example, a new drug or therapeutic procedure) has been successful. Participants assigned to the control group will not receive the intervention (that is, they will receive a placebo).
* Scientific messages may be interpreted in ways other than they were intended to be. Both societal and economic factors influence can influence the way data is collected and interpreted (the table in Appendix 3 provides some further examples of the misuse of the scientific process):
	+ **Climate variation data**: Research on the acceptance of climate variation data indicates that people may interpret the data in ways that reinforce their biases. Researchers[[7]](#footnote-8) suggest that ‘motivated reasoning’ underlies such misinterpretations. Political affiliation is an example of motivated reasoning, where ‘echo chambering’ of misinterpreted information reinforces biases. Economic factors also influence the interpretation of climate data. For example, opposition to carbon mitigation efforts have come from industry groups, whose main strategy is to cast doubt on climate variation data, and their interpretation.
	+ **Remedies for health conditions**: Groups with vested interests can influence how data about health remedies are generated and interpreted. For example, companies that manufacture remedies (for example nicotine patches and gums) to overcome nicotine addiction (to reduce or overcome tobacco smoking) have funded numerous studies into the effectiveness of such therapies. A meta-analysis of published studies into the use of nicotine replacement therapies indicated that industry-funded studies overwhelmingly supported the effectiveness of such therapies, compared to non-industry-funded trials. However, when the researchers corrected the data for biases, they found no difference in the results from industry-funded and non-industry-funded studies. The herbal medicine industry also makes claims about the health benefits (both curative and preventative) of the products they sell. However, few of those claims are scientifically substantiated. For example, the herbal product, kratom, is marketed as an anti-anxiety product. The US Drug Enforcement Agency has classified this herbal supplement as a ‘drug of concern’ because of its addictive properties, as well as potential microbial and heavy metal contamination of the product.
	+ **Manipulating statistical data**. Statistical outcomes are important for making predictions about future outcomes, as well as in decision-making processes. Researchers often use statistical tools to analyse the data collected in investigations when developing their conclusions. The statistical analyses of data collected in scientific investigation is an important aspect of data analyses. While errors during the conduct of such analyses can produce erroneous outcomes, some entities have deliberately manipulated statistical data to produce desirable outcomes. For statistical analyses to be valid, the design of the investigation is critical to obtaining reliable results. Biased sample and incorrect group assignments can produce nonsensical results, although such results may be used to substantiate desired outcomes. Such misrepresentations were behind the retraction of the paper describing the efficacy of the Mediterranean diet, as well as the recall of the drug Vioxx by Merck. Often, the raw data that is collected in an experiment is processed before further analyses. Such data processing includes the removal of outliers, removing erroneous measurements and fixing missing data. While such data processing is legitimate practices, incorrect data processing or deliberate manipulation of the raw data will produce invalid results. A poor graphing technique is a type of data manipulation that communicates incorrect messages.

### Drawing valid conclusions

* The goal of many scientific investigations is to develop explanations of natural phenomena. To do this, the researchers must establish a **causal** (**cause-and-effect**) relationship between the variables being investigated. Sometimes, confounding factors in an investigation can lead investigators to establish causal relationships where none exist.
* Several historical incidents illustrate the dangers of establishing causality when confounding factors may exist. These include:
	+ **The Hawthorne effect**. This effect describes the phenomenon where the participants of a study modify their behaviour when they are aware of being observed by the researchers. This effect was first described in relation to a study conducted between 1922 and 1933 in Hawthorne (near Chicago, USA). The management at the Western Electric telephone manufacturing factory decided to undertake research to identify factors that improve worker productivity. This involved several experiments where supervisors observed the work practices of the workers under different conditions (for example, under different lighting conditions). However, the results of the study were not clear. All variables tested resulted in improved productivity. While the research was abandoned, psychologists who evaluated the experiment concluded that the improved productivity was because the participants of the study knew that they were being observed and evaluated. The feeling of being observed results in the participants thinking about ‘expected behaviours’, and consciously or unconsciously alter their behaviours to meet those expectations[[8]](#footnote-9). This came to be known as the Hawthorne effect. The Hawthorne (observer) effect was subsequently studied in several research projects around the world. However, the role of the Hawthorne effect in human studies is still not clear. It is considered to be a possible bias (similar to the placebo effect) that may affect the interpretation of experimental data. All other explanations should be explored and discounted before concluding that the Hawthorn effect may be responsible for an observed outcome.
	+ **Hormone Replacement Therapy (HRT) and Coronary Heart Disease (CHD)**. In 1991, a much-publicised study[[9]](#footnote-10) on the beneficial effects of HRT on CHD was published. This claim was the result of an epidemiological study which used a statistical tool known as meta-analysis. According to the authors, women undergoing HRT will have a lower incidence of CHD. The authors even cited studies showing that the hormones used in HRT can favourably affect the lipid profiles of the subjects (unfavourable lipid profiles are a risk factor in developing CHD). However, numerous subsequent studies contradicted the findings of the 1991 paper. Some of the reasons for this were as follows:
	+ The meta-analysis provided only a correlation between HRT and CHD. The authors implied that there was a causal relationship between the two. However, this was not established through investigations. Although the hormones used in HRT can improve lipid profiles, they can also raise the levels of other risk factors associated with CHD.
	+ The authors were selective in the use of data from the literature. They ignored studies that contradicted with their thesis. This is poor scientific practice and can often lead to biased outcomes.
	+ Other variables that can confound this analysis were not contended with. For example, the socioeconomic status of people strongly correlates with their risk of developing CHD[[10]](#footnote-11). The authors did not control for these factors.
	+ **The Mozart effect**: A study published in 1993[[11]](#footnote-12) showed that students exposed to Mozart’s music (Mozart's sonata for two pianos in D major, K488) for 10 minutes prior to engaging in spatial reasoning tasks (Stanford-Binet intelligence scale; IQ test), performed better than those that listened to relaxation sounds or silence. However, this effect lasted for only 15 minutes after listening to the music, and did not enhance the intelligence of the participants. Despite the limitations of the study that the authors reported in their paper, the findings were disseminated in the popular media as ‘Mozart makes you smarter’. It spawned an industry devoted to enhancing child development through listening to classical music. Subsequent studies corroborated the original findings that the Mozart effect if it existed, was transient. Although other studies have shown many benefits of listening to music, there is no evidence that music enhances intelligence. A random controlled trial investigation[[12]](#footnote-13) on the effect of music on cognitive function revealed no difference in the abilities of children attending music classes and those attending other types of activities. Thus, at present, no mechanism to explain the causal relationship between listening to Mozart’s music and superior performance in spatial reasoning tasks is known.
* To establish causality, the following three conditions must be met:
	+ The cause must occur before effect
	+ When the cause changes, the effect should vary (this is called covariance)
	+ There are no other plausible alternatives: all other variables and confounding factors have been kept constant.

### Science communication and public understanding of science

* As scientists collect data through investigations and observations, some of that data will be used to construct explanations of natural phenomena. Over time, those explanations become scientific knowledge.
* Scientific knowledge is expressed in the form of theories, hypotheses, beliefs and laws.
	+ Scientific **theories** are explanations of a range of natural phenomena. They are constructed by integrating many scientific laws and hypotheses, each of which has been validated through numerous investigations. Therefore, scientific theories are supported by numerous lines of evidence. Scientific theories may be modified or even replaced in light of new evidence. Some examples of scientific theories are the Cell Theory, the Atomic Theory and the Big Bang Theory.
	+ Scientific **hypotheses** are tentative explanations for a narrow range of natural phenomena. They are supported by the evidence that is available at the time of formulation. Hypotheses often form the basis of experiments that are designed to validate the underlying scientific concepts. All hypotheses possess three characteristics: testability (a fair test can be designed to test the hypothesis), predictability (the hypothesis predicts some outcomes when certain conditions are met) and founded on scientific concepts. Scientific hypotheses are the basis of some inferential statistical analyses (for example, the use of null hypotheses).
	+ Scientific **laws** describe the relationship between the variables of a system. They are developed from scientific data and observations and describe the behaviour of the variables under certain conditions. Newton’s Law of Gravitation, Ohm’s Law and Boyle’s Law are examples of scientific laws. Scientific laws are usually expressed mathematically (as formulae or equations).
	+ A **belief** is an opinion or conviction that may or may not be supported by evidence. While beliefs are not part of scientific epistemology, scientists, like others, may hold on to certain beliefs (for example, religious, ethical or political views) that may impact on the types of research that they may undertake. For example, the Polish physicist Joseph Rotblat abandoned his involvement in the Manhattan Project because of his ethical views about the dangers of nuclear energy[[13]](#footnote-14). Strongly-held beliefs may influence decisions to address them in science: for example, the role of women in STEM-related careers (gender bias) and the award of research grants to racial groups (racial bias).
* Terms such as theories, hypotheses and laws are part of the common vernacular. However, the use of these terms in everyday language is different from their use in science. For example, in everyday usage, theories are conjectures, while hypotheses refer to guesses. This difference in the way such terms are used in scientific and non-scientific areas gives rise misunderstanding of scientific concepts in the lay public. For example, the theory of evolution by natural selection is a powerful scientific explanation that has been tested and is supported by many lines of evidence, is widely accepted as valid and forms the basis of many research undertakings worldwide. However, it is sometimes dismissed as being ‘just a theory’, giving the impression that the tenets of evolutionary theory may be speculative. Such misconceptions may also contribute to the erosion of the public’s understanding of scientific principles. More information on this is provided in misconceptions and alternative conceptions below.
* As per the conventions of the scientific process, research findings are communicated through **peer-reviewed** publications and other platforms (for example, conferences). Although such communication is directed towards other researchers, they may also be consumed by the general public, national bodies for making legal and policy decisions, as well as the private industry to inform technology development and business decisions.
* Scientific findings may be communicated directly to the public. Such communication also allows for informed decision making to occur. For example, scientific discoveries regarding the dangers of tobacco smoking or prolonged exposure to sunlight have been used to develop public education campaigns.
* Universities and research institutions may seek to publicise the publication of research papers by their staff. Usually, this occurs in the form of press releases. Press releases are worded in lay language, so that it may be understood by non-specialist readers. However, the messages in the original scientific publication may become ‘lost in translation’, be misinterpreted or over- or under-emphasise specific aspects of the research. This can lead to confusion about the scientific concepts being described or provide a wrong impression of the implications of the research, as [described](https://phylogenomics.blogspot.com/search/label/overselling%20the%20microbiome%20award) by Prof Jonathan Eisen from the University of California, Davis.
* When publishing scientific stories in general platforms such as magazines, newspapers, television & radio or websites, the authors of those stories strive to achieve ‘balance’ in their reporting. While it is fair to include all sides of the issues being reported, it is not axiomatic that all sides deserve the same weight. Balance should be based on the equity of evidence, and not solely on contrasting ideas. Another facet of some reporting is the sensationalisation of scientific findings[[14]](#footnote-15), or creating the impression of a controversy[[15]](#footnote-16) where none exists.

