

Science 9–10

Chapter 1 — Nature and development of science

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How scientific knowledge is validated and refined — replication, publication, peer review, consensus, and telling science from pseudoscience

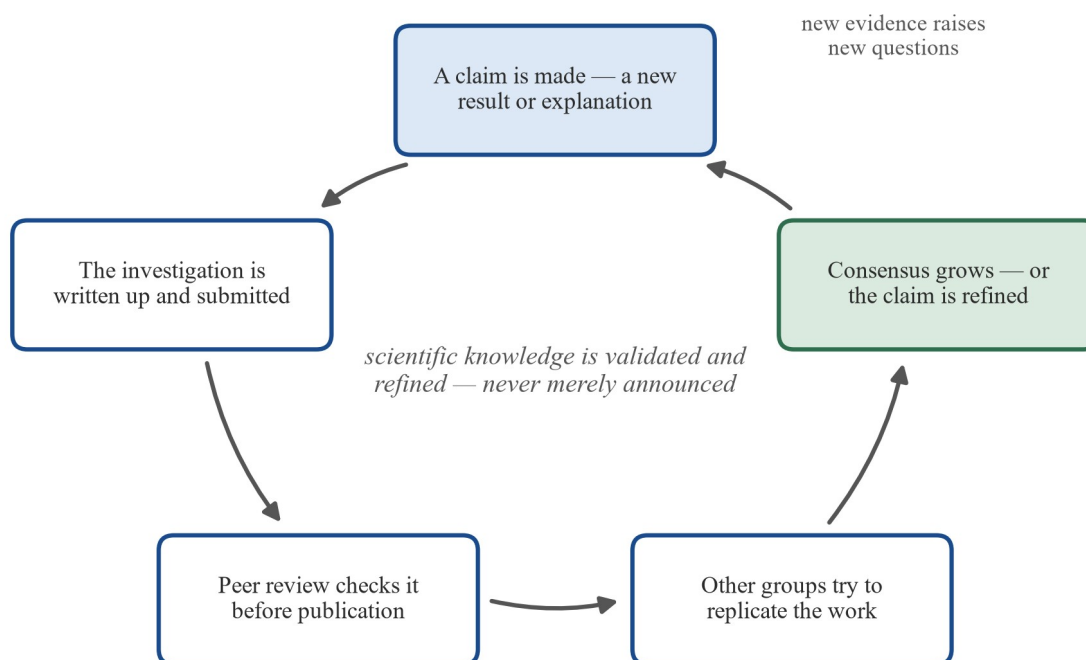
Chapter 1 — Nature and development of science (Science, Levels 9 and 10)

Subtopic 1A · VC2 Science — Nature and development of science

CD code: VC2S10H01 (this subtopic owns the whole CD) **Content description (verbatim):** “scientific knowledge is contestable and is validated and refined over time through expanding scientific methods, replication, publication, peer review and consensus” **Elaboration ids drawn on:** VC2S10H01.E01 · VC2S10H01.E02 · VC2S10H01.E03 · VC2S10H01.E04 · VC2S10H01.E05 · VC2S10H01.E06 · VC2S10H01.E07 **Achievement standard (verbatim):** “students analyse the importance of different scientific methods, critique, replication, publication and peer review in the development of scientific knowledge.” This subtopic serves the whole of that sentence: what each named check — methods, critique, replication, publication, peer review — adds, and how their agreement builds the consensus that turns a claim into scientific knowledge. It ends with the skill of recognising what only pretends to be science.

Theory

Science is contestable, and that is its strength. In science, no claim is true because somebody says it is — not because the person is famous, clever or confident. Every claim is open to being questioned, tested and shown wrong. That sounds like weakness, but it is the opposite: because every claim can be checked, the claims that survive checking are the ones worth trusting. The checks are the substance of this subtopic — expanding scientific methods, replication, publication, peer review, and the consensus that grows when independent checks agree — and the cycle below shows the order in which they work.

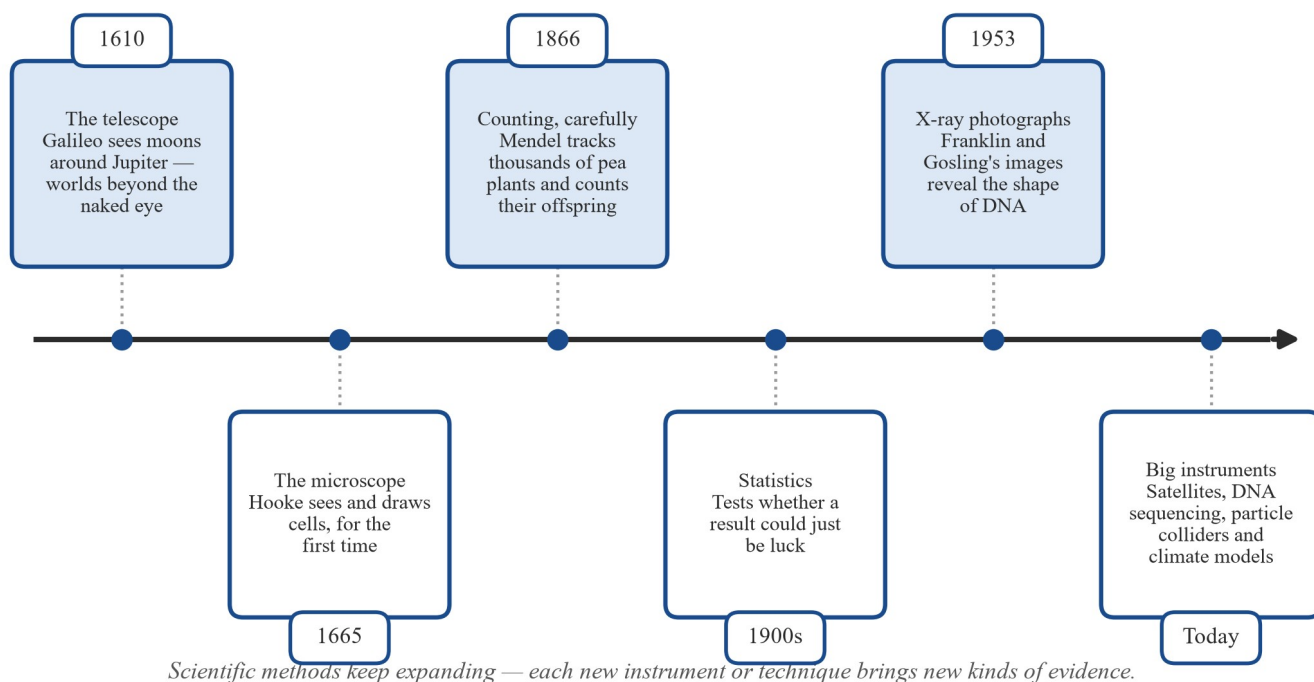


Five boxes joined in a ring by arrows: a claim is made; the investigation is written up and submitted; peer review checks it before publication; other groups try to replicate the work; consensus grows, or the claim is refined; an

arrow leads back to the start, with the note “new evidence raises new questions”. The centre reads: scientific knowledge is validated and refined, never just announced.

Read one way, the ring is a filter: weak claims tend to fall out at some step. Read another way, it is a builder: what passes every step becomes dependable knowledge. And the cycle never quite ends — a consensus is always open to new evidence, which is why science refines itself instead of standing still.

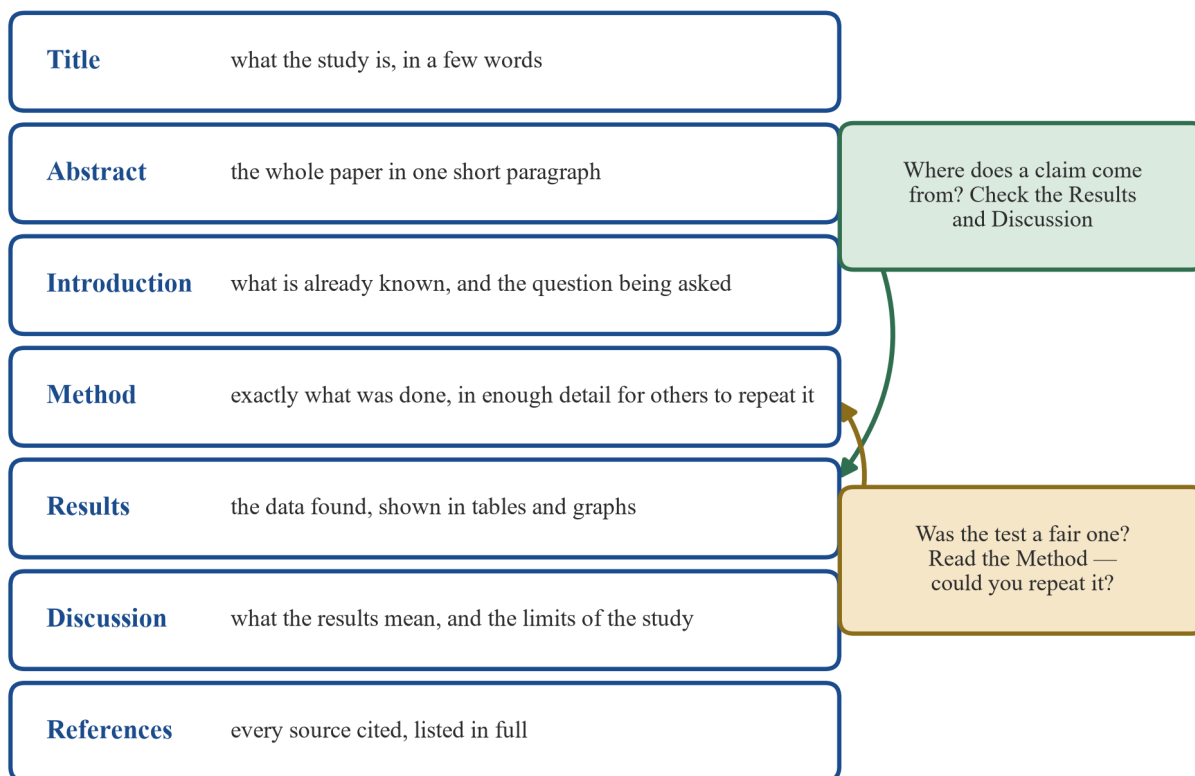
Expanding scientific methods. The content description says the methods *expand*, and the history is plain: each new instrument or technique added a kind of evidence nobody had before.



A timeline of six cards. 1610, the telescope: Galileo sees moons around Jupiter, worlds beyond the naked eye. 1665, the microscope: Hooke sees and draws cells for the first time. 1866, counting carefully: Mendel tracks thousands of pea plants and counts their offspring. 1900s, statistics: tests whether a result could just be luck. 1953, X-ray photographs: Franklin and Gosling's images reveal the shape of DNA. Today, big instruments: satellites, DNA sequencing, particle colliders and climate models. Caption: scientific methods keep expanding — each new instrument or technique brings new kinds of evidence.

Each card is also a reminder that a method does not replace the cycle — it feeds it. A telescope does not validate a claim; it supplies new evidence for the cycle to check. Statistics matters in a special way: once results are numbers, a mathematical test can ask whether a pattern could have arisen by luck alone. That test is used twice in this subtopic, on Mendel's peas and on astrology.

Publication: putting a claim on the record. A result enters science when it is published — written up in a scientific journal so that anyone, anywhere, can read exactly what was done and what was found. A paper has a fixed anatomy, and knowing it tells you where each kind of statement lives.