The [UK National Archives](https://webarchive.nationalarchives.gov.uk/20170405182745/http%3A/www.ingenious.org.uk/Read/Featuredsubjectscienceculture/Dumbingdown/Themessage/) described the distortion of scientific message in the media with the following fictional story:

**Researcher**: ‘Changes in acceleration when superconductors are levitated in a DC magnetic field have been detected.’

**Press officer**: ‘Researchers investigate antigravity properties of superconductors.’

**Broadsheet science page**: ‘Breakthrough as scientists beat gravity.’

**Tabloid**: ‘Beckhams are first in line for new antigravity car.’

* Dumas-Mallet et al (2017)[[16]](#footnote-17) studied how newspapers reported scientific research that examined risk factors for psychiatry (Attention Deficit Hyperactivity Disorder (ADHD), autism, major depression, and schizophrenia), neurology (Alzheimer's and Parkinson's diseases, epilepsy, multiple sclerosis) and four somatic diseases (breast cancer, glaucoma, psoriasis and rheumatoid arthritis). The authors found that newspapers were selective about the scientific stories that they published (only 156 of approximately 5000 papers were reported on). The newspaper reports focussed on initial discoveries and rarely reported on subsequent publications on those topics (including those that disputed those initial findings). Null findings were also not reported. Such reporting gives readers a less-than-complete understanding of the scientific stories, as well as the scientific concepts behind them. In an analysis of the value of single-studies (these types of articles are often reported in newspapers), Schoenfeld and Ioannidis (2013)[[17]](#footnote-18) found that 40 commonly-used ingredients in cooking had at least one scientific article indicating that they were associated with cancer risk (statistically increased, decreased or unchanged risk). As these articles were single-study assessments, they produced inflated effect sizes that were not supported by evidence. Yet, when newspapers report on single-study articles, such caveats are not included in the stories. Consequently, readers are left unaware of the validity of those stories. The reasons for such biases in reporting scientific stories in newspapers are varied[[18]](#footnote-19):
	+ Journalists prefer stories that are simple, novel and sensational (which contradict the scientific processes).
	+ Universities are likely to produce press releases for single-study (initial study) articles, rather than complex publications, such as meta-analyses. Furthermore, such press releases may be constructed using language that is emotive and sensationalised.
* According to Pew Research Center [Public and Scientists’ Views on Science and Society](https://www.pewresearch.org/science/2015/01/29/public-and-scientists-views-on-science-and-society/), the public perception of science and scientists is highly esteemed. Commercial groups with vested interests in the sale of harmful products or practices fraudulently portray science negatively for their ends. Groups such as the tobacco, fossil fuel and mining industries have either falsely represented or denigrated scientific findings so that the public will continue to support them. Appendix 3 outlines some examples of such practices.
* When evaluating claims, a form of cognitive bias, known as the **halo effect**, can influence their acceptance or rejection. The halo effect is defined as the tendency to form a positive impression of a trait of person or object based on a positive impression of another trait of that person or object. Such associations between different traits cause bias when evaluating claims, especially if the traits are unrelated.
* The phrase ‘halo effect’ was developed by the psychologist, Edward Thorndike, whose research team evaluated how senior army officers evaluated the qualities of their junior soldiers. The researchers noticed if a soldier received a positive evaluation for any assessed quality (for example, leadership), that soldier also received positive outcomes for all other qualities (for example, appearance or intelligence) that were evaluated.
* The halo effect is often used in advertising, where celebrity endorsement is used to enhance sales. The idea behind this is that the value of a product is proportional to the importance of the person endorsing it. The halo effect is enhanced if the endorsing person is seen to be authoritative – for example, Steve Jobs endorsing electronic devices, actors in lab coats endorsing medical and beauty products or athletes endorsing health food products. As another example, a social media statement by the French President Emanuel Macron that “the Amazon rain forest – the lungs which produces 20% of our planet’s oxygen – is on fire” gained widespread popularity (referenced in [Amazon fires are destructive, but they aren’t depleting Earth’s oxygen supply](https://theconversation.com/amazon-fires-are-destructive-but-they-arent-depleting-earths-oxygen-supply-122369?utm_medium=email&utm_campaign=Latest%20from%20The%20Conversation%20for%20August%2030%202019%20-%201397913167&utm_content=Latest%20from%20The%20Conversation%20for%20August%2030%202019%20-%201397913167+CID_121acc3474cf0b5297a3c8a43620d767&utm_source=campaign_monitor_us&utm_term=Amazon%20fires%20are%20destructive%20but%20they%20arent%20depleting%20Earths%20oxygen%20supply)). However, this claim is not scientifically supported (most of Earth’s atmospheric oxygen comes from the oceans).
* The halo effect is also a factor in misleading advertisements. A study[[19]](#footnote-20) published in the journal Paediatric Obesity showed that the placement of messages on healthy eating in advertisements of unhealthy foods caused the subjects of the study to assume that those food items were healthy. After viewing the halo advertisements, the children in the study rated the unhealthy foods to be healthy, in contrast to children who did not view those advertisements. In another study[[20]](#footnote-21), an analysis of breakfast cereals in the UK found that most of the cereals did not live up to the manufacturer’s claims of healthy foods (for example, the cereals contain high levels of sugar). However, the manufacturers employed halo advertising strategies, by including statements on vitamin and mineral content in those cereals. This gave the impression that the cereals were healthy foods, despite their poor nutritional value. In Australia, the Federal Court recently ruled[[21]](#footnote-22) that the Heinz food company was liable for misleading advertising (halo advertising), regarding the health value of one of its products.
* Some enterprises, such as astrology, numerology and iridology, use several strategies to create the impression that they represent legitimate scientific fields of inquiry (see Table 1). However, none of them follows established scientific processes. These enterprises are pseudoscientific because[[22]](#footnote-23):
	+ Its practitioners are not trained in science or medicine.
	+ The outcomes predicted by its practitioners are not valid or reliable.
	+ The outcomes are not changed or modified in the face of contrary evidence.
	+ The findings are not peer-reviewed. Neither are the methods and outcomes published in peer-reviewed journals or at scientific conferences.
	+ The precepts of these enterprises cannot be evaluated in fair tests.
	+ The findings do not lead to on-going research. Most of the precepts of astrology, numerology and iridology have been unchanged since they were devised.

Table 1: Some examples of pseudoscience that may be portrayed to be based on science

|  |  |  |
| --- | --- | --- |
| Enterprise | Summary | Reference |
| Astrology | Astrology is the belief that peoples’ lives are influenced by the movement of astronomical objects (Sun, Moon, planets, stars, constellations). One assumption of astrology is that a person’s zodiac sign at the time of birth is a strong predictor of his/her personality. Carlson (1985) tested this hypothesis using a double-blind experimental design. The astrologers in the study (considered to be prominent astrologers by their own community) were no better at correlating zodiac signs with personality inventories (a set of personality profiles developed by psychologists). | * Carlson, S., 1985. A double-blind test of astrology. Nature 318:419-425.
* [Why your zodiac sign is probably wrong](https://theconversation.com/why-your-zodiac-sign-is-probably-wrong-128818?utm_medium=email&utm_campaign=Latest%20from%20The%20Conversation%20for%20January%2024%202020%20-%201517414455&utm_content=Latest%20from%20The%20Conversation%20for%20January%2024%202020%20-%201517414455+Version+A+CID_1d95015fe89dcd1cd06c447f1bde3f32&utm_source=campaign_monitor_us&utm_term=Why%20your%20zodiac%20sign%20is%20probably%20wrong)
 |
| Numerology[[23]](#footnote-24) | Numerology is the idea that certain numbers have mystical properties and can predict specific life events. Numerology is a part of many cultures and often stems from assigning numbers to the letters of the alphabet. In doing so, numerology practitioners try to interpret the meanings of names and dates of births. The use of numbers in this endeavour gives it the veneer of scientific authenticity, although there is no basis for this. | None |
| Iridology | The idea that the variations in the colour and patterns of the iris indicate the health or disease status of individuals. This field appears to have been invented by the Hungarian physician, Ignatz Peczely. No anatomical or physiological basis exists for the claims of iridology. In a review of 77 published articles on iridology, only four were involved controlled experiments. In all of those publications, there were no significant differences between the treatment and control groups. The author of the review concluded that there is no diagnostic value in iridology. | Ernst E. Iridology: Not Useful and Potentially Harmful. Archives of Ophthalmology. 2000; 118(1):120–121. |

### Self-correction and the integrity of scientific knowledge

* Scientists communicate their research findings via several platforms, shown below.
	+ Publish primary research articles and literature reviews in peer-review science journals
	+ Publish articles in technical journals
	+ Present findings at scientific conferences and workshops
	+ Publish articles in popular science magazines
	+ Publish books

Of these methods of communication, publication in peer-reviewed journals is highly esteemed, as the quality of the work has been reviewed by fellow scientists and found to be acceptable

* There are different types of peer-reviews:
	+ **Open**: the authors and reviewers and editors know each other
	+ **Blind**: the authors do not know which reviewers are reviewing the manuscript, but the editors do. The reviewers know who the authors of the paper are.
	+ **Double-blind**: The authors and reviewers do not know each other, but the editors know which reviewers are conducting the review (the manuscript is de-identified).
	+ **Triple-blind**: The authors, reviewers and the editors do not know who’s-who in the peer-review process (this type of peer-review in coordinated by computer-based systems).
* Scientists are not paid for their articles by publishing companies when they publish their manuscripts in peer-reviewed journals, even if they are invited to publish (as experts in the field). Furthermore, the authors do not receive ‘royalties’ from their publications in peer-reviewed journals.
* While scientists are not paid for their peer-reviewed articles by publishing companies, they may receive incentives from their Universities or their governments[[24]](#footnote-25). In some countries (including Australia), institutional funding is linked to publications in peer-reviewed journals (the [Excellence for Research in Australia](https://www.arc.gov.au/excellence-research-australia) initiative). In some other countries, for example, China, Turkey and South Korea, researchers are given cash incentives for publishing in peer-reviewed journals.
* Some scientific journals are considered to be more prestigious than others (prestige is measured as the ‘journal impact factor’). Journals such as Nature, Science, and Proceedings of the National Academy of Sciences (USA) are more prestigious than other scientific journals. These journals only publish a small proportion (~7-8%) of the manuscripts they receive from researchers.
* For scientists, employment opportunities and workplace promotions are closely tied to their records of publications.
* Two important metrics of a scientist’s reputation are the number of peer-reviewed articles that he/she publishes, as well as the number of citations that those publications receive[[25]](#footnote-26). The number of times an article is cited in other papers is referred to as its citation index. There are different ways of calculating the citation index, such as the H-index, the G-index and the Google Scholar ranking.
* Some of the consequences of the pressure to publish scientific research (publish or perish) include:
	+ Researchers are publishing the results of a single investigation as a series of small papers (sometimes called ‘salami-slicing’). While this diminishes the impact of the papers, it increases the number of papers published by those researchers.
	+ Some authors may choose to publish the same research finding in multiple journals, after slightly modifying the manuscript. This is done to increase the number of publications for those authors. Such behaviour is scientifically fraudulent.
	+ The list of authors on a publication may include the names of people who did not contribute to the research, as well as ghost writers. Only the names of those people who have contributed to the design, conducting and analysis of the research, as well as those who prepared the manuscript for publication, can be authors.
	+ The pressure to publish in high-ranking journals (for example the Excellence for Research in Australia initiative) results in ‘important research not being published, disincentives for multidisciplinary research, authorship issues, and a lack of recognition for non-article research outputs’ according to this article from The Conversation, [Publish or perish culture encourages scientists to cut corners](https://theconversation.com/publish-or-perish-culture-encourages-scientists-to-cut-corners-47692).
	+ Negative results, though important, are usually not published.
* In the culture of pressure and competition, researchers may be tempted to compromise on research integrity and ethics (fabrication, falsification, or plagiarism). Although a few scientific papers are retracted each year (approximately 4 out of every 10,000 published papers), the reasons for those retractions vary, from genuine errors to scientific fraud[[26]](#footnote-27).
* The **self-correcting** mechanisms in science have led to the identification of such problems (see previous dot points) in the field[[27]](#footnote-28). These two articles from The Conversation highlight the views of Australia’s Chief Scientist, [(‘There is a problem’: Australia’s top scientist Alan Finkel pushes to eradicate bad science](https://theconversation.com/there-is-a-problem-australias-top-scientist-alan-finkel-pushes-to-eradicate-bad-science-123374)) as well as other scientists world-wide, ([Our survey found questionable research practices by ecologists and biologists](https://theconversation.com/our-survey-found-questionable-research-practices-by-ecologists-and-biologists-heres-what-that-means-94421)) regarding some of those issues. One key measure to combat those issues is the ‘opening up’ of scientific publications and the release of scientific data, to the general public as explored in this article from The Conversation, ([Scientific data should be shared: an open letter to the ARC](https://theconversation.com/scientific-data-should-be-shared-an-open-letter-to-the-arc-9458)) . Another approach is for enhanced collaboration (as discussed in [Nature](https://www.natureindex.com/) [‘Frequent collaborators are less likely to produce replicable results’](https://www.natureindex.com/news-blog/frequent-collaborators-are-less-likely-to-produce-replicable-results?utm_source=NI%20Newsletter&utm_medium=email&utm_campaign=24%20September%202019) ) between researchers (the [Australian Research Council](https://www.arc.gov.au/policies-strategies/strategy/international) now actively promotes collaborative research through its grants programs).
* In some instances, scientists have chosen to by-pass the peer-review process when communicating their research findings. Rather than publishing their findings in peer-reviewed journals, they may choose to use other communication platforms, such as press releases. The case of cold fusion shows another aspect of questionable scientific ethics[[28]](#footnote-29). **Stanley Pons** and **Martin Fleischmann** at the University of Utah concluded that they had found evidence of deuterium fusion occurring at room temperature (this was a ‘holy grail’ of energy research). Rather than publishing their findings in a peer-reviewed journal, they announced their findings at a press conference. Later, in an interview, Fleishmann claimed that the pair were pressured into doing the press release by the University of Utah. However, other scientists could not replicate Pons and Fleischmann’s experiments. A couple of weeks after the press release, Fleishman and Pons submitted a manuscript to the peer-reviewed journal, the Journal of Electroanalytical Chemistry. The manuscript was subjected to an abbreviated peer-review process (given the significance of the ‘discovery’, the journal editors wanted the manuscript to be published at the earliest opportunity)[[29]](#footnote-30). The manuscript was not well-received. A few weeks later, the U.S. Department of Energy concluded that Pons and Fleischmann had not achieved cold fusion. Although their work was not considered to be scientific fraud, it was unethical as they did not follow the scientific process.
* In recent times, the volume of scientific papers that have been published has increased exponentially. It has been estimated that 2.5 million scientific papers are published every year. Several **predatory** or **fake** journals[[30]](#footnote-31) have entered the sphere of scientific publishing, providing avenues of researchers who find it difficult to publish in the established scientific journals to publish their research. Such predatory journals charge publication costs and generally have an online presence. However, they do a disservice to science because of their sub-par peer-review processes. This was cleverly exposed by the American engineer **Alex Smolyanitsky**. He produced a manuscript consisting of completely random words generated by a text editor and titled it ‘Fuzzy Homogeneous Configurations’. The fictitious authors were Maggie Simpson, Edna Krabappel, and Kim Jong Fun. He included fake institutional affiliations (Belford University). That manuscript was accepted for publication by two predatory journals, the [Journal of Computational Intelligence and Electronic Systems](http://www.aspbs.com/jcies.htm) (a notice on its website indicates that the journal is discontinued), as well as the now withdrawn [Aperito Journal of NanoScience Technology](http://aperito.org/journal/journal_desc/23). Similarly, **Tim Spears**, a Canadian journalist, prepared a fake and incoherent scientific manuscript. Eight predatory journals accepted the manuscript for publication. These examples highlight the difficulty of policing the fraud that is perpetrated under the guise of legitimate science communication. Such fraud has ramifications beyond scientific circles and impacts on the general public’s perception of science and the scientific process:
	+ Causes reduced trust in science, particularly in evaluating claims, and confidence in the ethical conduct of research.
	+ Makes it difficult for the public to distinguish between real and fake science.
	+ Affects knowledge production and the development of knowledge-dependent economies (for example, technology).
	+ Allows false and unsubstantiated claims to be made in the furtherance of specific agendas.
* Apart from deliberate fraud, the lack of reproducibility of research outcomes is not due to a fault of the scientific or peer-review processes, but due to[[31]](#footnote-32):
	+ A lack of scientific rigour
	+ Rewarding flashy and exciting results
	+ The tendency to ‘cut corners’ to improve publication rates, so as to benefit careers, obtain rewards or research grants
* Many editorial boards now set minimum standard thresholds for publication. These standards are designed to ensure openness of data sharing (researchers must deposit raw experimental data into data repositories before manuscripts are published), ensuring high standards for statistical replication and testing are achieved, disclosure of conflicts of interests and funding sources.
* In their response to a discredited article that suggested exposure to non-ionising radiofrequency radiation causes numerous adverse health effects, Grimes and Bishop (2017)[[32]](#footnote-33) suggest that readers should ask the following questions to distinguish polemics from scientific commentaries:
	+ Is there a plausible mechanism for the effect?
	+ Does evidence come from peer-reviewed sources?
	+ Are all relevant studies considered?
	+ Are the results of specific studies misrepresented?
	+ Are there claims of impacts on multiple diseases and disorders?
	+ Are causal claims based on experiment, correlation or analogy?
	+ Is technical, scientific terminology used to obfuscate rather than clarify?
	+ What are the academic credentials and track record of the authors?
	+ Is there a conflict of interest?

## Opportunities for extended concepts

The media has an important role to play in communicating scientific ideas to the public. Many universities and research institutions have media officers on their staff. These officers issue press releases and other communications to various media outlets. In doing so, they convey key scientific findings in a form that is accessible to the general public, irrespective of their background in science. However, the public also has a responsibility to disentangle incorrectly portrayed scientific stories from true stories of scientific discoveries. Three strategies that are used by some elements of the media to distort scientific discoveries are:

* **Creating false balances**. In trying to highlight a story from all perspectives, journalists can create a false impression that all of those perspectives are equally valid and provide evidence that is equally strong. [Ice cores offer clues to global warming question](https://undsci.berkeley.edu/articles/sciencetoolkit_samplearticle.php) on a climate science research project provides an example of false balances. [False Equivalence: Why It's So Dangerous | Above the Noise](https://www.youtube.com/watch?v=oFC-0FR2hko) (duration 4:56) provides an introduction to false equivalences when evaluating information.
* **Sensationalisation of stories**. Emotive, sensationalised stories sell. This is a business model used by some elements of the media[[33]](#footnote-34). For example, some early discoveries in the field of gene therapy were reported in media as “[miracle drugs](https://undsci.berkeley.edu/article/%3C?%20echo%20$baseURL;%20?%3E_0_0/sciencetoolkit_05)”, even though there were no scientific bases to those claims. However, this practice continues today. Scientific organisations[[34]](#footnote-35) continue to push for evidence-based journalism and there has been some success on that front. The American Council on Science and Health conducted an investigation into science in the media - [Infographic: The Best And Worst Science News Sites](https://www.acsh.org/news/2017/03/05/infographic-best-and-worst-science-news-sites-10948). The infographic produced ranked media publications on evidence-based journalism (in science) in their products. Magazines such as Popular Science and Scientific American have a mixed record in the area of evidence-based journalism (similar to many internationally-recognised newspapers).
* **Creating the perception of controversy (where none exists).** Scientific dialogue is sometimes portrayed as controversies in the field. An essential aspect of the development of scientific knowledge is the use of models. Sometimes, there may be multiple models in a scientific discipline. However, this does not mean that scientists are unsure, each scientific model is built on many lines of evidence. For example, in evolutionary biology, gradualism and punctuated equilibrium are two models that explain speciation. This is sometimes portrayed in the media as evidence that evolution is an ‘unsettled’ scientific idea)[[35]](#footnote-36). This is not true, as all biologists accept evolutionary theory, but understand that the different models indicate multiple mechanisms operate in evolution.