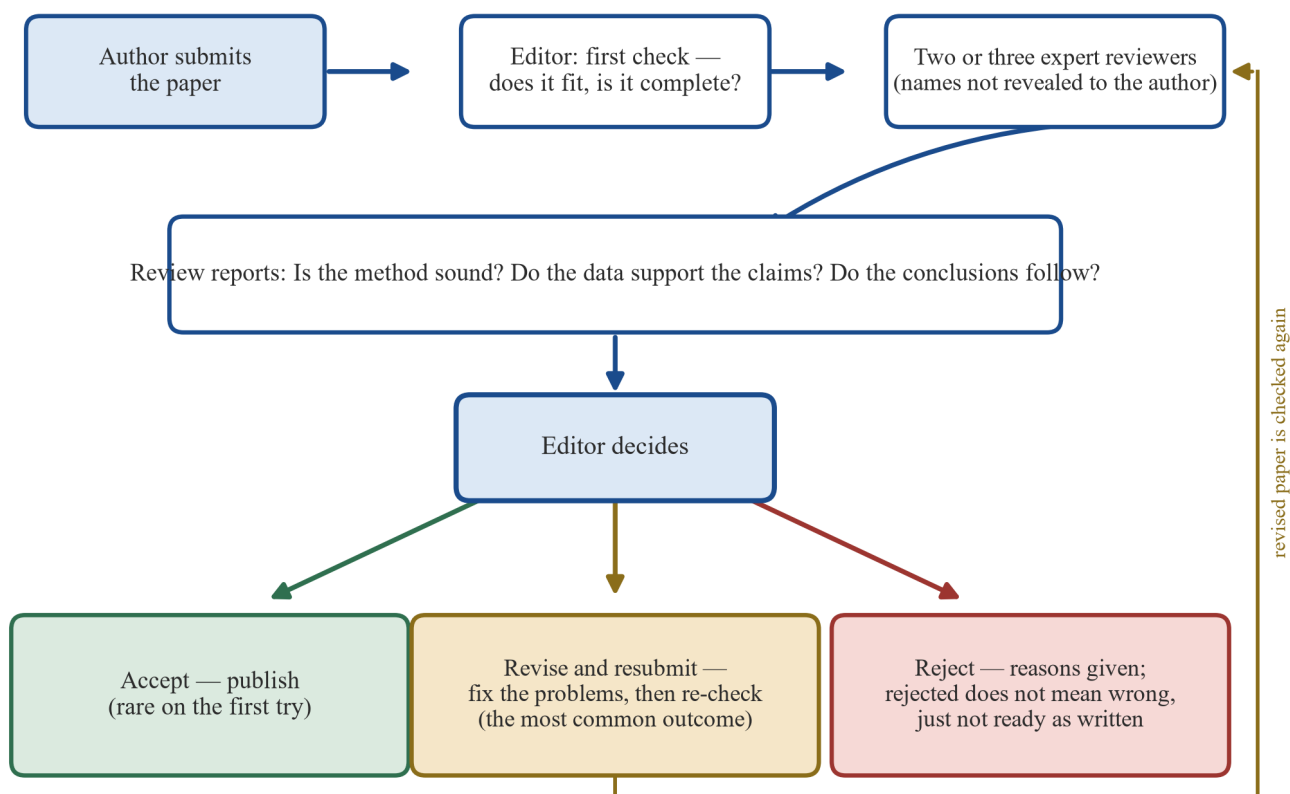


The Abstract is read first, but the Method is the part you need to judge the work.

The seven sections of a scientific paper stacked as labelled bars: Title, Abstract, Introduction, Method, Results, Discussion, References, each with a one-line description. Two callouts: “Where does a claim come from? Check the Results and Discussion”, pointing at Results; “Was the test a fair one? Read the Method — could you repeat it?”, pointing at Method. Caption: the Abstract is read first, but the Method is the part you need to judge the work.

The Method is the hinge of the whole system, because it is what makes replication possible. A paper whose Method is too vague to repeat has not really published a claim — it has announced one.

Peer review: the check before publication. Before a journal publishes a paper, the editor sends it to two or three experts in that field who were not part of the work, without their names being revealed to the author. They read it as a check, not a prize-giving: Is the method sound? Do the data support the claims? Do the conclusions follow? The editor then decides.



Reviewers test the work, not the person: the only question is whether the evidence supports the claim.

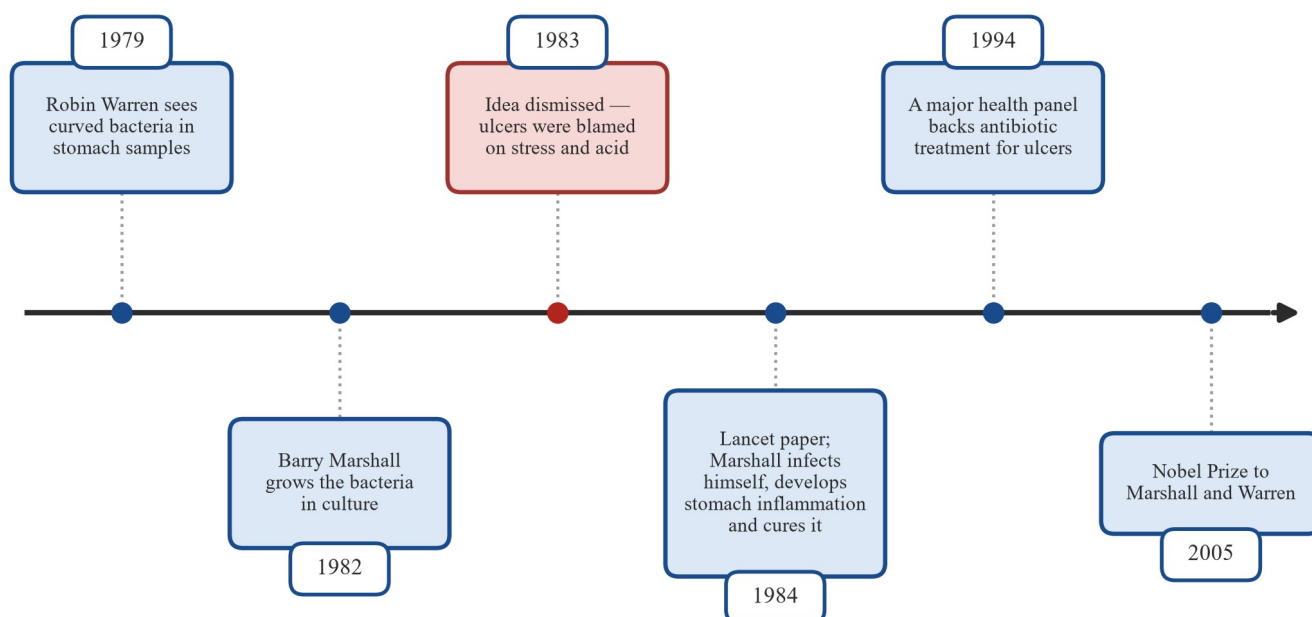
Flow chart. The author submits the paper; the editor makes a first check; two or three expert reviewers, names not revealed to the author, write reports asking whether the method is sound, the data support the claims and the conclusions follow; the editor decides between three outcomes — accept and publish, rare on the first try; revise and resubmit, the most common outcome; or reject with reasons given, where rejected does not mean wrong, just not ready as written. A return line shows the revised paper being checked again. Caption: reviewers test the work, not the person: the only question is whether the evidence supports the claim.

Two things about peer review matter here. First, it is critique by experts looking for faults, so mistakes are usually caught before publication rather than after. Second, it is not the final word: a reviewed paper is a claim that has passed one check, and the harder check — replication by other groups — comes after publication. Peer review is a good filter; replication is the test.

Replication and consensus. Replication means another group, in another lab, doing the same work with its own equipment and getting the same answer. One group can make a mistake, or be fooled by its own hopes; two independent groups making the same mistake the same way is far less likely, and three still less so. When results repeat across independent groups, and reviewed papers pile up on the same side, consensus grows. A consensus is not a vote and not an opinion: it is the state reached when the checks have all been run and they agree. Consensus is what textbooks are allowed to report; until a claim has it, the claim is still on trial.

Six real cases now, one for each elaboration id, each showing a different check doing its work.

Case study 1 — Marshall and Warren: rejected, then validated (VC2S10H01.E01). Until the 1980s the settled view was that stomach ulcers came from stress and acid, and were treated with rest and medicine that calmed the acid. In 1979 the Perth doctor Robin Warren noticed curved bacteria in stomach samples. With Barry Marshall he grew the bacteria and argued that they caused the disease. The claim was dismissed — it contradicted the settled view, and early reports were rejected. Marshall even swallowed a culture of the bacteria himself and developed an inflammation of the stomach lining, which he then cured with antibiotics: dramatic, but one person is a sample of one. What changed minds was what the cycle demands — other labs grew the same bacteria, found it in ulcer patients, and trials showed that antibiotics cured ulcers. Replication did what announcement could not. A major health panel backed antibiotic treatment for ulcers in 1994, and in 2005 Marshall and Warren shared the Nobel Prize in Physiology or Medicine.



What changed minds was replication: other labs grew the bacteria, found it in ulcer patients, and antibiotics cured ulcers.

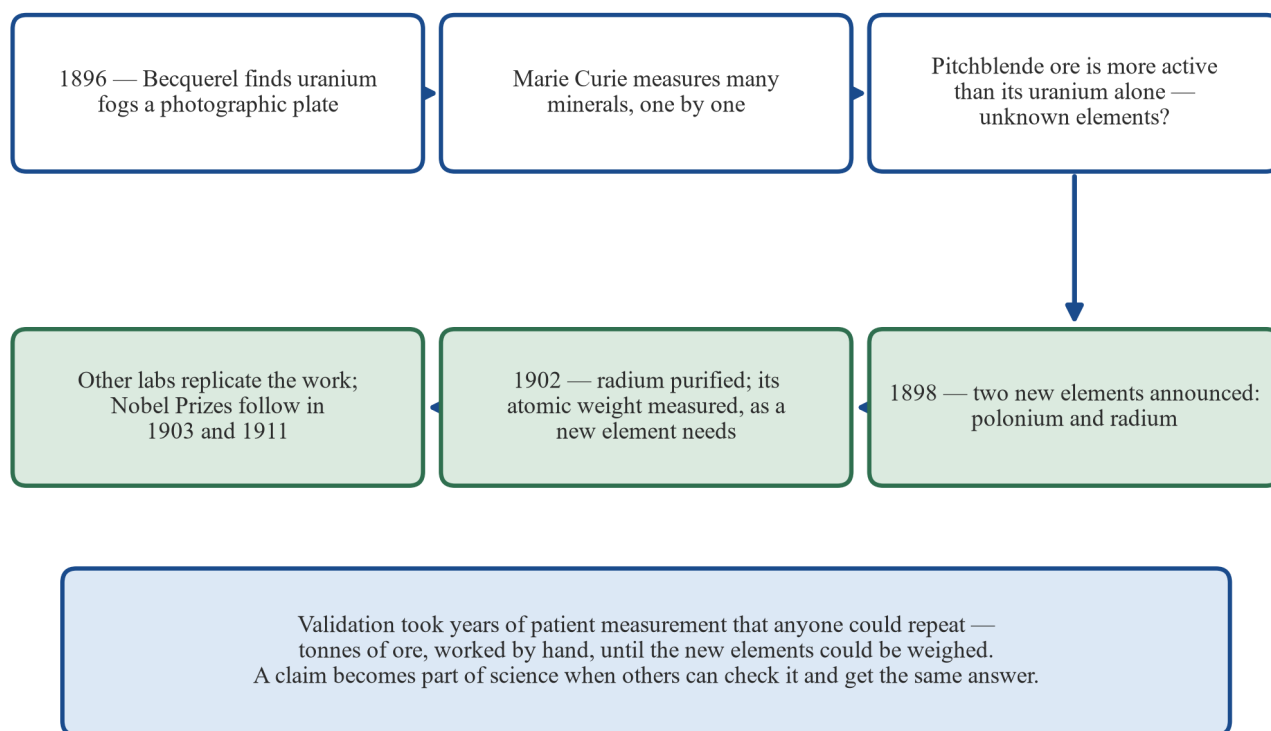
A timeline from 1979 to 2005. 1979: Robin Warren sees curved bacteria in stomach samples. 1982: Barry Marshall grows the bacteria in culture. 1983: the idea is dismissed — ulcers were blamed on stress and acid. 1984: a Lancet paper; Marshall infects himself, develops stomach inflammation and cures it. 1994: a major health panel backs antibiotic treatment for ulcers. 2005: Nobel Prize to Marshall and Warren. Caption: what changed minds was replication: other labs grew the bacteria, found it in ulcer patients, and antibiotics cured ulcers.

NobelPrize.org, “The Nobel Prize in Physiology or Medicine 2005 — Summary”, 2005.

<https://www.nobelprize.org/prizes/medicine/2005/summary/> — retrieved 2026-08-21. NobelPrize.org, “Barry J. Marshall — Nobel Lecture”, 2005. <https://www.nobelprize.org/prizes/medicine/2005/marshall/lecture/> — retrieved 2026-08-21. B. J. Marshall and J. R. Warren, *The Lancet*, vol. 323, pp. 1311–1315, 1984.

[https://doi.org/10.1016/S0140-6736\(84\)91816-6](https://doi.org/10.1016/S0140-6736(84)91816-6) — retrieved 2026-08-21.

Case study 2 — the Curies: validation by measurement anyone could repeat (VC2S10H01.E03). In 1896 Henri Becquerel found that uranium fogs a photographic plate — the metal gives off rays of its own. Marie Curie, with Pierre Curie, measured mineral after mineral, and found one ore more active than its uranium alone could explain. Her answer was a bold claim: the ore must contain unknown elements, more active than uranium. In 1898 the Curies announced two new elements, polonium and radium. Announcing was the easy part. For the new elements to be accepted, others had to be able to check them, so the Curies worked tonnes of ore by hand until, in 1902, enough radium was purified for its atomic weight to be measured. Other labs repeated the work, the results held, and the Nobel Prizes followed — Physics in 1903, shared with Becquerel, and Chemistry in 1911 to Marie alone.