Organisations such as the [Australian Science Media Centre](https://www.smc.org.au/) seeks to provide the Australian public with evidence-backed science stories. They approach practicing researchers to review published scientific papers and publish the feedback on their website.

## Alternative conceptions and misconceptions

Research indicates that students should be explicitly taught the meanings and usage of terms such as theory and hypothesis. As such terms are part of the common vernacular, their scientific usage may be misunderstood by students, giving rise to a multitude of misconceptions/alternative conceptions. Table 2 summarises the scientific and lay usage of key scientific vocabulary, including some teaching strategies that teacher may choose to explore.

Table 2: Comparison of scientific and lay usage of terms describing the scientific process, including relevant teaching strategies.

|  |  |  |  |
| --- | --- | --- | --- |
| Scientific term | Scientific usage | Everyday language | Teaching points |
| Theory | A broad explanation for a wide range of phenomena. Some features of scientific theories:* concise
* coherent
* systematic
* predictive
* broadly scope
* integrates many hypotheses
* supported by many lines of evidence
 | Often used to mean a hunch, with little evidential support. | An example of a theory is the Theory of Evolution by Natural Selection. This theory explains the unity and diversity of life. It includes a large volume of evidence from diverse fields of science, such as zoology, botany, microbiology, molecular biology, genetics, geology, palaeontology, chemistry and physics. While new discoveries many modify this theory, it is highly unlikely to be overturned. All scientific theories are predictive. For example, based on available evidence, evolutionary theory predicted that terrestrial life originated in the oceans and that certain adaptations were required for the colonisation of land. Subsequent discoveries such as the Tiktaalik fossils and the lungfish confirmed that prediction. Such discoveries add to the confidence of the evolutionary theory. |
| Hypothesis | A tentative explanation for a narrow set of phenomena. Features of hypotheses include: * testability
* predictive
* based on prior experience, observation or knowledge
* supported by many lines of evidence
* more than predictions, hypotheses have explanatory power
 | Refers to an educated guess or an idea that we are quite uncertain about.  | Science textbooks frequently misuse the term. They may ask students to make a hypothesis about the outcome of an experiment (for example, table salt will dissolve in water more quickly than rock salt will). This is simply a prediction or a guess (even if a well-informed one) about the outcome of an experiment. The idea that ‘table salt dissolves faster than rock salt’ is not a hypothesis. A restatement, such as ‘the amount of surface area a substance has affects how quickly it can dissolve’ becomes a hypothesis: ‘More surface area means a faster rate of dissolution.’ This hypothesis has some explanatory power, it gives us an idea of why a particular phenomenon occurs and it is testable because it generates expectations about what we should observe in different situations. If the hypothesis is accurate, then we'd expect that, for example, sugar processed to a powder should dissolve more quickly than granular sugar. Students could examine rates of dissolution of many different substances in powdered, granular, and pellet form to further test the idea. The statement "Table salt will dissolve in water more quickly than rock salt" is not a hypothesis, but an expectation generated by a hypothesis. |
| Law | A generalisation about data. It describes the relationship between variables. Scientific laws are often represented mathematically. They may be specific to certain conditions and contain exceptions. Generally, scientific laws are not explanatory and do not provide mechanisms that underlie the observed relationships (although they spur further investigations to uncover those mechanisms). | A rule that must be abided or something that can be relied upon to occur in a particular situation. | * Some laws are physical and can be measured (for example, Ohm’s Law).
* Some laws describe an ‘ideal’ state, from which many exceptions and deviations are observed (for example, the Ideal Gas Law).
* Some laws describe abstract properties that are difficult to visualise (for example, entropy, which is described in the Second Law of Thermodynamics).
* Some laws feature prominently in scientific theories (for example, Mendel’s Laws of Inheritance became the centrepiece of the Chromosomal Theory of Inheritance)
 |
| Belief | Belief is not the basis of scientific thinking or knowledge construction. However, scientists, like all people, do form beliefs about many things. In the scientific context, the belief that a scientist holds refers to the scientific idea is the most accurate available based on a critical evaluation of the evidence (not based on faith, dogma or conviction). | The word belief is often associated with ideas about which we have strong convictions, regardless of the evidence for or against them.  |  |
| Fact | * A scientific statement that is known to be true through direct observation.
* Scientists also use the term "fact" to refer to a scientific explanation that has been tested and confirmed so many times that there is no longer a compelling reason to keep testing it or looking for additional examples[[36]](#footnote-37).
 | In everyday usage, facts are a highly valued form of knowledge because we can be so confident in them.  | * Although science values facts, scientists use many other forms of information to construct knowledge. Therefore, science is not simply a collection of facts but a body of knowledge.
* For example, it may be a fact that there are three trees in your backyard. However, our knowledge of how all trees are related to one another is not a fact; it is a complex body of knowledge based on many different lines of evidence and reasoning that may change as new evidence is discovered and as old evidence is interpreted in new ways. Through our knowledge of tree relationships is not a fact, it is broadly applicable, useful in many situations, and synthesises many individual facts into a broader framework
 |
| Error | An error is a difference between a measurement and the true value, often resulting from taking a sample. Scientific errors are usually statistical in nature. | In everyday language, an error is simply a mistake.  | For example, imagine that you want to know if corn plants produce more massive ears when grown with a new fertiliser, and so you weigh ears of corn from those plants. You take the mass of your sample of 50 ears of corn and calculate an average. That average is a good estimate of what you are really interested in: the average mass of all ears of corn that could be grown with this fertiliser. Your estimate is not a mistake but it does have an error (in the statistical sense of the word) since your estimate is not the true value. Sampling error of the sort described above is inherent whenever a smaller sample is taken to represent a larger entity. Another sort of error results from systematic biases in measurement (for example, if your scale were calibrated improperly, all of your measurements would be off). Systematic error biases measurements in a particular direction and can be more difficult to quantify than sampling error. |
| Model | * In science, the term model can mean several different things (for example, an idea about how something works or a physical model of a system that can be used for testing or demonstrative purposes). However, as a research method, modelling often means creating a mathematical model, a set of equations that indirectly represents a real system.
* Given a set of parameters, a model can generate expectations (hypotheses) about how the system will behave in a particular situation.
 | The word model is used in a variety of ways, including* Making replicas
* Models of cars
* Fashion models
* Artistic models
 | Modelling often involves idealising the system in some way, leaving some aspects of the real system out of the model to isolate particular factors or to make the model easier to work with computationally. For example, the Bohr model of the atom is based on the heliocentric model of the solar system. However, while the Bohr model explained many of the available observations and data, many other lines of evidence could not be explained by it. Eventually, the Bohr model of the atom was replaced by the Standard Model of the atom. However, given its simplicity and elegance, the Bohr model is still used to explain some simple features of atomic structure and properties. |

## Conceptual difficulties

While this module provides opportunities for students to explore the nexus between scientific knowledge and science messaging in society, teachers should focus of students’ development of scientific argumentation skills. A fundamental aspect of scientific argumentation is the use evidence-based reasoning. Students may find it difficult to construct explanations that incorporate evidence-based reasoning. When teaching this module, teachers may choose to frame the lessons using the **claim-evidence-reasoning** matrix. The following template (Table 3) may be used to teach students explicitly the skills involved in argumentation. Teachers should be aware that this is a cognitively complex process, and, through the use of suitable learning activities, students will gradually acquire high-level scientific argumentation skills.

Table 3: Template for teaching scientific argumentation. Note: teachers may choose to remove the explanatory text in bold lettering before issuing the template to students.

|  |
| --- |
| Planning scientific argumentation |
| Research question (and/or hypothesis) |
| ClaimA statement that answers the research question |
| EvidenceEmpirical data (or observations) from first-hand or second-hand investigation. |
| Reasoning**The scientific principles the link evidence to the claim** |

## Suggested teaching strategies

* The Utah Education Network has a lesson titled ‘[Separating fact from fiction](https://www.uen.org/lessonplan/view/37278)’ – this may be used as starter activity or formative assessment activity for this module.
* The [ABC education website](https://www.abc.net.au/education/media-literacy/?utm_source=sfmc&utm_medium=email&utm_content=&utm_campaign=%5beducation_sfmc_29_01_20_education%5d%3a10759&user_id=e19a4e732e3f422ba3302502adfd6a9a74e0fdf181ee87efdc59aab2277eb837&WT.tsrc=email&WT.mc_id=Email%7c%5beducation_sfmc_29_01_20_education%5d%7c10759Hero_CTA) has several resources media literacy, including ‘spotting misinformation and disinformation’. These may be useful resources for use in the classroom.

## Depth studies

‘Fact or fallacy’ provides students with opportunities to engage with the social (societal) aspects of science. As such students can relate to many socio-scientific issues that are discussed in the classroom, as well as in other settings. Thus, a Depth Study based on this module can deepen students’ understanding of relevant scientific concepts, as well as their engagement with the subject.

Outcomes detailed below are from [Investigating Science Stage 6 Syllabus](https://educationstandards.nsw.edu.au/wps/portal/nesa/11-12/stage-6-learning-areas/stage-6-science/investigating-science-2017) © 2017 NSW Education Standards Authority (NESA) for and on behalf of the Crown in right of the State of New South Wales.

### 1. Testing claims

The following (Table 4) Depth Study outline (Module 7) is derived from [NESA’s sample program](https://educationstandards.nsw.edu.au/wps/portal/nesa/11-12/stage-6-learning-areas/stage-6-science/investigating-science-2017).

Table 4: Outline of a Depth Study for Module 7. This is a 15-hour Depth Study.

|  |  |
| --- | --- |
| Part | Depth Study activity |
| 1 (3 hours) | Students re-examine/reinforce the targeted outcomes of this unit through the Depth Study to communicate scientific understanding and information about factual or fallacious claims* Students conduct research on a product selected from one of the following industries that has made claims about a product’s efficacy:
	+ Cosmetics
	+ Food
	+ Pharmaceuticals
* Students research the types of claims made about the product and conduct initial research into the methods that have led to or could be used to test these claims
* Students gather evidence about the availability of research data that supports the claim
* Students maintain a media file of articles which report scientific research in popular media. For each article students:
	+ make a brief description of the research
	+ comment on the use of scientific terminology
	+ evaluate the validity of the data

evaluate the reliability of the information source |
| 2 (2hours) | * Students research the analytic methods used by industry and those that can be used in class to test the claims made by the company about its product.

Students are too design an appropriate method to test the claims, either by executing a primary investigation or by reporting on secondary-sourced data |
| 3 (2hours) | * Students collect and collate the data from the primary investigation or from the secondary-sourced investigation

Students investigate, in depth, the ways in which the collected data can be interpreted, analysed and understood |
| 4 (3hours) | Students investigate the type of evidence that supports or refutes the claims made by each of the three companies in order to draw valid conclusions |
| 5 (3hours) | * Students investigate, in depth, how reporting of each product in the media, advertising and/or general news stories influences the general public’s acceptance of each claim
 |
| 6 (2hours) | * Students research and report on the process of peer review using a scientific article from a recognised and reliable scientific journal
* Students present their report and participate in a class peer-review process
* In the report that analyses the claims of the manufacturer, students must consider and comment on the following:
	+ validity and reliability of the investigative techniques
	+ if an experiment was performed the possible bias of the researcher/s
	+ sample size and selection

reliability of the data presented |

### 2. Science in movies

#### Outcomes

* **INS11/12-1** develops and evaluates questions and hypotheses for scientific investigation
* **INS11/12-4** selects and processes appropriate qualitative and quantitative data and information using a range of appropriate media12-5 analyses and evaluates primary and secondary information
* **INS11/12-6** solves scientific problems using primary and secondary data, critical thinking skills and scientific processes12-7 communicates scientific understanding using suitable language and terminology for a specific audience or purpose
* **INS11/12-7** communicates scientific understanding using suitable language and terminology for a specific audience or purpose12-13 describes and explains how science drives the development of technologies
* **INS12-14** uses evidence-based analysis in a scientific investigation to support or refute a hypothesis

#### Task Outline

You will be investigating the authenticity of scientific claims made in movies.

While movies provide a medium for communicating scientific ideas, such ideas may not be portrayed accurately in movies. Movies typically employ a variety of persuasive techniques to provoke certain emotions in their audience. Such techniques may ‘modify’ scientific concepts to such an extent that they may no longer be accurately represented. This may contribute to misconceptions by the viewing audience. By analysing scientific concepts that are portrayed in movies, it is possible to uncover potential biases or inaccuracies in their representation. After analysing the movies, you will use evidence-based reasoning to determine if the scientific content in those movies are fact or fallacy.

Choose ONE of the science movies listed below and determine its validity (if you have an option that is not on the list, it will need to be discussed with your teacher first). You are to write a film review of the film. The film review must incorporate the science that is “fallacy” in the movie but must then present “real science” and include the following aspects:

* The ‘fake’ science: what is depicted, explain the reasoning behind why it is fake Science. This would include a detailed account of the consequences behind this fallacy.
* The ‘real’ science. What would really happen if scientific facts were considered?
* Options[[37]](#footnote-38):
	+ Jurassic Park
	+ Interstellar
	+ Gravity
	+ The Martian
	+ Dawn of the Planet of the Apes.

Some resources to initiate classroom conversations about science in movies include:

* [Science in Hollywood](https://www.sciencenewsforstudents.org/article/science-hollywood)
* [Top 5 “science done right” moments in movies](https://www.smithsonianmag.com/science-nature/top-5-science-done-right-moments-in-movies-46123392/)
* [The 10 most accurate and (10 least accurate) Sci-Fi movies](https://www.popularmechanics.com/culture/movies/g753/the-10-most-and-least-accurate-sci-fi-movies/)

#### The Depth Study

* Pre-understanding of the science addressed in this film. This would include research and a rationale of what scientific concept the real science relates to. (2 hours)
* Watch the film (2 to 3 hours)
* Analysing the film by writing a critical film review of the “fake science” addressed in the movie, providing reasons and consolidating the reasons with evidence. (2 hours)
* This review must be presented in a report format
* You will also be required to analyse and evaluate the reliability and accuracy of scientific concepts addressed in the movie you watched.
* You will also be assessed on your report writing style, scientific language/terminology and correct referencing.

#### Rubric

Table 5: A marking rubric for the ‘fact or fallacy’ Depth Study

|  |  |  |  |  |  |  |  |
| --- | --- | --- | --- | --- | --- | --- | --- |
| SectionOutcomes | 0 marks | 1 mark | 2 marks | 3 marks | 4 marks | 5 marks | Mark |
| INS12-14 uses evidence-based analysis in a scientific investigation to support or refute a hypothesis  | no inquiry question present | inquiry question is present but may be weak or not relevant to the literature review | develops a relevant inquiry question with some guidance | develops a highly relevant inquiry question with limited guidance |  |  |  |
| INS12-14 uses evidence-based analysis in a scientific investigation to support or refute a hypothesis  | no explanation of any scientific concepts | states **one** scientific concept in the movie | states at least t**wo** scientific concepts in the movie**or**thoroughly explains **one** scientific concept in the movie  | explains at least **two** scientific concepts in the movie | explains at least **three** scientific concepts in the movie**or**thoroughly explains at least **two** scientific concepts in the movie | thoroughly explains at least **three** scientific concepts in the movie |  |
| INS12-14 uses evidence-based analysis in a scientific investigation to support or refute a hypothesis  | no assessment of accuracy or reliability of the scientific concepts addressed | makes a statement of accuracy and reliability of the scientific concepts | assesses the accuracy **or** reliability of some of the scientific concepts addressed | assesses the accuracy **or** reliability of all the scientific concepts addressed | assesses the accuracy **and** reliability of some of the scientific concepts addressed | assesses the accuracy **and** reliability of all of the scientific concepts addressed |  |
| INS12-6 solves scientific problems using primary and secondary data, critical thinking and scientific processes | no scientific explanation of each scientific concept to determine whether it is a fact or fallacy using primary and secondary data | a limited scientific explanation of each scientific concept to determine whether it is a fact or fallacy using primary and secondary data | a basic scientific explanation of each scientific concept to determine whether it is a fact or fallacy using primary and secondary data | a sound scientific explanation of each scientific concept to determine whether it is a fact or fallacy using primary and secondary data | a good scientific explanation of each scientific concept to determine whether it is a fact or fallacy using primary and secondary data | a thorough scientific explanation of each scientific concept to determine whether it is a fact or fallacy using primary and secondary data |  |
| INS12-15 evaluates the implications of ethical, social, economic and political influences on science | no evaluation of the impact the movie has on people’s perception  | limited evaluation of the impact the movie has on people’s perception  | basic evaluation of the impact the movie has on people’s perception  | sound evaluation of the impact the movie has on people’s perception  | a good evaluation of the impact the movie has on people’s perception  | a thorough evaluation of the impact the movie has on people’s perception  |  |
| INS12-4 Selects and processes appropriate qualitative and quantitative data and information using a range of appropriate media | no data is presented | data is disorganised  | selects data and information and represents them using a range of formats | selects qualitative and quantitative data and information and represents them using a range of formats | selects some relevant qualitative and quantitative data and information and represents them using a range of formats | selects relevant qualitative and quantitative data and information and represents them using a range of formats |  |
| INS12-5 Analyses and evaluates primary and secondary data and information | no evaluation of secondary sources | there are some comments as to the relevance **or** accuracy **or** reliability of secondary sources. This may be weak | there is an evaluation of secondary sources including relevance, accuracy and reliability. Some aspects may be missing | there is a sound evaluation of secondary sources including relevance, accuracy and reliability | there is a good evaluation of secondary sources including relevance, accuracy and reliability | there is a well-developed evaluation of secondary sources including relevance, accuracy and reliability |  |
| INS12-7 Communicates scientific understanding using suitable language and terminology for a specific audience or purpose | report is very brief, with sections missing and with incorrect information | report is brief and difficult to read. Sections miss key information or contain incorrect information | report is brief **or** difficult to read. Sections miss key information or contain incorrect information | uses appropriate language on the whole for a specific audience and displays good written communication but it does contain areas that are unclear or hard to understand | uses appropriate language effectively for a specific audience and displays good written communication which is clear and concise | uses appropriate language proficiently for a specific audience and displays very high-quality written communication which is clear and concise |  |
| INS12-7 Communicates scientific understanding using suitable language and terminology for a specific audience or purpose | most of the report is grammatically correct | spelling, grammar and formatting have many errors | spelling, grammar and formatting is to a good standard but contains some errors | spelling, grammar and formatting is to a very high standard and adds to the clarity of writing. There are very minor or no errors |  |  |  |
| INS12-7 Communicates scientific understanding using suitable language and terminology for a specific audience or purpose | no reference list | the reference list contains many mistakes and missing references | there is a reference list that contains all sources used in the text. The sources are referenced with a few mistakes and inconsistencies | there is a reference list that contains all sources used in the text. The sources are consistently and correctly referenced with no mistakes |  |  |  |

**Total**  /44

## Practical activities

Possible Investigations. Students should research the claim and design a valid experiment to test the claims (Introduction and Research, Aim, Hypothesis, Equipment, Risk assessment, Method, Results, Discussion and Conclusion).