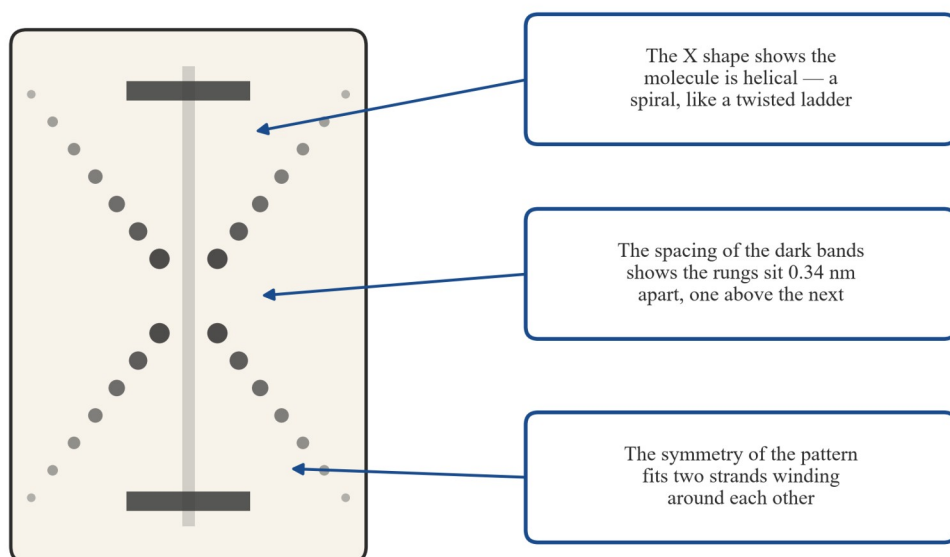


A flow of six boxes. 1896: Becquerel finds uranium fogs a photographic plate. Marie Curie measures many minerals, one by one. The ore is more active than its uranium alone — unknown elements? 1898: two new elements announced, polonium and radium. 1902: radium purified and its atomic weight measured, as a new element needs. Other labs replicate the work; Nobel Prizes follow in 1903 and 1911. Caption box: validation took years of patient measurement that anyone could repeat — tonnes of ore, worked by hand, until the new elements could be weighed; a claim becomes part of science when others can check it and get the same answer.

NobelPrize.org, “The Nobel Prize in Physics 1903 — Summary”, 1903.

<https://www.nobelprize.org/prizes/physics/1903/summary/> — retrieved 2026-08-21. NobelPrize.org, “The Nobel Prize in Chemistry 1911 — Summary”, 1911. <https://www.nobelprize.org/prizes/chemistry/1911/summary/> — retrieved 2026-08-21.

Case study 3 — Photo 51: publication, credit and the shape of DNA (VC2S10H01 .E04). In 1952 Rosalind Franklin and Raymond Gosling, working in London, sent X-rays through a fibre of DNA and recorded the pattern of spots now known as Photo 51. The pattern was evidence of rare quality: the X shape showed the molecule is a spiral, the dark bands fixed the spacing of the rungs at 0.34 nm, and the symmetry of the pattern fitted two strands wound around each other. Without Franklin’s knowledge, the photograph was shown to James Watson, who was building models of DNA with Francis Crick in Cambridge; Watson recognised the spiral at once. In 1953 Watson and Crick published their double-helix model in *Nature* — and in the same issue, Franklin and Gosling published their own paper, the X-ray evidence any model had to fit. The episode shows publication doing two jobs at once: putting evidence on the record where it can check claims, and fixing who contributed what. Franklin and Gosling’s data were critical to the model, and the record shows it — which is why this subtopic names their paper beside Watson and Crick’s. Franklin died in 1958; the 1962 Nobel Prize went to Watson, Crick and Maurice Wilkins, the prize not being awarded after death.



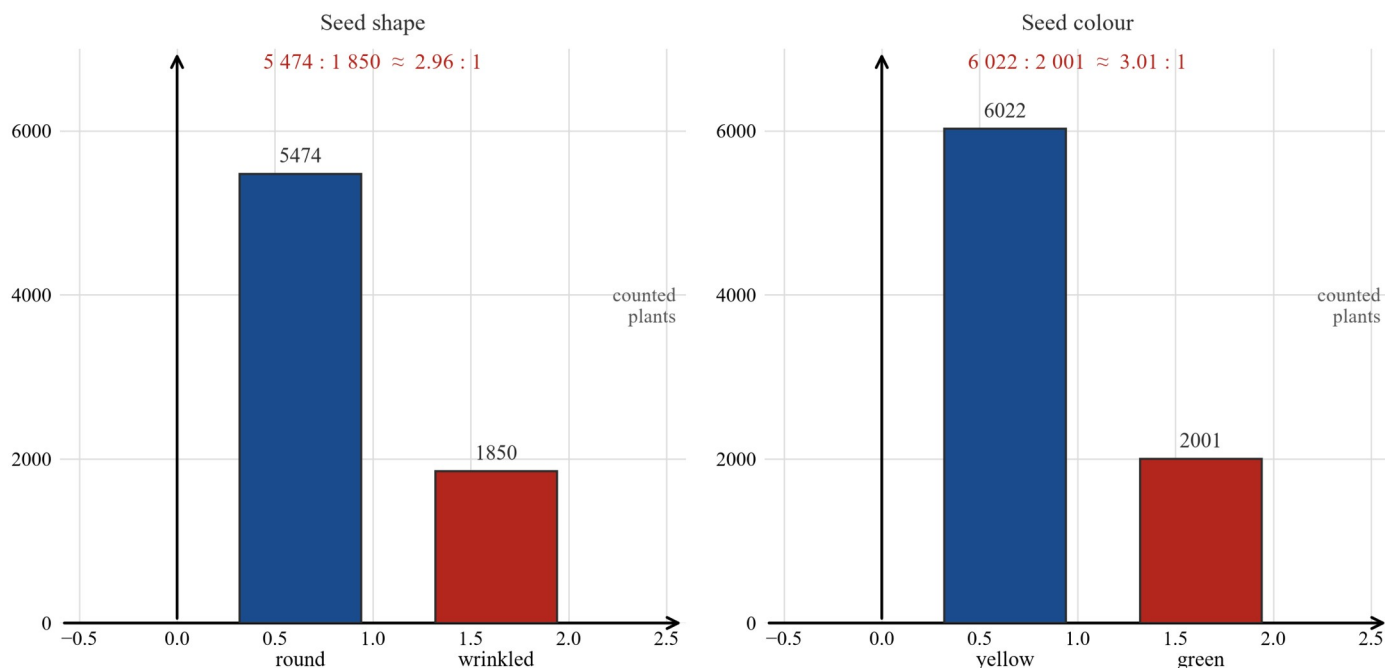
Schematic drawing of Photo 51 — not the photograph itself

X-rays sent through a DNA fibre make this pattern — a way of seeing a molecule far too small for any microscope.

A drawing, labelled as a stand-in for the photograph itself, of Photo 51: a film showing an X of dark spots with strong bands above and below. Three callouts: the X shape shows the molecule is a spiral, like a twisted ladder; the spacing of the dark bands shows the rungs sit 0.34 nm apart, one above the next; the symmetry of the pattern fits two strands winding around each other. Caption: X-rays sent through a DNA fibre make this pattern — a way of seeing a molecule far too small for any microscope.

*J. D. Watson and F. H. C. Crick, “Molecular Structure of Nucleic Acids”, *Nature*, vol. 171, pp. 737–738, 1953. <https://doi.org/10.1038/171737a0> — retrieved 2026-08-21. R. G. Franklin and R. G. Gosling, “Molecular Configuration in Sodium Thymonucleate”, *Nature*, vol. 171, pp. 740–741, 1953. <https://doi.org/10.1038/171740a0> — retrieved 2026-08-21. NobelPrize.org, “The Nobel Prize in Physiology or Medicine 1962 — Summary”, 1962. <https://www.nobelprize.org/prizes/medicine/1962/summary/> — retrieved 2026-08-21.*

Case study 4 — Mendel’s peas: large data sets and statistics (VC2S10H01 . E05). Gregor Mendel, a monk in Brno, crossed pea plants for eight years and published his counts in 1866. What set the work apart was scale: he counted thousands of plants, so his ratios were not impressions but numbers. For seed shape he counted 5 474 round against 1 850 wrinkled — about 2.96 to 1 — and for seed colour 6 022 yellow against 2 001 green — about 3.01 to 1. With small counts, a ratio like that could be luck; with thousands of plants the pattern is stable enough to test against, which is exactly what a large data set gives a science. Yet the paper was overlooked for about 34 years — the scientists of the day did not see what the numbers meant. Around 1900, three plant scientists working separately replicated his crosses and found the same ratios in their own counts; only then was Mendel’s paper validated, decades after publication. Validation is not a date; it is a process that waits for the checks to catch up.

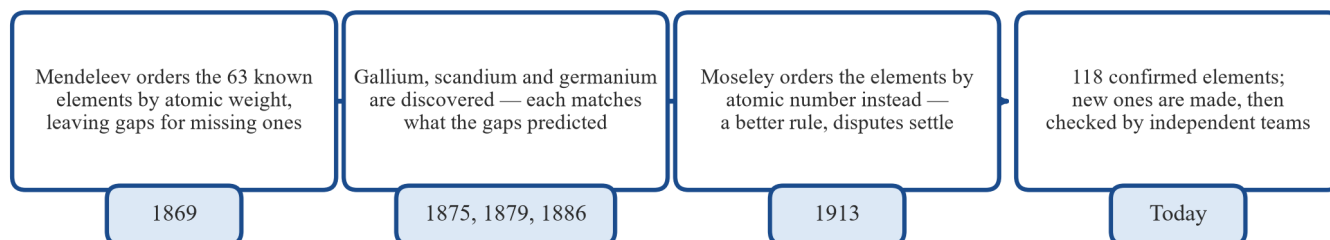


Two bar charts of Mendel's published counts, labelled as real data. Seed shape: 5 474 round against 1 850 wrinkled, ratio $\approx$ 2.96 to 1. Seed colour: 6 022 yellow against 2 001 green, ratio $\approx$ 3.01 to 1.

G. Mendel, "Versuche über Pflanzen-Hybriden", 1866; English translation, MendelWeb.

<https://www.mendelweb.org/Mendel.plain.html> — retrieved 2026-08-21.

Case study 5 — the periodic table: disputed, then refined (VC2S10H01.E06). In 1869 Dmitri Mendeleev ordered the 63 known elements by atomic weight — and left gaps where the order demanded elements nobody had seen. The table made predictions: the missing metal below aluminium should have a density near 5.9 g/cm³ and an atomic weight near 68. When gallium was discovered in 1875, its measured density was 5.91 g/cm³ and its atomic weight 69.7 — close enough to the prediction to make the table famous; scandium (1879) and germanium (1886), two more elements, filled two further gaps just as predicted. A table that successfully predicts what no one has seen yet earns trust. The table stayed disputed — chemists argued for decades over the ordering rule — until 1913, when Henry Moseley refined it by ordering the elements by atomic number instead of atomic weight, settling the disputes and fixing the modern form. Today the count stands at 118 confirmed elements (IUPAC, the international body that names new elements, keeps the official list), and a new one is accepted only after independent teams replicate the detection. Dispute and refinement were not the table's weakness; they were its validation working.



The gallium case: what Mendeleev predicted, and what was measured

Property	Predicted (1871), before discovery	Measured (1875), after discovery
density	5.9 g/cm ³	5.91 g/cm ³
atomic weight	68	69.7

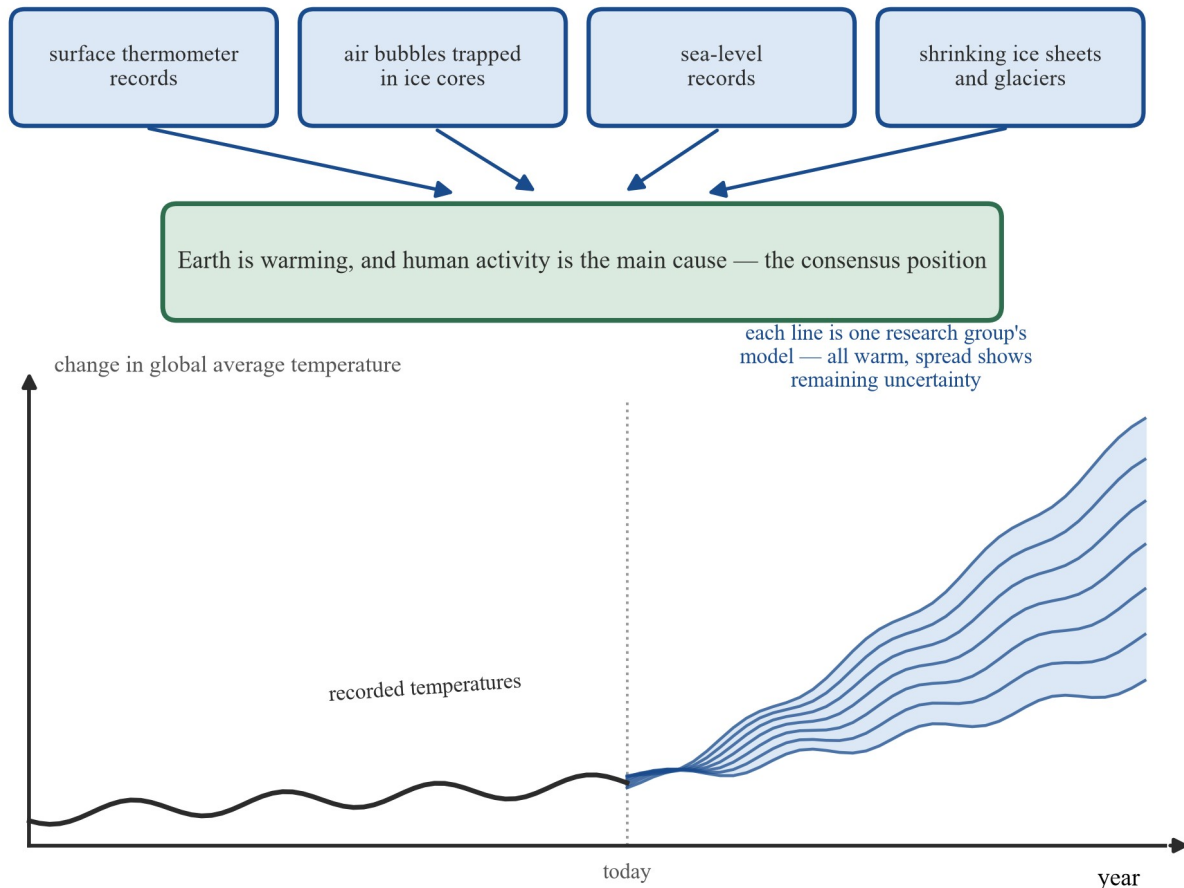
A table that successfully predicts what no one has seen yet earns trust — and a better ordering rule refined it again in 1913.

A timeline of four boxes. 1869: Mendeleev orders the 63 known elements by atomic weight, leaving gaps for missing ones. 1875, 1879, 1886: gallium, scandium and germanium are discovered — each matches what the gaps predicted. 1913: Moseley orders the elements by atomic number instead — a better rule, disputes settle. Today: 118 confirmed elements; new ones are made, then checked by independent teams. Below, a table of the gallium case: predicted in 1871, density 5.9 g/cm³ and atomic weight 68; measured in 1875, 5.91 g/cm³ and 69.7. Caption: a table that successfully predicts what no one has seen yet earns trust — and a better ordering rule refined it again in 1913.

M. E. Weeks, “The discovery of the elements. XV. Some elements predicted with the periodic system”, *Journal of Chemical Education*, vol. 9, pp. 2027–2045, 1932. <https://doi.org/10.1021/ed009p2027> — retrieved 2026-08-21. IUPAC, “Periodic Table of Elements”. <https://iupac.org/what-we-do/periodic-table-of-elements/> — retrieved 2026-08-21.

Case study 6 — climate: consensus from many lines of evidence (VC2S10H01 . E02). The climate consensus is a good test of whether you understand what a consensus is, because a common objection runs: “scientists use different models, so they cannot agree”. Look instead at the structure of the evidence. Surface thermometer records, air bubbles trapped in ice cores, sea-level records and shrinking ice sheets and glaciers are independent lines of evidence — different instruments, different groups, different methods — and they point the same way. Research groups also run different climate models, built with different choices; the models disagree about some details, yet they all show warming driven by human activity. Agreement across *different* methods is stronger than agreement across identical ones, because one hidden mistake could not survive in all of them at once. A 2021 review of 88 125 peer-reviewed papers found that more than 99% of publishing climate scientists agree that Earth is warming and human activity is the main cause. In Australia, the measured record shows warming of 1.51 ± 0.23 °C since 1910.

One conclusion, many independent lines of evidence



Panel B is a schematic — drawn to show the idea, not real projections.

Top panel: four boxes — surface thermometer records; air bubbles trapped in ice cores; sea-level records; shrinking ice sheets and glaciers — all feeding one conclusion box: Earth is warming, and human activity is the main cause, the consensus position. Bottom panel, drawn to show the idea rather than real projections: recorded temperatures as one line up to today, then seven model lines, each line one research group's model, all warming, with a shaded band showing the remaining uncertainty.

Cornell Chronicle, "Over 99% consensus on human-caused climate change confirmed by new study", 2021.

<https://news.cornell.edu/stories/2021/10/over-99-consensus-human-caused-climate-change> — retrieved 2026-08-21.

CSIRO and Bureau of Meteorology, "State of the Climate 2024", 2024.

<https://www.csiro.au/en/research/environmental-impacts/climate-change/State-of-the-Climite> — retrieved 2026-08-21.

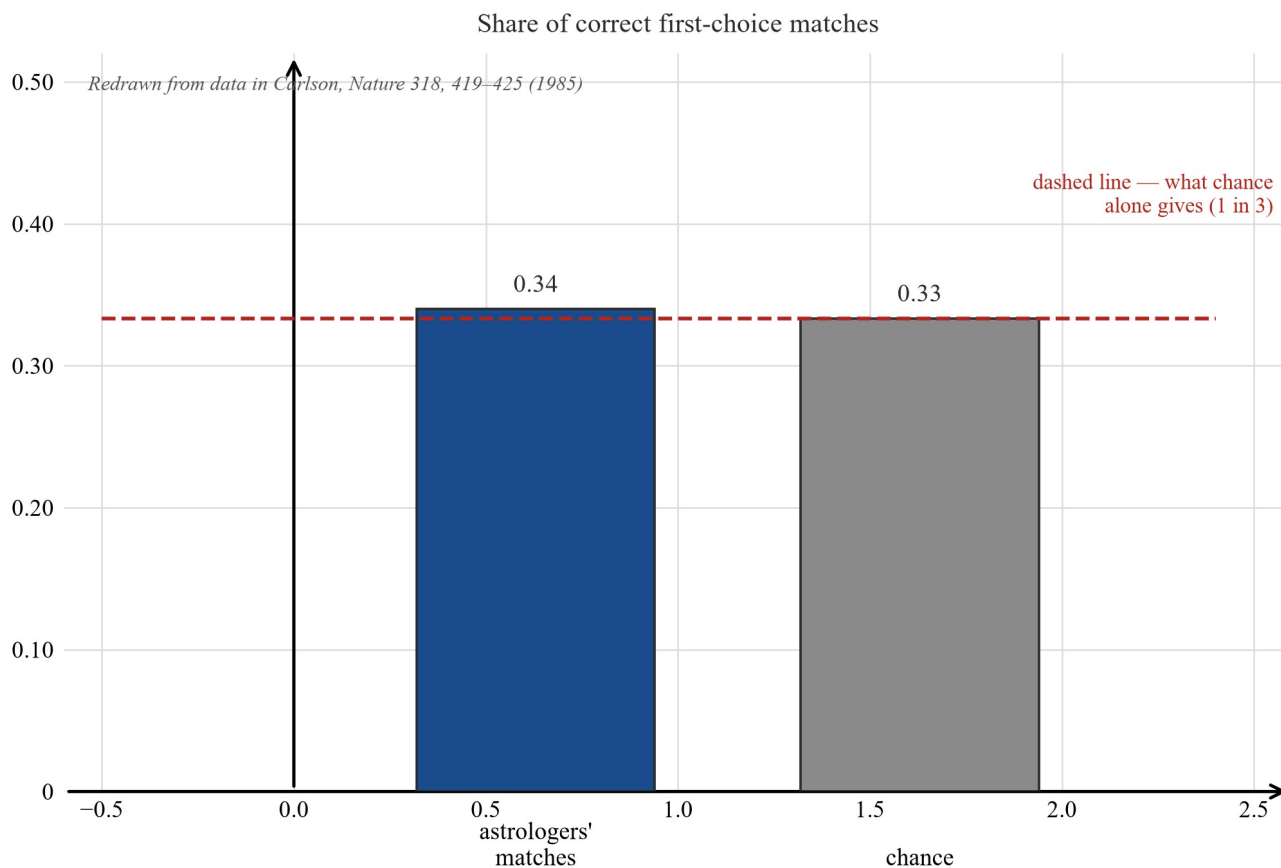
Science and pseudoscience (VC2S10H01 .E07). Pseudoscience is not bad science, or science done badly; it is what claims to be science while refusing the checks. The marks are stable enough to make a checklist.

Science	Pseudoscience
What marks it out	What gives it away
Claims can be tested — an investigation could show them wrong	Claims cannot really be tested — no result could ever show them wrong
Independent tests are welcome	Tests are avoided, or failures are explained away after the event
Results repeat when other groups do the same work	Results rely on personal stories and do not repeat
Ideas change as the evidence changes	Ideas stay the same for decades, whatever the evidence shows

*Outside science is not pseudoscience — music, taste and values make no scientific claims at all.
Pseudoscience is what claims to be science without the checks.*

Two columns, Science and Pseudoscience, with four paired rows. Science: claims can be tested — an investigation could show them wrong; pseudoscience: claims cannot really be tested — no result could ever show them wrong. Science: independent tests are welcome; pseudoscience: tests are avoided, or failures are explained away after the event. Science: results repeat when other groups do the same work; pseudoscience: results rely on personal stories and do not repeat. Science: ideas change as the evidence changes; pseudoscience: ideas stay the same for decades, whatever the evidence shows. Caption: outside science is not pseudoscience — music, taste and values make no scientific claims at all; pseudoscience is what claims to be science without the checks.

The curriculum's own examples — astrology (reading personality or future from the stars at birth), dowsing (finding water with a swinging rod or forked stick), graphology (reading personality from handwriting) and phrenology (reading character from the bumps on the skull) — all fail the checklist in the same way: no test could ever show the claim wrong, because every failure is explained away after the event. And where a claim *can* be tested, testing it gives science's answer. In 1985 *Nature* published a double-blind test of astrology: 28 astrologers were given sets of personality descriptions and birth charts and asked to match each chart to the right description; with three choices per person, chance alone gives 1 in 3 correct. The astrologers scored 0.34 — no better than guessing. Astrology's claims survived for centuries exactly because they were never put at risk; the first well-built test settled the question the usual way — a repeatable method, blind checking, and statistics.



Bar chart, redrawn from data in Carlson, *Nature* 318, 419–425 (1985): share of correct first-choice matches, with one bar for the astrologers' matches at 0.34 and one for chance at 0.33, and a dashed line marking what chance alone gives, 1 in 3.

S. Carlson, "A double-blind test of astrology", *Nature*, vol. 318, pp. 419–425, 1985. <https://doi.org/10.1038/318419a0> — retrieved 2026-08-21.

The checks are the knowledge. Tie the cases back to the content description. In every one, the claim was contestable — and what made it knowledge was not confidence or fame but the checks: expanding methods that supplied new evidence, publication that put the claim and its Method on the record, peer review that critiqued it before publication, replication that tested it after, and consensus that grew when the independent checks agreed. Where the checks are refused, what remains is pseudoscience. That is the whole sentence of the CD, and the whole of this subtopic.

Activities

Activity 1 — Map the cycle onto a real case. Take the Marshall–Warren timeline and the validation cycle. For each of the five boxes of the cycle, write down the event on the timeline that best shows that step (some steps match more than one event; say which). Then answer in one sentence each: (a) which step was failing in 1983? (b) which step did the other labs supply after 1984? (c) which event shows consensus had been reached?

Activity 2 — Run a peer review. In groups of three, take the roles of author, reviewer and editor. The claim card below is **invented practice material for this activity**.

Claim card (invented): "Plants grow taller if you talk to them. We talked to five plants every day for two weeks, and they grew 3 cm more than five plants nobody talked to."

The reviewer writes a short report using the three review questions from the peer-review picture: Is the method sound? Do the data support the claim? Do the conclusions follow? (Hint: what else, besides the talking, might have differed between the two groups of five?) The editor reads the report and gives one of the three decisions. Then rotate roles and review a second claim card written by the group.

Activity 3 — Apply the checklist. Using the science-versus-pseudoscience picture, test each claim below and give the one-line reason for your verdict: (a) a daily horoscope tells you what kind of day you will have; (b) a person can find underground water by walking with a forked stick; (c) graphology can read your personality from your handwriting; (d) phrenology can read your character from the bumps on your skull; (e) ulcers are cured by antibiotics that kill the stomach bacteria. Which column does each claim belong in, and which row of the picture settles it?

Activity 4 — Consensus with different models (elaboration VC2S10H01.E02). Look at the climate picture. (a) List the four independent lines of evidence in the top panel. (b) The seven model lines in the bottom panel disagree about some details — why does that disagreement *strengthen* the shared conclusion rather than weaken it? Answer using the idea of a hidden mistake. (c) Explain in one sentence why “scientists agree” would be a weak argument, while “independent checks agree” is a strong one.

Worked examples

Example 1 — scaffolded

The Marshall–Warren case, step by step.

- Which check failed the claim in 1983, and what does the peer-review picture say rejection actually means?
- What did Marshall’s self-experiment add, and why was it not enough on its own?
- Which step of the cycle did the other labs supply after 1984?
- Which event on the timeline shows consensus?

Working	Comment
(a) Publication — early reports were rejected	Rejected does not mean wrong, just not ready as the reviewers saw it; the claim still had to face the checks.
(b) One more data point — a sample of one	Dramatic, but with no control and no repeat by others, one person cannot be replication.
(c) Replication — other labs grew the bacteria, found it in ulcer patients, ran the treatment trials	Independent groups, own equipment, same answer: the step that changed minds.
(d) The 1994 health panel backing antibiotic treatment	A panel can only back a treatment once the reviewed and replicated evidence has piled up on one side.