### First-hand investigations

* Shampoos and skincare products and their claims of pH and greasy feel with skin.
* Amount of Vitamin C in Ribena
* Percentage of chocolate in choc chip cookies
* The acid-neutralising power of antacids

### Second-hand investigations

* [Do Vaccines cause Autism?](https://www.historyofvaccines.org/content/articles/do-vaccines-cause-autism?fbclid=IwAR2rEDIcyO-RSu1dKTNKFERsoKycTogFMydDTTMo3QJOVPbQrey5KVk-VJY)

* [Pete Evans’ controversial health claims](https://www.nowtolove.com.au/news/local-news/the-ama-slams-pete-evans-over-extreme-health-advice-36273)
* [The Magic Pill: How do the health claims in Pete Evans’ paleo diet doco stack up?](https://www.abc.net.au/news/health/2018-06-21/pete-evans-diet-doco-magic-pill-health-claims-evaluated/9891470)
* [Australian Cancer Cure - In 48 Hours - Blushwood Berry](https://www.youtube.com/watch?v=1iDYhNR5t2k&fbclid=IwAR0UkcEwzGu5mH0rrvV_5cew2F3MQobbypEH66kVwyX4X-JXY15zd9ojopk) (duration 2:46)
* [Dark chocolate is now a health food. Here’s how that happened.](https://www.vox.com/science-and-health/2017/10/18/15995478/chocolate-health-benefits-heart-disease?fbclid=IwAR3XCQeb7n9wrXxnSxpQOGRcXKRCbm7ITtOX0tlMrKrDrm7Jq5LdsRVeKLc)
* [21 Pictures that conclusively prove the earth is flat](https://wokesloth.com/pictures-that-conclusively-prove-the-earth-is-flat/masha/?utm_content=bufferf8d45&utm_medium=facebook&utm_source=thegoodlordabove&utm_campaign=bloomjoy&fbclid=IwAR2SLFN9XvzlyamsbO7vqIr9WmIaI-3U6F-sq_4h4v0lPnLnnPgmcs7doMo)
* [Night Parrot research labelled “fake news” by experts after the release of the damning report](https://mobile.abc.net.au/news/2019-03-22/report-confirms-dubious-night-parrot-research/10925900?fbclid=IwAR0yrEu0pA0CcTLCdRLhlWN69RBPqC7YgwhhBbuq5A4tZmrJS5nDv6DV7tQ&pfmredir=sm) (How scientists can deliberately mislead the public)
* ASCIA Position Statement [Unorthodox Techniques for the Diagnosis and Treatment of allergy, Asthma and Immune Disorders](https://www.allergy.org.au/hp/papers/unorthodox-testing-and-treatment) (Discusses the evidence or lack of it for many unorthodox allergy treatments, includes uses, method and evidence (lack of)).
* [A woman injects herself with fruit juice to get healthy, nearly dies](https://www.bbc.com/news/world-asia-china-47623816)
* [GMO crops create “halo effect” that benefits organic farmers, says new research](https://allianceforscience.cornell.edu/blog/2018/03/gmo-crops-create-halo-effect-benefits-organic-farmers-says-new-research/?fbclid=IwAR0tFCWws8IRCI54wQ0hE96jjO3ruJC-5-7_FDBPYRHdXmpuyBWNgsaqcDU)
* [Vitamins: Sorting science from scam](https://www.sbs.com.au/news/insight/vitamins-sorting-science-from-scam?fbclid=IwAR23rSr1RzxY3OkkQkhUViPW0HeXxnH6jM2ElRFa3H_ZpJUGpqZobBq49-k)
* [Is Gwyneth Paltrow Wrong About Everything? When celebrity culture and science clash](https://www.penguinrandomhouse.com/books/417402/the-science-of-celebrity----or-is-gwyneth-paltrow-wrong-about-everything-by-timothy-caulfield/) (book)
* Omega-3, our brains and behaviour
* [Scientific Myths that are too good to die](https://www.nytimes.com/1998/12/06/weekinreview/scientific-myths-that-are-too-good-to-die.html)

## Resources

### Impacts on investigations

#### Experimental design

* [Double-blind studies in research](https://www.verywellmind.com/what-is-a-double-blind-study-2795103)
* [Double Blind Trials Workshop](https://www.centreofthecell.org/wp-content/uploads/Double_Blind_Trials.pdf)
* [What is the placebo effect?](https://www.webmd.com/pain-management/what-is-the-placebo-effect#1)
* [Placebo Effect - Better Health Channel](https://www.betterhealth.vic.gov.au/health/conditionsandtreatments/placebo-effect)
* [What is a control group?](https://www.britannica.com/science/control-group)

#### Societal and economic influences

##### Predicting variation in climate

* [Climate change connection - How can we predict climate?](https://climatechangeconnection.org/science/how-can-we-predict-climate/)
* [What are climate models and how accurate are they?](https://blogs.ei.columbia.edu/2018/05/18/climate-models-accuracy/)
* [Economic Impacts of Climate Variability in South Africa and Development of Resource Prediction Models](https://journals.ametsoc.org/doi/full/10.1175/1520-0450%282002%29041%3C0046%3AEIOCVI%3E2.0.CO%3B2)

##### Suggesting remedies for health conditions

* [Pete Evans’ controversial health claims](https://www.nowtolove.com.au/news/local-news/the-ama-slams-pete-evans-over-extreme-health-advice-36273)

##### Manipulating statistical data

* [Political Effect of Economic Data Manipulation: Evidence from Chinese Protests](https://dukespace.lib.duke.edu/dspace/bitstream/handle/10161/15284/Li_duke_0066N_14058.pdf?sequence=1&isAllowed=y)
* [Media manipulation and disinformation](https://datasociety.net/research/media-manipulation/)
* [The Use-and Misuse-of Statistics: How and Why Numbers Are So Easily Manipulated](http://knowledge.wharton.upenn.edu/article/the-use-and-misuse-of-statistics-how-and-why-numbers-are-so-easily-manipulated/)

### Evidence-based Analysis

#### Define correlation and causation.

* Khan Academy [Video Fundamentals: Correlation and causation](https://www.khanacademy.org/partner-content/wi-phi/wiphi-critical-thinking/wiphi-fundamentals/v/critical-thinking-fundamentals-correlation-and-causation) (duration 7:08)
* [Clearing up confusion between correlation and causation](https://theconversation.com/clearing-up-confusion-between-correlation-and-causation-30761)
* [Spurious correlations](https://www.tylervigen.com/spurious-correlations)

#### The Hawthorne Effect

* [What is the Hawthorne effect?](https://www.investopedia.com/terms/h/hawthorne-effect.asp)
* [Hawthorne Effect: Definition & History](https://www.statisticshowto.datasciencecentral.com/experimental-design/hawthorne-effect/)
* [The Hawthorne Effect (historical accounts)](https://www.library.hbs.edu/hc/hawthorne/anewvision.html#e).

#### HRT and Coronary Heart Disease

* [Debate: The potential role of estrogen in the prevention of heart disease in women after menopause](https://www.ncbi.nlm.nih.gov/pmc/articles/PMC59620/)
* [Commentary: Hormone replacement therapy and coronary heart disease: four lessons](https://academic.oup.com/ije/article/33/3/461/716692)

#### The Mozart effect on child development

* [The Children’s Group The Mozart Effect](https://www.childrensgroup.com/product.php?mode=cat&cid=mozart_eng)
* [The Mozart Effect: Fact or fiction?](https://childdevelopmentinfo.com/development/the-mozart-effect-fact-or-fiction/#.XKW6yJgzaUk)
* [Will Mozart make my child smarter?](https://www.theguardian.com/lifeandstyle/2014/jan/12/will-mozart-make-child-smarter-classical-music-iq)

### Reading between the lines

#### General

* [Deepfakes: Can You Spot a Phony Video? | Above the Noise](https://www.youtube.com/watch?v=Ro8b69VeL9U&feature=youtu.be)(duration 6:15)

#### Peer-reviewed articles versus articles in popular media

* [Chocolate is a better cough suppressant than your cough syrup, study says](https://www.ajc.com/news/world/chocolate-better-cough-suppressant-than-medicine-study-says/zVm2Wr0OvQOdaca9zSwYwJ/)
* [Professor Says Chocolate Is Better For You than Cough Syrup](http://www.ladbible.com/news/food-professor-says-chocolate-is-better-for-you-than-cough-syrup-20190110)

#### Conflicts of interest

##### Tobacco industry and lung cancer

* [Inventing Conflicts of Interest: A History of Tobacco Industry Tactics](https://www.ncbi.nlm.nih.gov/pmc/articles/PMC3490543/)
* [Cigarette Company Paid for Lung Cancer Study](https://www.nytimes.com/2008/03/26/health/research/26lung.html)
* [Lung Cancer Screening Trial Financed by Tobacco-Funded Foundation, Sparks Debate](https://academic.oup.com/jnci/article/100/10/690/905461)

##### Fossil fuel industry and climate change

* [Tweet the Story of the Fossil Fuel Industry's Climate Deception](https://www.ucsusa.org/global-warming/fight-misinformation/tweet-facts-about-fossil-fuel-industry-climate-change-deception)
* [Holding Major Fossil Fuel Companies Accountable for Nearly 40 Years of Climate Deception and Harm](https://www.ucsusa.org/global-warming/fossil-fuel-companies-knew-about-global-warming)

##### Asbestos mining and lung cancer

* [Asbestos-related diseases in mineworkers: a clinicopathological study](https://openres.ersjournals.com/content/3/3/00022-2017)

#### The Halo effect

##### Celebrities endorsing products or viewpoints

* [Why the Halo Effect Influences How We Perceive Others](https://www.verywellmind.com/what-is-the-halo-effect-2795906)
* [Pete Evans’ controversial health claims](https://oversixty.com.au/health/caring/pete-evans-most-dangerous-health-claims)

##### Misleading advertising claims

* [Ribena Vitamin C claims ‘may have mislead customers’](https://www.accc.gov.au/media-release/ribena-vitamin-c-claims-may-have-misled-consumers)
* [Schoolgirls rumble Ribena’s vitamin claims](https://www.theguardian.com/world/2007/mar/27/schoolsworldwide.foodanddrink)
* [Thousands claim compensation for misleading Nurofen products](https://www.smh.com.au/national/thousands-claim-compensation-for-misleading-nurofen-products-20180111-h0gy9p.html)
* [Court finds Nurofen made misleading Specific Pain claims](https://www.accc.gov.au/media-release/court-finds-nurofen-made-misleading-specific-pain-claims)

#### Pseudo-scientific claims

* [10 Pseudo-science theories we’d to see retired forever](https://io9.gizmodo.com/10-pseudo-science-theories-wed-like-to-see-retired-fore-1592128908?IR=T)
* [Drawing the line between science and pseudo-science](https://blogs.scientificamerican.com/doing-good-science/drawing-the-line-between-science-and-pseudo-science/)

##### Astrology

* [Is Astrology a pseudoscience?](https://www.thoughtco.com/astrology-is-astrology-a-pseudoscience-4079973)
* [Astrology: Is it scientific?](https://undsci.berkeley.edu/article/astrology_checklist)
* [Astrology isn’t fake-it’s just been ruined by modern Psychology](https://qz.com/1170481/horoscopes-2018-astrology-isnt-fake-its-just-been-ruined-by-modern-psychology/)

##### Numerology

* [Why is numerology considered a pseudoscience?](https://www.quora.com/Why-is-numerology-considered-a-pseudoscience)

### Science as self-correcting

#### Falsification of scientific results

* [The MMR vaccine and autism: Sensation, refutation, retraction, and fraud](https://www.ncbi.nlm.nih.gov/pmc/articles/PMC3136032/)