Example 2 — scaffolded

Mendel’s published counts, as ratios.

- From the Mendel picture, state the round and wrinkled counts and compute round : wrinkled to two decimal places.
- Do the same for yellow : green.
- Which of the two ratios sits closer to 3 : 1?
- Explain why counting thousands of plants matters, using the word *luck*.

Working	Comment
(a) $5\,474 : 1\,850$; $5\,474 \div 1\,850 = 2.96$ (2 d.p.)	The picture’s ratio, $\approx 2.96 : 1$, checked by division.
(b) $6\,022 : 2\,001$; $6\,022 \div 2\,001 = 3.01$ (2 d.p.)	Same move: divide the larger count by the smaller.
(c) 3.01 is closer to 3 than 2.96 is	Both are within 0.04 of 3 : 1 — the pattern is real, not exact.
(d) With small counts, a ratio near 3 : 1 could arise by luck; with thousands of plants, luck cannot hold the ratio that steady	This is the statistical idea: large data sets make the pattern plain enough to test.

Example 3 — unscaffolded

Carlson’s double-blind astrology test (elaboration VC2S10H01.E07). Each astrologer received one birth chart and three personality descriptions, and chose which description matched. The astrology picture shows the result: a first-choice match share of 0.34.

- (a) What share of correct first choices would chance alone give, and why?
- (b) Compare the astrologers' 0.34 with that value.
- (c) What does the comparison say about astrology's claim to read personality from the stars at birth?
- (d) The test was double-blind: the astrologers could not see the people, and the judges scoring the matches did not know which chart went with which description. Why does that matter?
- (e) With three choices per chart, guessing at random is right once in every three tries, so chance alone gives a share of 1 in 3, about 0.33.
- (f) 0.34 is 0.01 above 0.33 — inside what luck would produce. The astrologers performed no better than guessing.
- (g) If the stars at birth really fixed personality, the astrologers' share would sit clearly above the chance line. It does not, so the claim fails its own test — and the claim *could* be tested, which is precisely what makes it a scientific question with a scientific answer: no.
- (h) Blinding stops extra clues. If an astrologer could meet the person, or a judge knew the intended pairing, hints and expectations could nudge the score; a double-blind test measures the claim itself, nothing else.

Example 4 — unscaffolded

The periodic table case (elaboration VC2S10H01.E06).

- (a) From the periodic-table picture, state what Mendeleev predicted for the missing element below aluminium, and what was measured after gallium's discovery in 1875.
 - (b) Explain why a successful prediction earns more trust than explaining what is already known.
 - (c) In 1913 Moseley changed the ordering rule from atomic weight to atomic number. Was that the table failing, or the cycle working? Justify your choice.
 - (d) The table began with 63 elements and now confirms 118. What check must a newly made element pass before it is accepted?
 - (e) Predicted (1871): density 5.9 g/cm³, atomic weight 68. Measured (1875): density 5.91 g/cm³, atomic weight 69.7.
 - (f) A prediction sticks its neck out: if gallium had been very different, the table would have been shown wrong in front of everyone. Explaining known facts can always be done after the event; surviving a risk could not. That is why the close match earned the table its trust.
 - (g) The cycle working. The new rule kept every success the weight-ordering had, settled the disputes the old rule could not, and made the gaps exact — a refinement, which is what the CD says scientific knowledge does over time.
 - (h) Replication — the detection is repeated by independent teams, and accepted only when the results repeat.
-

Practice questions

Scaffolded questions

Question 1 Words that matter. (a) State the working meaning this subtopic gives to *replication*. (b) State what *peer review* is, and when it happens. (c) State what a *consensus* is — and what it is not. (d) State what *pseudoscience* is.

Question 2 The cycle in order. (a) Name the five boxes of the validation cycle in order, starting from “a claim is made”. (b) Which note on the picture says the cycle never quite ends?

Question 3 Paper anatomy. (a) Which section of a paper would you read to check whether the test was fair and repeatable? (b) Which sections would you read to find where a claim came from? (c) Why does the References section matter for replication?

Question 4 Peer review outcomes. (a) Name the three decisions open to the editor. (b) Which is the most common outcome, and which is rare on the first try? (c) What does “rejected” mean, according to the picture?

Question 5 Reading Mendel’s chart. (a) State the two ratios shown in the Mendel picture. (b) Which trait’s ratio is closer to 3 : 1? (c) Mendel published in 1866; his work was validated around 1900. Roughly how long did the wait take?

Question 6 The checklist. (a) From the science-versus-pseudoscience picture, list the four marks that give pseudoscience away. (b) The caption says music, taste and values are not pseudoscience. Why not?

Unscaffolded questions

Question 7 Marshall and Warren again. (a) Why was the bacteria claim dismissed in 1983? (b) Which step of the cycle changed minds between 1984 and 1994? (c) The 2005 Nobel Prize came 26 years after Warren’s 1979 observation. What does that gap say about how fast validation can be?

Question 8 The Curies again. (a) Announcing polonium and radium took one paper in 1898; validating them took until 1902. What exactly did the four extra years of work supply? (b) “A claim becomes part of science when others can check it and get the same answer.” Name the step of the cycle that sentence describes.

Question 9 Photo 51 again. (a) What three features of the pattern did the picture name, and what did each show? (b) Franklin and Gosling’s paper appeared in the same issue of *Nature* as Watson and Crick’s. Why does publishing the evidence beside the model matter? (c) Watson saw Photo 51 without Franklin’s knowledge. Does that change the science, the credit, or both? One sentence each.

Question 10 Mendel overlooked. (a) Mendel’s paper sat overlooked for about 34 years. Did the neglect make the ratios wrong? (b) What happened around 1900 that validated the paper at last? (c) Which two steps of the cycle did those 34 years delay?

Question 11 Prediction and trust. (a) State the gallium prediction and measurement from the periodic-table picture. (b) A classmate says a theory that explains known facts is as strong as one that predicts new ones. Use the gallium case to disagree.

Question 12 The climate consensus. (a) Name two of the four independent lines of evidence in the climate picture. (b) More than 99% of publishing climate scientists agree on human-caused warming. State what makes that agreement a consensus rather than a vote. (c) Australia’s measured record shows warming of 1.51 ± 0.23 °C since 1910. What do the “ ± 0.23 ” and the “since 1910” each tell you?

Question 13 The astrology test. (a) State the chance share and the astrologers’ share from the astrology picture. (b) If astrology worked as claimed, what would you expect the astrologers’ bar to show? (c) A defender says “0.34 is above 0.33, so astrology works a little.” Answer using the idea of luck.

Question 14 Sort the claims. Place each in the science or pseudoscience column, giving the row of the picture that settles it: (a) “Your handwriting reveals your personality.” (b) “Antibiotics cure ulcer disease caused by stomach bacteria.” (c) “The bumps on your skull fix your character.” (d) “A forked stick swings over underground water.”

Question 15 The self-experiment. (a) Marshall’s swallow gave one person’s result. Name two reasons a sample of one cannot be replication. (b) Should students test treatments on themselves to settle an argument? Give the one-word answer and the reason.

Question 16 “Science is just opinion.” A commenter writes: “Scientists agree by voting, so a consensus is just a group opinion.” Answer the commenter in three or four sentences, using at least three of the cycle’s checks by name.

Answers

Question 1 (a) another group doing the same work with its own equipment and getting the same answer; (b) a check by two or three field experts, before publication, who were not part of the work; (c) the state reached when independent checks have all been run and agree — not a vote, not an opinion; (d) what claims to be science while refusing the checks. **Question 2** (a) claim made → written up and submitted → peer review before publication → other groups replicate → consensus grows or the claim is refined; (b) “new evidence raises new questions”. **Question 3** (a) the Method; (b) Results and Discussion; (c) it lists every source, so another group can find exactly what was done and repeat it. **Question 4** (a) accept and publish; revise and resubmit; reject with reasons; (b) revise and resubmit is most common; accept is rare on the first try; (c) not wrong — just not ready as written. **Question 5** (a) $5\,474 : 1\,850 \approx 2.96 : 1$ and $6\,022 : 2\,001 \approx 3.01 : 1$; (b) seed colour (3.01); (c) about 34 years. **Question 6** (a) claims cannot really be tested; tests avoided or failures explained away; results rely on personal stories and do not repeat; ideas stay the same whatever the evidence; (b) they make no scientific claims at all — pseudoscience is what *claims* to be science. **Question 7** (a) it contradicted the settled stress-and-acid view; (b) replication; (c) validation can take decades — it waits for the checks to catch up. **Question 8** (a) enough purified radium for its atomic weight to be measured — a check anyone could repeat; (b) replication. **Question 9** (a) the X shape → a spiral; the band spacing → rungs 0.34 nm apart; the symmetry → two strands wound around each other; (b) the evidence any model had to fit sits on the record beside the model, for all to check; (c) the science is unchanged — the pattern checks the model either way; the credit is the issue, which is why this subtopic names Franklin and Gosling’s paper. **Question 10** (a) no — neglect is not a check; the counts were what they were; (b) three plant scientists replicated the crosses and found the same ratios; (c) replication and consensus. **Question 11** (a) predicted 5.9 g/cm³ and 68; measured 5.91 g/cm³ and 69.7; (b) see solution. **Question 12** (a) any two of: thermometer records, ice-core bubbles, sea-level records, shrinking ice sheets and glaciers; (b) it follows independent checks agreeing, not a show of hands; (c) ± 0.23 is the uncertainty of the measured figure; since 1910 says what the change is measured against. **Question 13** (a) 0.33 (1 in 3) and 0.34; (b) clearly above the chance line; (c) see solution. **Question 14** (a) pseudoscience — results do not repeat when tested; (b) science — the claim was tested and results repeated; (c) pseudoscience — no result could show it wrong; (d) pseudoscience — tests are avoided or explained away. **Question 15** (a) no control for comparison, and no repeat by an independent group (also: one body is not a trial); (b) no — ethics and sample size; the checks belong to proper trials. **Question 16** see solution.

Fully-worked solutions

Question 7 (a) The claim contradicted the settled view that ulcers came from stress and acid, and as the peer-review picture says, the first reports were rejected — dismissed, not yet validated. (b) Replication. Other labs grew the same bacteria, found it in ulcer patients, and trials showed antibiotics cured ulcers — independent groups, same answer. (c) That validation is a process, not a moment. The claim waited for replication, reviewed trials and a consensus panel; checks of that size can take decades, and the 2005 prize marks the cycle completed, not begun.

Question 9 (a) The X shape showed the molecule is a spiral; the spacing of the dark bands fixed the rungs at 0.34 nm apart; the symmetry fitted two strands wound around each other. (b) Publishing the evidence in the same issue put the data any model had to fit on the public record beside the model itself — so every reader could check the model against the pattern, which is replication’s raw material. (c) The science: unchanged — the pattern checked the double-helix model regardless of how Watson saw it. The credit: that is where the episode stings, and why the record — and this subtopic — names Franklin and Gosling’s paper beside Watson and Crick’s.

Question 11 (b) Explaining known facts can be done after the event — a story can always be fitted to what already happened. A prediction is a risk: Mendeleev’s table said an unseen metal would weigh in near 5.9 g/cm³ and 68, and if gallium had been very different the table would have been shown wrong. It measured 5.91 g/cm³ and 69.7. Surviving that risk in front of everyone is what earned the table trust, and it is why predicting the unknown counts for more than describing the known.

Question 13 (c) 0.34 against a chance value of 0.33 is a gap of 0.01 — well inside the swing that luck produces in any single run, which is exactly what the statistics step of the method exists to detect. If the effect were real it would grow as tests repeat; luck does not. Repeated well-built tests of astrology have never lifted the score above chance, so the tiny excess here is luck, not “a little astrology”.

Question 16 A consensus in science is not a vote taken at a meeting; it is the state reached after the checks have all been run and agree. Each claim is critiqued in peer review before publication, then replication by independent groups tests it after, on different equipment in different labs — and expanding methods keep supplying new kinds of evidence, as ice cores and satellites do for climate. When thousands of reviewed papers and independent lines of evidence pile up on one side, the agreement rests on the checks, not on anybody’s opinion. That is why a scientific consensus can be wrong in principle but is never “just opinion” — it is the most checked opinion humans know how to make.

Where this leads: Subtopic 1B takes the same “advances by checks” picture to science, technology and engineering, including Australian cases and big-instrument science (VC2S10H02). The inquiry spine then puts the checks in your hands: Subtopic 3A plans methods reproducible enough to replicate, Subtopics 5A and 5B evaluate evidence and build the evidence-based argument, and Subtopic 6A writes the report that publication and peer review will one day judge. In VCE, every science subject’s key science skills begin exactly here — separating a scientific claim from an opinion, and naming the checks that validated it (reference-only for this book, TOC §5); in Psychology Units 1 and 4, validating research is an area of study in its own right. This subtopic teaches the checks; the rest of the book teaches you to run them.