#### Scientific publishing

##### Pons and Fleischmann’s cold fusion

* [It’s not cold fusion… But It’s something](https://blogs.scientificamerican.com/guest-blog/its-not-cold-fusion-but-its-something/)
* [Cold fusion: A case study for scientific behaviour](https://undsci.berkeley.edu/article/0_0_0/cold_fusion_01)

##### Alex Smolyanitsky’s falsified scientific paper

* [A Study by Maggie Simpson And Edna Krabappel Has Been Accepted by Two Scientific Journals](https://www.sciencealert.com/two-scientific-journals-have-accepted-a-study-by-maggie-simpson-and-edna-krabappel)

##### Tom Spears’ nonsense journal submission

* [Spears: How my fake science paper earned me a shot at an editor's job](https://ottawacitizen.com/news/local-news/ok-no-problem-fakery-is-fine-at-bottom-feeding-journal)

#### Benefits of peer review

* [Advantages of Peer Reviews](https://explorable.com/advantages-of-peer-reviews)
* [10 Benefits of peer review in writing research](https://simplyeducate.me/2013/06/24/10-benefits-of-peer-review-in-research-writing/)

#### Impact of fake science journals

* [The public perception of Science](https://journals.sagepub.com/doi/pdf/10.1068/p150231)
* [Predatory publishers: the journals that churn out fake science](https://www.theguardian.com/technology/2018/aug/10/predatory-publishers-the-journals-who-churn-out-fake-science)

# Appendices

## Appendix 1: Evaluating scientific investigations

**Note to teachers:** this Appendix is reproduced from Appendix 1 to Module 5.

### The limitations of generating scientific data

Scientific advances rely on a solid foundation of evidence. The strength of any scientific concept is only as strong as the quality of the evidence that supports it. Thus, scientists place great emphasis on gathering, manipulating, and analysing evidence.

Data are measurements and observations that scientists use to develop scientific conclusions. The term measurement refers to the amount or quantity of some particular property that a system possesses (for example, the mass of an object). Often, scientists manipulate raw measurements before using them as the data. Scientific investigations do not produce single measurements. Rather, the data are the averages of multiple, independent measurements. Most measurements contain errors (note that scientific errors are not mistakes, this is discussed in a later section). It is important to anticipate, identify and minimise (or even eliminate) sources of error in measurements. Indeed, proper data analysis requires an understanding of measurement errors. Every aspect of a scientific investigation must be scrutinised for errors, as they may affect the investigator’s conclusions. When experiments are repeated, the errors of measurement may compound. Therefore, scientists use several criteria to decide if an experiment, and the conclusions derived from it, are acceptable.

Table 6 (on the next page) defines criteria that are used to evaluate scientific investigations[[38]](#footnote-39).

Table 6: Definitions of the quality of scientific investigations. These definitions are used in NESA syllabuses.

|  |  |  |  |
| --- | --- | --- | --- |
| Term | Definition | Synonym(s) | Notes |
| Accuracy | The extent to which a measured value agrees with its true value (that is, the reference value). | Exact | Requires prior knowledge about the measured variable (that is the reference values)  |
| Reliability | The extent to which the findings of repeated experiments, conducted under identical or similar conditions, agree with each other. | ConsistencyRepeatabilityReproducibilityStability  |  |
| Validity | The extent to which an experiment addresses the question under investigation. | - | The criterion examines how well the design, conduct and analyses of an investigation address the inquiry question/hypothesis being investigated. |

After learning about the meaning and use of these terms, students should explore the relationships between them. For example, measurements may be accurate but not reliable. Validity is a holistic evaluation of scientific investigations and relies on all aspects of investigations to be accurate/precise and reliable. An unreliable investigation cannot be valid, but a reliable investigation may be invalid if it does not address the question under investigation.

**Note that while accuracy refers to the agreement between a measured value to its true value, the closeness of the repeated measurements of a variable within an experiment in referred to ‘precision’. NESA does not use the term ‘precision’ in the Investigating Science syllabus: accuracy encompasses precision**.

## Appendix 2: Errors and uncertainties of measurement

### Errors of measurement

In science, measurement errors refer to the difference between the measured and true values of a quantity. It is important to note that a scientific error is not a mistake in making the measurements.

Generally, there are two classes of errors of measurement. [Note that errors of measurement should not be confused with statistical errors].

* **Systematic errors**: Systematic errors are deviations from the true value by a constant amount. They are also called ‘biases’. Systematic errors affect the accuracy, but not the reliability of measurements. Repeating the measurements will not improve the accuracy of the data. If a piece of equipment does not read zero when it should, it is not calibrated correctly. If a bathroom scale reads 2 kg when no one is standing on it, it will measure a person’s mass as being 2 kg heavier than it actually is. Calibration error can be minimised by zeroing the equipment before it is used or by subtracting the false reading (what it reads when it should read zero) from each measurement.
* **Random errors**: These are the ‘component of measurement error that in replicate measurements varies unpredictably’. Random errors cause deviations from true values by varying amounts. An example of a random error is the effect of environmental factors on measurement (for example, temperature or humidity). Random errors affect the precision and reliability of measurements. Repeating the measurements can reduce random errors of measurement.
	+ Parallax error. This is an example of a random error. When the object being measured is viewed at an angle, the scale being used to measure the object may not line up exactly with the object. This will lead to the measured value being higher or lower than the actual value. For example, when a car speedometer is viewed from the passenger’s seat, it will appear to show a higher speed than when viewed from the driver’s seat. Parallax error can be minimised. When reading from a scale, the scale needs to be viewed from directly in front. Some electrical meters have a mirror behind the needle; if the reflection of the needle can be seen, the observer is not viewing the scale from directly in front.

Predictably, the closer the measured value is to its real value, the lower the error of measurement. Conversely, the lower the error, the greater the accuracy of the measurement. Therefore, we must be aware of the errors of measurements when conducting and analysing experiments.

Figure 2. Summary of the key features of random and systematic errors.

### Uncertainty

Uncertainty refers to the spread or dispersion of measurements. It implies that the true value of a measurement is not known accurately, but that it lies within a range of values. When reporting measurements, the uncertainty is shown with a ± symbol. Therefore, the measurement is reported as

Measurement ± uncertainty (for example, 0.86 ± 0.05 s)

There are two ways of determining the uncertainty associated with measurements:

* **Analogue instruments** (for example, a ruler): the uncertainty is half of smallest division. For example, standard laboratory thermometers show gradations of 1oC. Therefore, the uncertainty of measurements associated with this device is 0.5oC (that is, temperature ± 0.5oC).
* **Digital instruments** (for example, voltmeter): the uncertainty is half of the highest significant figure. Consider a digital voltmeter that provides measurements to two decimal places. For example, if a voltmeter provides a reading of 1.55V, then the error of measurement is associated with the value of the number in the second decimal place (in this case, 0.05V). Since this number varies by 0.01V (the reading lies between 1.55V and 1.56V), the uncertainty of measurement is half of this value, or 0.005V. Therefore, this measurement is reported as 1.550 ± 0.005V.

## Appendix 3: Misuse of science

At various times, industry groups have discredited scientific findings, or have manipulated the scientific process, to obtain outcomes that benefit them. There is increasing demand for openness in scientific research and publishing. Scientific journals require authors to declare their sources of funding, as well as any conflicts of interests that may exist. The following table (Table 7) provides examples of the misuse of science.

Table 7: Examples of misuse of science by industry groups

|  |  |
| --- | --- |
| Case | Summary |
| Tobacco industry[[39]](#footnote-40) | The adverse health effects of tobacco smoking were evident by the early 1950s. Industry entities adopted a strategy to cast doubt on scientific findings that were contrary to their business interests. This strategy involved ‘engineering’ science, seemingly supporting science, especially scientific scepticism. The tobacco industry set up research institutes (the Tobacco Industry Research Center) and funded scientific research at universities. Such funding came with the proviso that none of the research findings could be published without the approval of the funding agencies. The industry emphasised the differences in the use of the term ‘uncertainty’ in science and the general public. Claiming that scientific uncertainty equated with the lack of proof, tobacco industry representatives and scientists sponsored by the industry asserted that there was “no proof” of the link between tobacco smoking and adverse health effects. This orchestrated strategy proved to be successful in eroding the public’s acceptance of scientific messages. Presently, the industry funds research into the use of e-cigarettes. The industry claims that e-cigarettes are safe alternatives to tobacco smoking, despite the lack of evidence for such claims. There is also no scientific support for the claim that e-cigarettes help smokers to stop tobacco smoking[[40]](#footnote-41). The strategy of “attacking the science” has been so powerful that it has been adopted by other industry and vested-interest groups to drive their agenda. |
| Dangers of asbestos[[41]](#footnote-42) | Asbestos is a collection of six distinct silicate minerals that form fibres (crystals). Inhalation of asbestos fibres has been linked to several disease conditions, such as asbestosis (inflammation of the lung), lung cancer (mesothelioma), as well as ovarian and laryngeal cancers[[42]](#footnote-43). Georgia Pacific sold construction material containing asbestos. Despite knowledge of the potential adverse health effects of asbestos exposure, the company did not inform its users of the dangers[[43]](#footnote-44). In the face of a growing threat of litigation from the public, Georgia Pacific published 11 false ‘scientific’ articles. These articles were ghost-written. Ghost writing is a significant problem in research, where the authors of the published papers are not researchers who conducted the research (this occurs with industry-funded research or those conducted by industry-based researchers)[[44]](#footnote-45). The authors of the Georgia Pacific publications did not declare their conflicts of interest, or their funding sources. Industry can claim scientific legitimacy through these publications, even though the science may be irrelevant. Ultimately, those articles contained misinformation about the link between asbestos exposure and developing cancer. |
| Climate change and the fossil fuel industry | The ability of some gases to trap and radiate heat energy is known for more than a century. In the atmosphere, these gases can act as a blanket, prevent the radiation of reflected heat from the Earth’s surface into space. Atmospheric measurements have indicated that the concentration of these gases (called greenhouse gases) have continued to increase in the last century. Modelling of this and other data point to raising global temperatures, resulting in significant effects to the biosphere. Human activities contribute to the increasing in the concentrations of greenhouse gases in the atmosphere, resulting in rising global temperatures (anthropogenic warming). The use of fossil fuels is a significant contributor to the release of greenhouse gases into the atmosphere. The fossil fuel industry has championed the attacks on scientific studies that highlight this connection. Internal memos and other documents from fossil fuel companies indicate that they were aware of global warming resulting from the emission of greenhouse gases. Despite this, they resolved to mislead the public about climate change. The strategy employed by this industry is similar to those used by the tobacco industry; to discredit the science behind the findings, including the communication of disinformation, such as false scientific data and conclusions, as well as manufactured uncertainty. Greenwashing is a tactic used by the industry to convey the impression that they are involved in developing solutions to limit climate change, while trying to influence legislation and policies to prevent the shift to non-carbon-based solutions. Furthermore, they supported the formation of grassroots organisations that disseminated misinformation about the science behind climate change. Some of the documents from the fossil fuel industry regarding climate change denial and the campaign to misinform the public may be accessed at the [Union of Concerned Scientists](https://www.ucsusa.org/resources/climate-deception-dossiers) website. |
| Effectiveness of Vioxx (an anti-arthritis drug)[[45]](#footnote-46) | Scientists at Merck (the company that manufactured Vioxx) manipulated the design of a clinical trial, which was designed to demonstrate the effectiveness of the new drug. Rather than comparing the effects of Vioxx against a placebo, Merc scientists compared it to the painkiller, Naproxen. They concealed the fact that Vioxx increased the incidence of cardiovascular events by 400%. After numerous premature deaths and other adverse outcomes that were attributed to the use of Vioxx, the drug was recalled worldwide, including in Australia[[46]](#footnote-47). |
| Misrepresenting the risk of sugars in disease[[47]](#footnote-48) | The Sugar Research Foundation is an organisation set up by the sugar industry. It has funded several research projects that were aimed at moderating the risk of sugar consumption in the development of coronary heart disease. |

Recent work has uncovered new strategies used by groups with vested interests to spread misinformation about scientific knowledge. One such social media strategy is the use of [malicious bots and trolls](https://theconversation.com/malicious-bots-and-trolls-spread-vaccine-misinformation-now-social-media-companies-are-fighting-back-123430) to spread misinformation, which were employed to spread falsehoods about vaccination.

### Corporate manipulation of research

A comprehensive review[[48]](#footnote-49) of the corporate manipulation of scientific research across five industries (tobacco, pharmaceutical, chemical and silicosis-generating industries) revealed similar strategies being adopted across those industries. Those strategies included:

* funding research (both internal and external) that supports the industry's interests
* publishing in scientific literature of research that supports the industry's interests (‘cherry picking’ and using only those data that support their positions)
* suppressing industry-sponsored research in cases where the results do not support the industry's interests
* distorting public discourse on research that does not support the industry's interests
* setting scientific standards that favour the industry's interests (this includes setting methodology criteria or unsafe exposure thresholds)
* disseminating favourable research directly to decision makers and the public

All of these tactics not only served to undermine legitimate scientific research, but also to protect the companies from litigations. These strategies were placed in the public record only after protracted litigations through various legal systems.

## Appendix 4 Understanding graphs

Graphs are a visual medium used for communicating quantitative observations. They are often persuasive and be used to convey abstract ideas easily. Improperly constructed graphs can misguide conversations about the underlying concepts. Some important aspects of graphing include:

* Ensuring the relevant axis are drawn to scale and labelled
* All of the data (including any outliers) are represented
* The type of data (for example, raw data or averaged data) used to construct the graph is indicated (in the description)
* If available, the results of statistical tests are indicated (for example, error bars, significance of differences).

The English statistician, Francis Anscombe, developed 4 different datasets from which he constructed graphs. All of the graphs (lines of best fit) look identical, even though the distribution of the datapoints are different. This set of graphs is known as Anscombe’s quartet is shown in Figure 3. The graphs demonstrate how seeming similar messages can be conveyed by graphs, even though they may not be supported by the underlying data (in the case of Anscombe’s quartet, only one of the four graphs is supported by the data)



Figure 3. Anscombe’s quartet. X1, X2, X3 and X4 are different datasets. However, the line of best fit (blue line) for each of the datasets produce identical graphs. Image credit: [Schultz (2010)](https://en.wikipedia.org/wiki/Anscombe%27s_quartet#/media/File:Anscombe's_quartet_3.svg), distributed under [CC By SA 3.0](https://creativecommons.org/licenses/by-sa/3.0/)

The article at Politifact, [Chart shown at Planned Parenthood hearing is misleading and ‘ethically wrong’](https://www.politifact.com/factchecks/2015/oct/01/jason-chaffetz/chart-shown-planned-parenthood-hearing-misleading-/) shows how incorrectly-scaled graphs can be used to convey the wrong impression of some concept to be communicated.

The first graph in the article shows a comparison of abortion rates and the rates of cancer screening and prevention services in the United States. This was presented at an inquiry by an anti-abortion group against the Planned Parenthood organisation. The graph was used to convey the message that while the rates of cancer screening decreased between 2006 and 2013, the rates of abortion had increased during the same period. The graph is not to scale and lacks a vertical axis. When corrected for these defects, the corrected graph appears later in the article. The abortion rate remains relatively constant during that period.

## Appendix 5: Publish or perish

Approximately 50 million peer-reviewed articles are published every year. The majority of those are uncited or are poorly cited (<5 citations). The top five cited papers are shown in the table[[49]](#footnote-50) below (Table 8):

Table 8: Most cited scientific publications

|  |  |  |
| --- | --- | --- |
| Rank | Publication | Citations |
| 1 | Lowry, O. H., Rosebrough, N. J., Farr, A. L. & Randall, R. J. Protein measurement with the folin phenol reagent. Journal of Biological Chemistry. 193, 265–275 (1951). | 305,148 |
| 2 | Laemmli, U. K. Cleavage of structural proteins during the assembly of the head of bacteriophage T4. Nature 227, 680–685 (1970). | 213,005 |
| 3 | Bradford, M. M. A rapid and sensitive method for the quantitation of microgram quantities of protein utilizing the principle of protein-dye binding. Analytical. Biochemistry. 72, 248–254 (1976). | 155,530 |
| 4 | Sanger, F., Nicklen, S. & Couslon, A. R. DNA sequencing with chain-terminating inhibitors. Proceedings of the National Academy of Sciences. USA 74, 5463–5467 (1977). | 65,335 |
| 5 | Chomczynski, P. & Sacchi, N.Single-step method of RNA isolation by acid guanidinium thiocyanate-phenol-chloroform extraction. Analytical Biochemistry. 162, 156–159 (1987). | 60,397 |

### Interesting facts[[50]](#footnote-51)

* The top five most-cited articles are all in the field of Biological Science.
* All of the top five most-cited papers are ‘methodological’ papers that describe specific scientific methods (protocols) which are widely used in biological sciences research.
* Only two papers in the top-100 most-cited list describe Nobel-prize winning work.
* Einstein’s paper on special relativity, Watson and Crick’s paper on the structure of DNA and Hubble’s paper on the discovery of red-shifting galaxies are not in top100.
* Some of the most famous discoveries have become common knowledge and are no longer cited in publications.
1. The mean, standard deviation (standard error) and the variance of the data are used in statistical tests to determine if the differences between groups are significant. Similarly, statistical tests can also reveal if the correlations between groups (variables) are statistically significant. [↑](#footnote-ref-2)
2. Turner BO, Paul EJ, Miller MB, Barbey AK. Small sample sizes reduce the replicability of task-based fMRI studies. Communications biology. 2018; 1(1):62. [↑](#footnote-ref-3)
3. Estruch R, Ros E, Salas-Salvadó J, Covas MI, Corella D, Arós F, Gómez-Gracia E, Ruiz-Gutiérrez V, Fiol M, Lapetra J, Lamuela-Raventos RM. Primary prevention of cardiovascular disease with a Mediterranean diet. New England Journal of Medicine. 2013; 368(14):1279-90. [↑](#footnote-ref-4)
4. Estruch R, Ros E, Salas-Salvadó J, Covas MI, Corella D, Arós F, Gómez-Gracia E, Ruiz-Gutiérrez V, Fiol M, Lapetra J, Lamuela-Raventos RM. Primary prevention of cardiovascular disease with a Mediterranean diet supplemented with extra-virgin olive oil or nuts. New England Journal of Medicine. 2018 Jun 21; 378(25): e34. [↑](#footnote-ref-5)
5. [Nutrition, health and related claims](http://www.foodstandards.gov.au/industry/labelling/Pages/Nutrition-health-and-related-claims.aspx). [↑](#footnote-ref-6)
6. DeKosky ST, Williamson JD, Fitzpatrick AL, Kronmal RA, Ives DG, Saxton JA, Lopez OL, Burke G, Carlson MC, Fried LP, Kuller LH. Ginkgo biloba for prevention of dementia: a randomized controlled trial. Jama. 2008;300(19):2253-62. [↑](#footnote-ref-7)
7. Guilbeault D, Becker J, Centola D. Social learning and partisan bias in the interpretation of climate trends. Proceedings of the National Academy of Sciences. 2018; 115(39):9714-9. [↑](#footnote-ref-8)
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11. Rauscher FH, Shaw GL, Ky CN. Music and spatial task performance. Nature. 1993;365(6447):611 [↑](#footnote-ref-12)
12. Mehr SA, Schachner A, Katz RC, Spelke ES (2013) Two Randomized Trials Provide No Consistent Evidence for Nonmusical Cognitive Benefits of Brief Preschool Music Enrichment. PLoS ONE 8(12): e82007. [↑](#footnote-ref-13)
13. "Shaping scientists." [Understanding Science](http://www.understandingscience.org). University of California Museum of Paleontology. 3 November 2019 [↑](#footnote-ref-14)
14. [Too tentative: Is the scientific community's confidence in the ideas accurately portrayed?](https://undsci.berkeley.edu/article/0_0_0/sciencetoolkit_05) [↑](#footnote-ref-15)
15. [What controversy: Is a controversy misrepresented or blown out of proportion?](https://undsci.berkeley.edu/article/0_0_0/sciencetoolkit_06) [↑](#footnote-ref-16)
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22. Adapted from ‘[Is astrology scientific?](https://undsci.berkeley.edu/article/0_0_0/astrology_checklist)’ [↑](#footnote-ref-23)
23. Not to be confused with scientific numerology, which discusses the patterns of numbers seen in nature. For example, the speed of light or the Planck’s constant are examples of numbers that recur in nature. Scientists do not ascribe any mystical properties to those numbers (Gamow G. Numerology of the Constants of Nature. Proceedings of the National Academy of Sciences of the United States of America. 1968;59(2):313). Note that scientific numerology is not accepted by all scientists. [↑](#footnote-ref-24)
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