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Science, technology and engineering advance together — Australian cases and big-instrument science

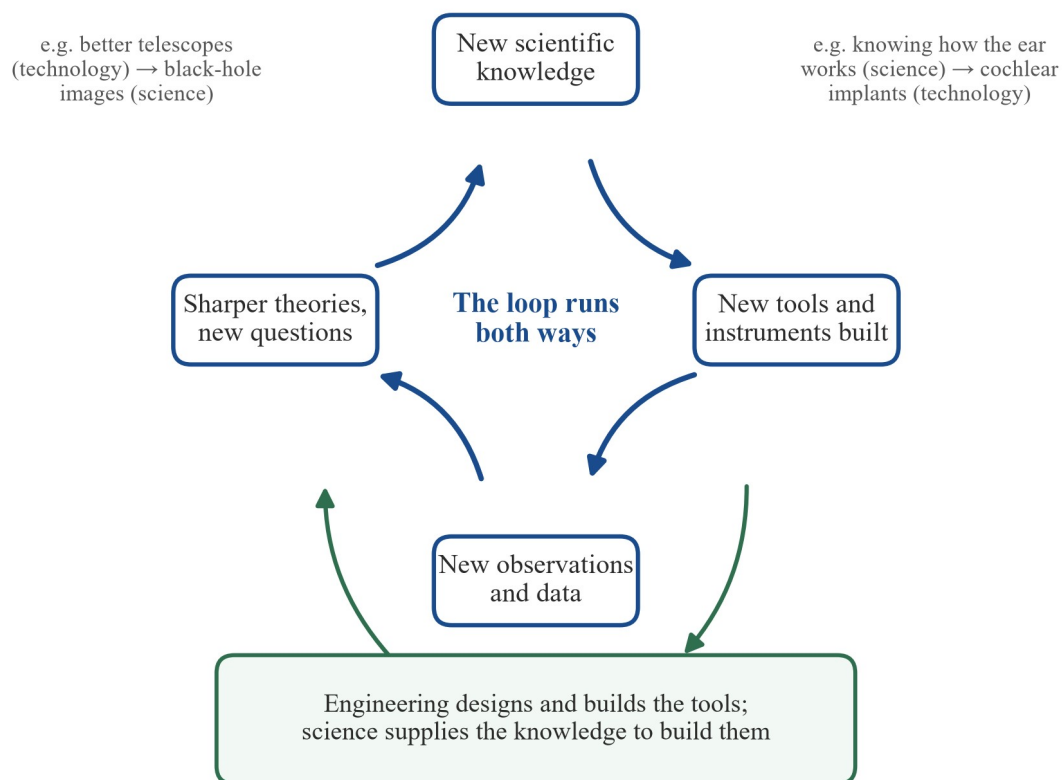
Chapter 1 — Nature and development of science (Science, Levels 9 and 10)

Subtopic 1B · VC2 Science — Nature and development of science

CD code: VC2S10H02 (this subtopic owns the whole CD) **Content description (verbatim):** “advances in technologies have enabled advances in science, while science has contributed to developments in technologies and engineering” **Elaboration ids drawn on:** VC2S10H02.E01 · VC2S10H02.E02 · VC2S10H02.E03 · VC2S10H02.E04 · VC2S10H02.E05 · VC2S10H02.E06 **Achievement standard (extract served):** “They examine the relationship between science, engineering and technologies.” This subtopic serves that sentence with real cases: what the science supplied, what the technology and engineering supplied, and what each made possible for the other.

Theory

The loop that runs both ways. Science, technology and engineering are three different kinds of work that feed each other. **Science** builds tested knowledge about the natural world — the kind of knowledge Subtopic 1A shows being checked by replication, publication, peer review and consensus. **Technology** is the tools and devices that knowledge makes possible. **Engineering** is the work of designing and building those tools so they are safe, reliable and useful. The content description for this subtopic says the traffic runs in both directions: new technology lets science see further and measure better, and new science gives engineers the knowledge to build what was impossible before. Neither is the boss of the other; they advance together, in a loop.



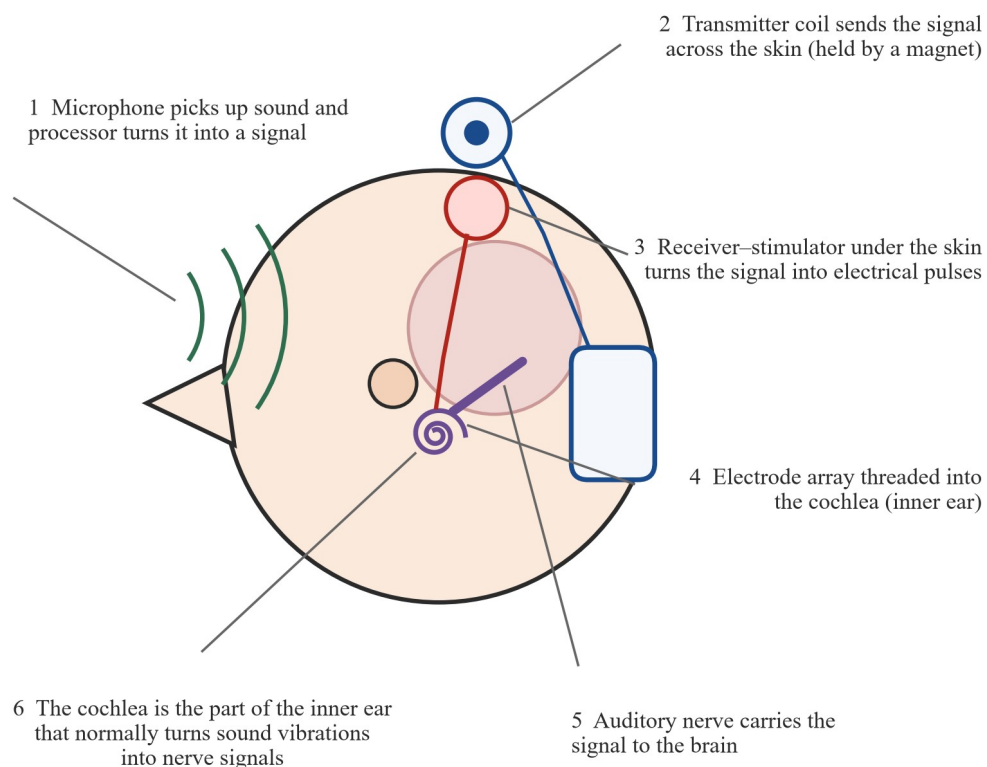
A ring of four boxes joined by arrows that run both ways: new scientific knowledge; new tools and instruments built; new observations and data; sharper theories, new questions. The centre reads: the loop runs both ways. Below the ring, a box says: engineering designs and builds the tools; science supplies the knowledge to build them. Two side notes give examples: knowing how the ear works (science) leads to cochlear implants (technology); better telescopes (technology) lead to black-hole images (science).

Read the loop either way around and the Australian cases below all sit on it. Four of them — the cochlear implant, the bionic eye, spray-on skin and the maths behind wi-fi — are the curriculum’s own Australian examples, and they are worth a close look.

Case 1 — The cochlear implant: science of the ear, built into a device (elaboration VC2S10H02 .E01). In a healthy ear, sound makes the eardrum vibrate, and those vibrations reach the **cochlea**, the spiral-shaped part of the inner ear that normally changes vibrations into nerve signals. The **auditory nerve** — the hearing nerve — then carries the signals to the brain. When the cochlea is damaged, the sound still arrives but the signal never starts, and the person hears little or nothing.

That science — cochlea, nerve, signal — is what made the **cochlear implant** possible: a device, or **implant**, that does the cochlea’s job. A microphone picks up sound, a small computer turns it into a signal, a coil sends the signal across the skin, and a wire thread of **electrodes** — small electrical contacts — sits inside the cochlea and gives the auditory nerve the pulses it would normally get from the ear. The nerve carries them on, and the person hears. Every part is engineering; every part rests on the science of how the ear works.

How a cochlear implant works



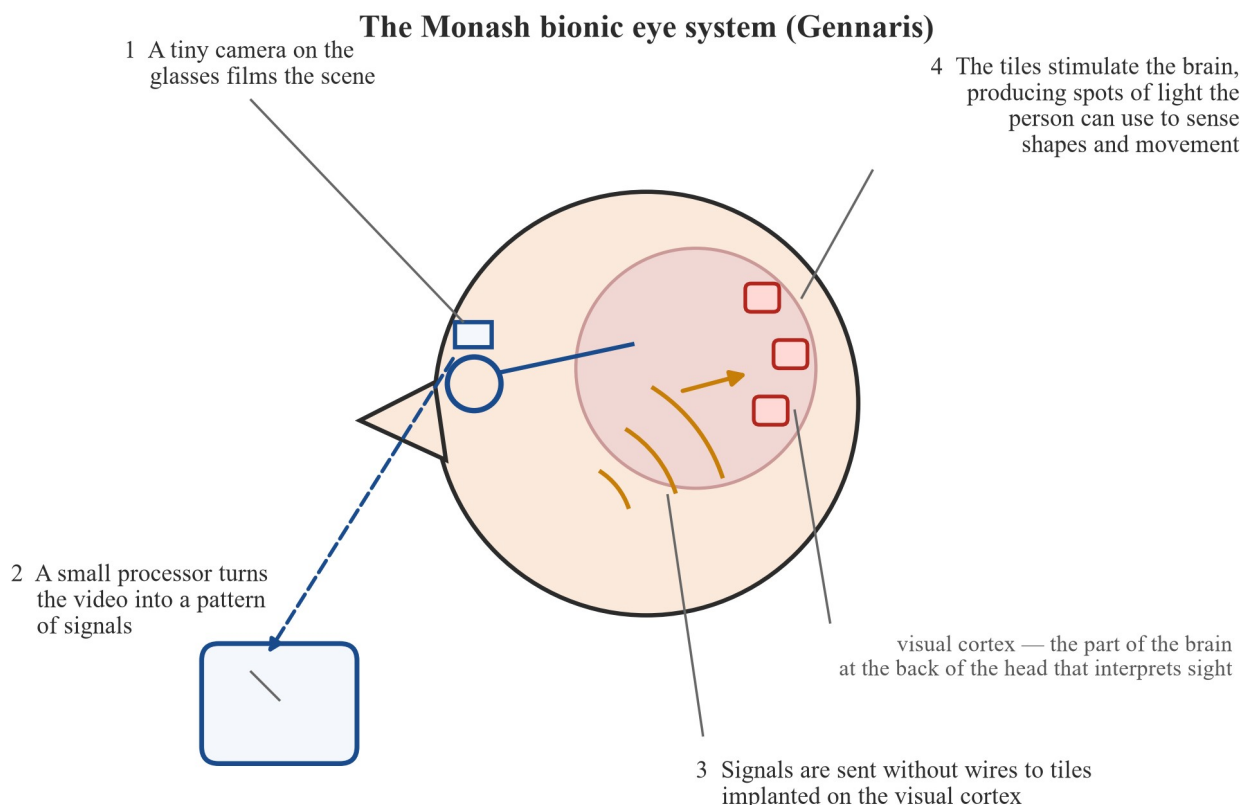
A head in profile with the parts of a cochlear implant numbered. 1: a microphone behind the ear picks up sound and a processor turns it into a signal. 2: a transmitter coil held on the skin by a magnet sends the signal across the skin. 3: a receiver-stimulator under the skin turns the signal into electrical pulses. 4: an electrode array threaded into the cochlea, the spiral of the inner ear. 5: the auditory nerve carries the signal to the brain. 6: the cochlea is the part of the inner ear that normally turns sound vibrations into nerve signals.

The first operation to fit a multi-channel implant — one with several electrodes, so the user can tell sounds apart — was performed in Melbourne in 1978, by a team led by Professor Graeme Clark of the University of Melbourne at the Royal Victorian Eye and Ear Hospital; the patient was Rod Saunders. The implant was approved for use in the USA in 1985, and hundreds of thousands of people with profound hearing loss have since received one. Science gave the target, engineering built the device, and the device — fitted to real ears — fed new science back about how the nerve carries sound.

G. M. Clark, “Cochlear implant surgery for profound or total hearing loss”, *Medical Journal of Australia*, 1978. <https://doi.org/10.5694/j.1326-5377.1978.tb131753.x> — retrieved 2026-08-21. G. M. Clark, “The multichannel

cochlear implant for severe-to-profound hearing loss”, *Nature Medicine*, 2013. <https://doi.org/10.1038/nm.3340> — retrieved 2026-08-21.

Case 2 — The bionic eye: bypassing the eye entirely (elaboration VC2S10H02 . E01). Some people cannot see because the eye itself is damaged, even though the brain’s sight centre — the **visual cortex**, the part of the brain at the back of the head that interprets sight — still works. A Monash University team built a system, named Gennaris, that bypasses the eye: a tiny camera on a pair of glasses films the scene, a small processor turns the video into a pattern of signals, and the signals are sent without wires to small tiles implanted on the visual cortex. The tiles send tiny electrical pulses into the brain, producing spots of light the person can use to sense shapes and movement. In 2020 the team published safety tests of the tiles, the step that has to be passed before human trials can go ahead.



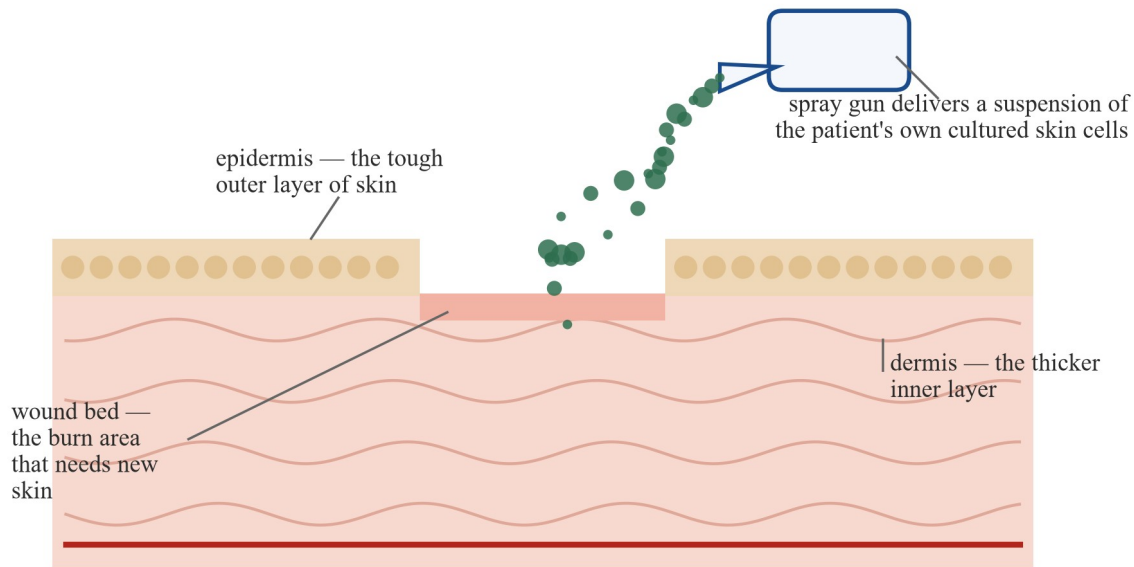
A head in profile with the Monash bionic eye system, numbered. 1: a tiny camera on the glasses films the scene. 2: a small processor turns the video into a pattern of signals. 3: the signals are sent without wires to tiles implanted on the visual cortex, shown as small squares at the back of the brain. 4: the tiles send pulses to the brain, producing spots of light the person can use to sense shapes and movement. A note defines the visual cortex as the part of the brain at the back of the head that interprets sight.

Compare the two cases: the cochlear implant uses a healthy nerve the science had mapped; the bionic eye goes one step further into the brain. Both are the loop in action — the science of hearing and sight made the devices thinkable, and every fitted device teaches the science something new about the nerves it uses.

*J. V. Rosenfeld et al., “Tissue response to a chronically implantable wireless intracortical visual prosthesis (Gennaris array)”, *Journal of Neural Engineering*, 2020. <https://doi.org/10.1088/1741-2552/ab9e1c> — retrieved 2026-08-21.*

Case 3 — Spray-on skin: growing a patient’s own skin (elaboration VC2S10H02 . E01). A severe burn destroys the skin’s outer layer, the **epidermis**, and the body cannot close a large wound fast enough on its own. In 1993, in Perth, Professor Fiona Wood began working with the medical scientist Marie Stoner on growing skin cells in the laboratory. Their work led to **spray-on skin**: a small sample of the patient’s own healthy skin is taken, the cells are grown in the laboratory, and the cells are then sprayed over the wound as a fine suspension, where they attach and grow into new skin. Using the patient’s own cells means the body does not reject them, and by the early 2000s the spray was being used to treat severe burns.

Spray-on skin for burns



A small sample of healthy skin is grown in the laboratory, then the cells are sprayed onto the wound, where they attach and grow.

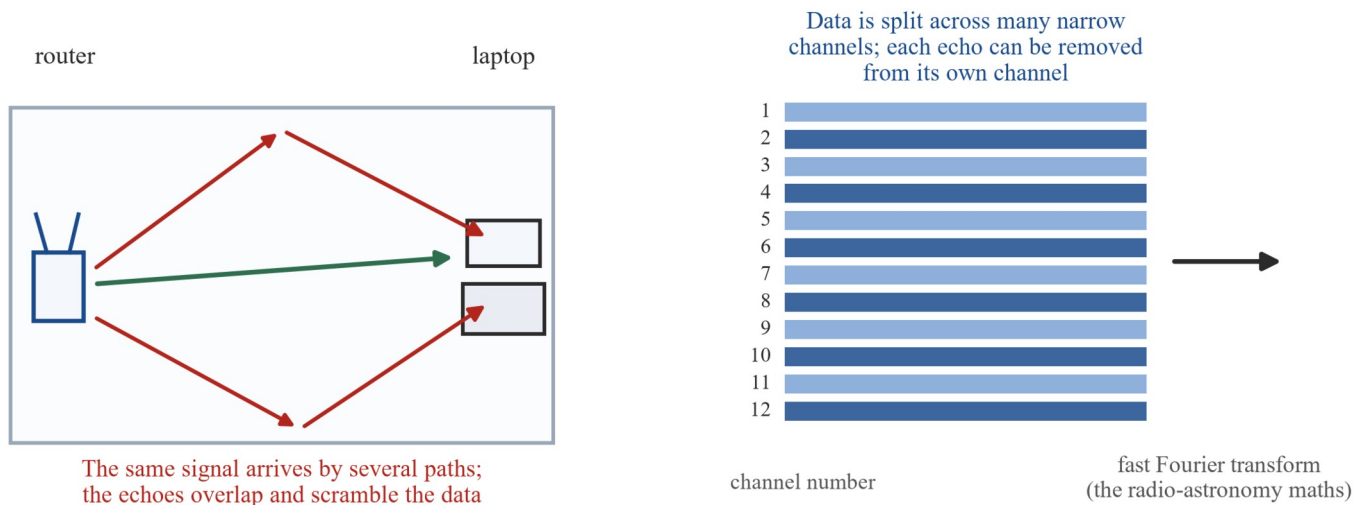
A cross-section of skin with a wound gap in the outer layer. Labels name the epidermis (the tough outer layer), the dermis (the thicker inner layer) and the wound bed (the burn area that needs new skin). Above the wound, a spray gun delivers a suspension of the patient's own cells grown in the laboratory; a caption explains that the cells are sprayed onto the wound, where they attach and grow.

The science here is cell biology — what skin cells need to grow and attach. The technology is the spray device and the laboratory method of growing the cells. The engineering is making both work reliably in a hospital, for a real patient, in the time a burn allows. Wood's and Stoner's published research through the 1990s and 2000s records the science; the patients treated record the technology.

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Case 4 — From black holes to wi-fi (elaboration VC2S10H02 . E01). Indoors, a wireless signal reaches a laptop by several paths at once — straight from the router, and as echoes off the walls, ceiling and floor. The echoes arrive late and overlap, scrambling the data. The fix used in fast indoor wireless networks is to split the data across many narrow channels, so each echo can be undone from its own channel. Untangling the echoes takes a mathematical method called the **fast Fourier transform** — a way of breaking a messy signal into its clean parts.

Indoor wireless: problem and fix

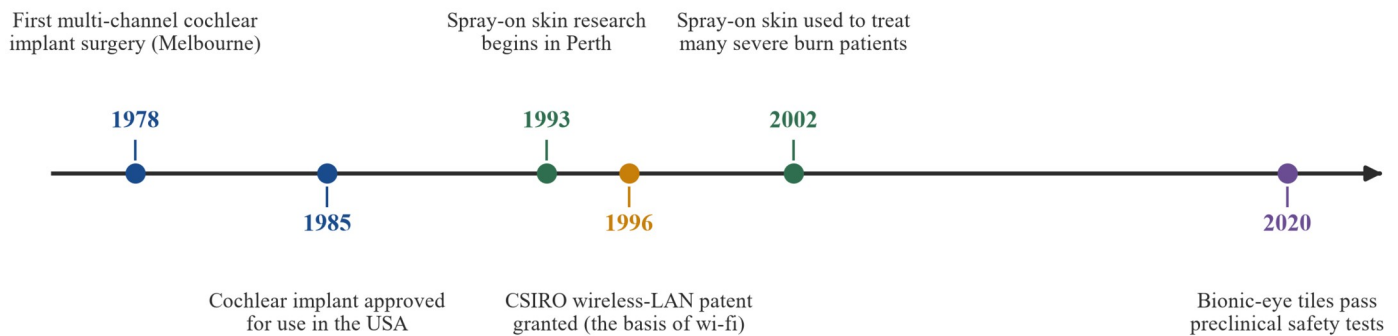


Two panels. Left: a room with a router and a laptop; a direct signal and two reflected echoes reach the laptop by different paths, and a caption says the same signal arrives by several paths, so the echoes overlap and scramble the data. Right: the data split across twelve narrow numbered channels, with a caption saying each echo can be removed from its own channel, and a label naming the fast Fourier transform as the radio-astronomy maths.

That maths did not come from a communications laboratory. In the 1970s, CSIRO radio-astronomers led by Dr John O'Sullivan developed it while searching for signals from exploding black holes — the search found no black holes, but the signal maths turned out to be exactly what indoor wireless needed. CSIRO patented the method — the patent was granted in the USA in 1996 — and the invention became a building block of modern wi-fi. Astronomy drove the science; engineering turned a by-product of that science into a technology used billions of times a day.

CSIRO, "Wireless LAN" (US patent 5 487 069, J. D. O'Sullivan and co-inventors), granted 1996.
<https://patents.google.com/patent/US5487069A> — retrieved 2026-08-21.

Four advances on one line. Set beside each other, the four cases form a single Australian story of the loop, from 1978 to 2020.



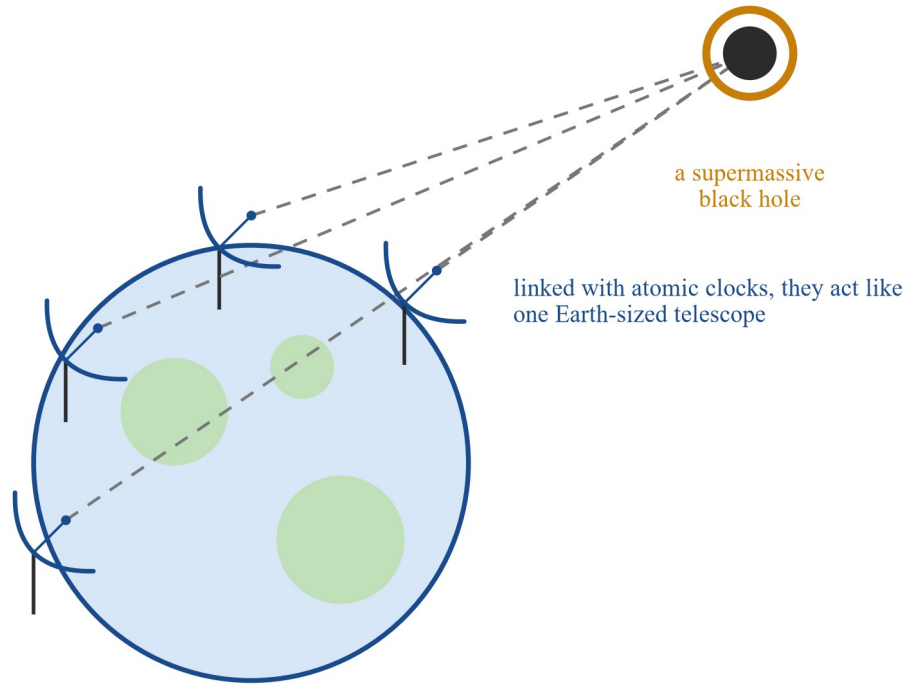
Australian advances in medicine and communications, 1978–2020

A horizontal timeline of six events. Above the line: 1978, first multi-channel cochlear implant surgery (Melbourne); 1993, spray-on skin research begins in Perth; 2002, spray-on skin used to treat many severe burn patients. Below the line: 1985, cochlear implant approved for use in the USA; 1996, CSIRO wireless-LAN patent granted (the basis of wi-fi); 2020, bionic-eye tiles pass preclinical safety tests. Caption: Australian advances in medicine and communications, 1978–2020.

Big instruments, fast computers (elaboration VC2S10H02 . E02). Some questions in science are too big for any one instrument, so engineers build instruments that act as one, and fast computers join them together. Four current examples show the pattern.

The **Event Horizon Telescope** is not one telescope but radio dishes on different continents, all watching the same object at the same instant, timed by **atomic clocks** — the most exact clocks there are. Joined by computers, they act like a single telescope the size of Earth, and in April 2019 they produced the first image of a **supermassive black hole** — a black hole millions of times heavier than the Sun — at the centre of a far-away galaxy. No dish that size could ever be built; the technology of linking them made the science possible.

The Event Horizon Telescope: a telescope the size of Earth

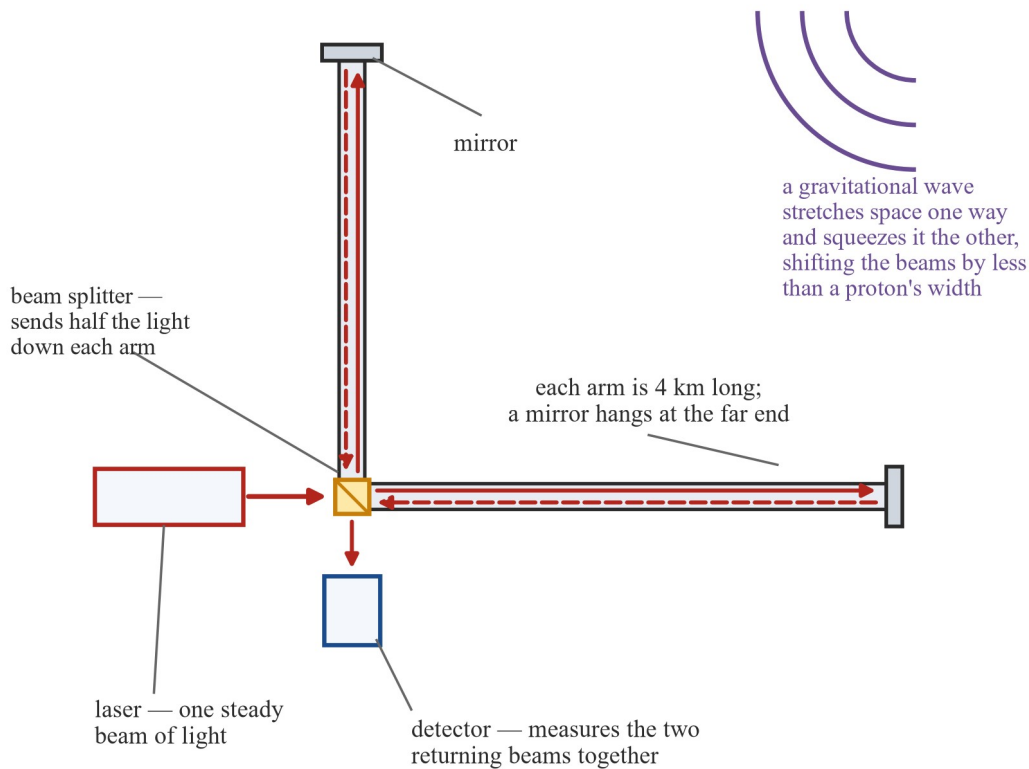


Radio telescopes on different continents all watch the same object at the same instant

The Earth drawn with four radio dishes on its rim, all aimed at one object: a black ring with an orange halo labelled a supermassive black hole. Dashed lines run from each dish to the black hole, and a label says that linked with atomic clocks, the dishes act like one Earth-sized telescope. Caption: radio telescopes on different continents all watch the same object at the same instant.

LIGO, in the USA, detects **gravitational waves** — ripples in space itself, sent out when huge objects such as black holes collide far away. It has two arms, each 4 km long, with a mirror hanging at the far end of each. A laser beam is split and sent down both arms; when a gravitational wave passes, it stretches space one way and squeezes it the other, changing the arms' lengths by less than a proton's width, and the two returning beams show the change. The first detection was made on 14 September 2015, a century after the waves were predicted. Only engineering of the finest kind — mirrors, lasers, vacuum tubes — could measure so small a change, and only fast computers could find the signal in the noise.

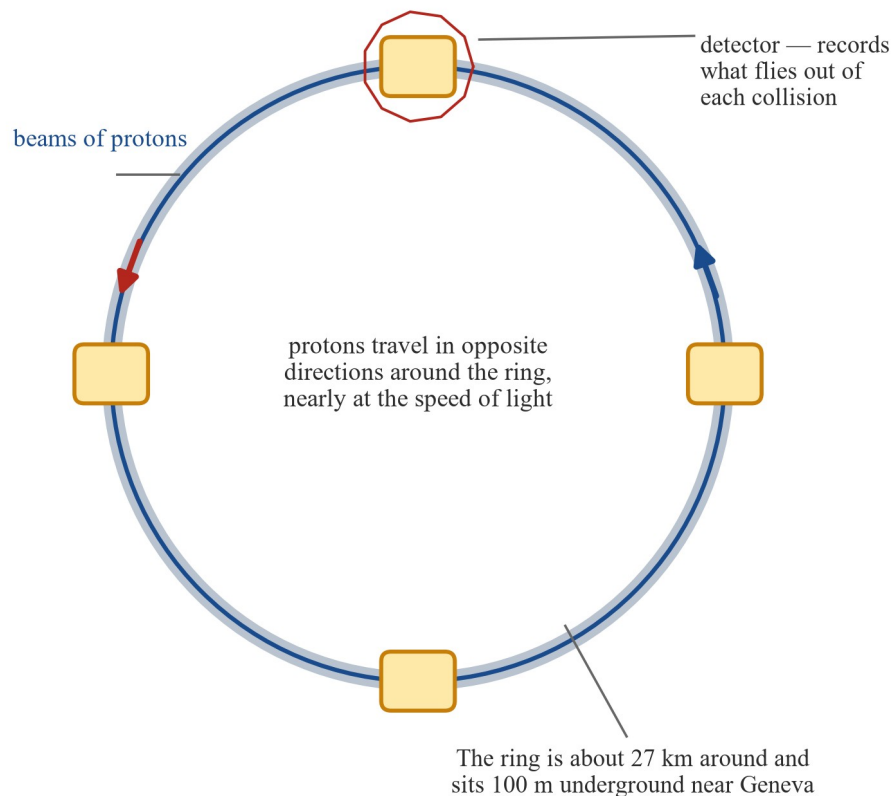
LIGO: measuring ripples in space with light



An L-shaped instrument. A laser sends one steady beam of light to a beam splitter, which sends half the light down each arm; each arm is 4 km long with a mirror at the far end; the two returning beams are measured together at a detector. Arcs at the corner represent a gravitational wave, with a note that it stretches space one way and squeezes it the other, shifting the beams by less than a proton's width.

The **Large Hadron Collider** near Geneva runs the loop the other way: it is the technology, and the science it serves is the smallest there is. Protons travel in opposite directions around a ring about 27 km around, sitting about 100 m underground, at nearly the speed of light; where the beams cross, the protons collide and giant **detectors** record what flies out. In 2012 two of those detectors found the **Higgs boson**, the particle physicists had searched for over decades — the particle that explains why other particles have mass at all.

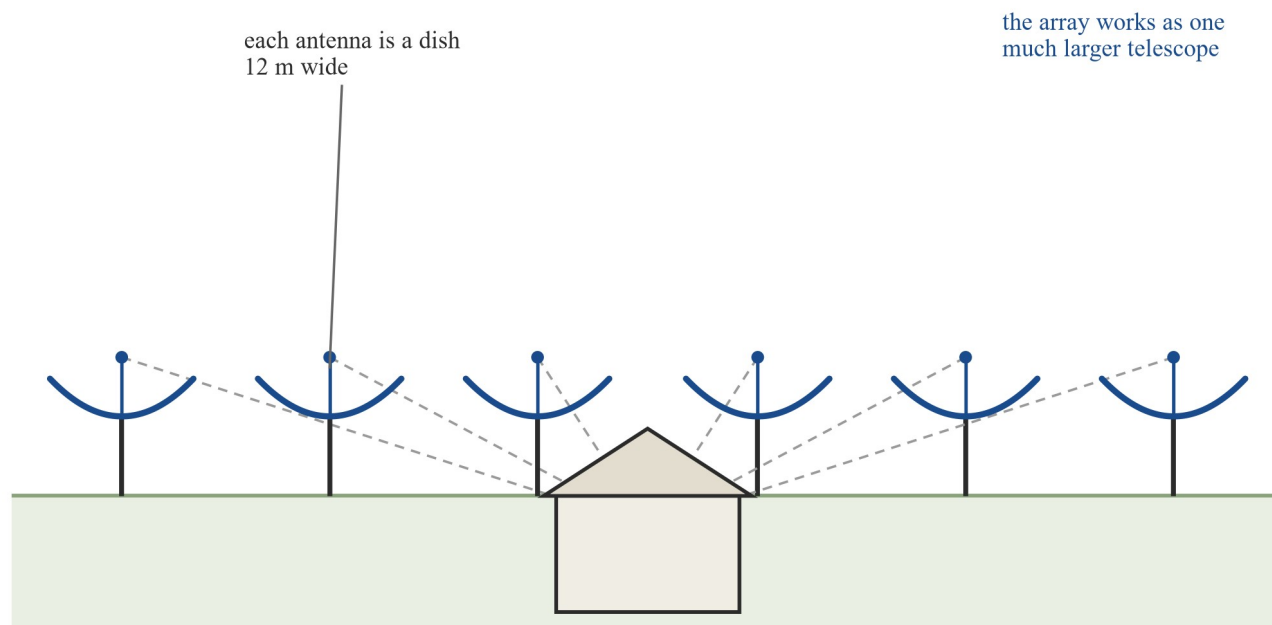
The Large Hadron Collider: collisions at the frontiers



A ring with four detector boxes on it and two arrows running opposite ways around the ring, labelled beams of protons. A star shape at the top detector is labelled: detector — records what flies out of each collision. The centre reads: protons travel in opposite directions around the ring, nearly at the speed of light. A note says the ring is about 27 km around and sits 100 m underground near Geneva.

ASKAP, in the outback of Western Australia, is the Australian member of this family. Its 36 antennas are each a dish 12 m wide, spread over the desert at the CSIRO Murchison Radio-astronomy Observatory. No single dish sees much; a central computer combines the signals from all 36 so the array works as one much larger telescope, surveying the radio sky faster than any dish could.

ASKAP: many small dishes acting as one



a central computer combines the signals from all 36 antennas

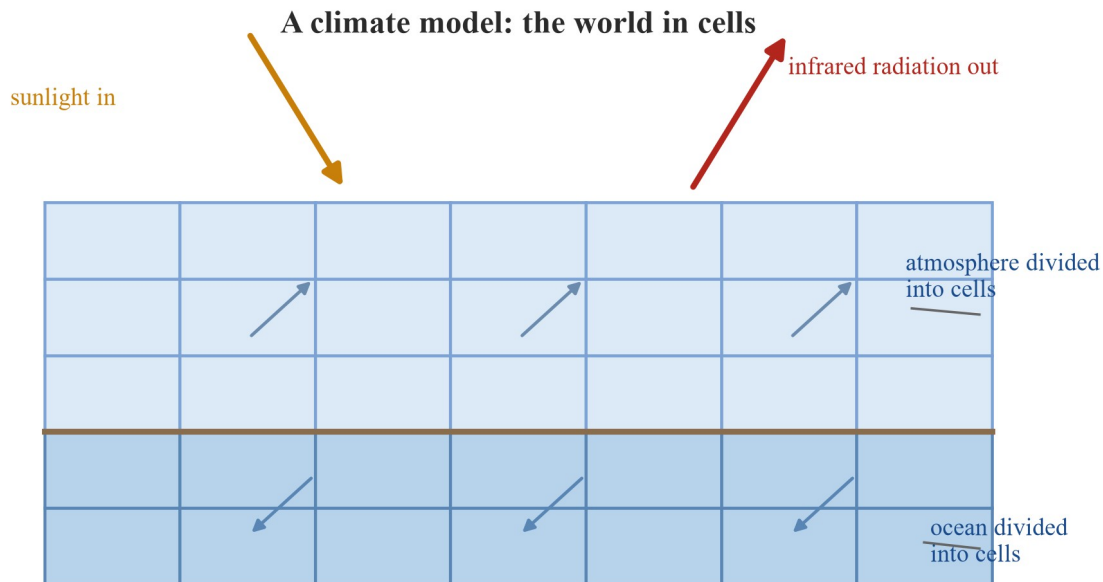
ASKAP, at the CSIRO Murchison Radio-astronomy Observatory, Western Australia

A row of six dishes on stands above a ground line, each joined by a dashed line to a small building labelled: a central computer combines the signals from all 36 antennas. Notes say each antenna is a dish 12 m wide, and the array works as one much larger telescope. Caption: ASKAP, at the CSIRO Murchison Radio-astronomy Observatory, Western Australia.

Fast computers also changed biology in the same period: **DNA sequencing** — reading the coded instructions inside cells — went from a project of years to a routine task, because the reading is done by machines and joined up by computers. In every case the pattern of the content description holds: the technology enabled the science, and the science keeps giving the engineers new things to build.

The Event Horizon Telescope Collaboration, “First M87 Event Horizon Telescope Results. I. The Shadow of the Supermassive Black Hole”, The Astrophysical Journal Letters, 2019. <https://doi.org/10.3847/2041-8213/ab0ec7> — retrieved 2026-08-21. B. P. Abbott et al. (LIGO Scientific Collaboration and Virgo Collaboration), “Observation of Gravitational Waves from a Binary Black Hole Merger”, Physical Review Letters, 2016. <https://doi.org/10.1103/PhysRevLett.116.061102> — retrieved 2026-08-21. G. Aad et al. (ATLAS Collaboration), “Observation of a new particle in the search for the Standard Model Higgs boson with the ATLAS detector at the LHC”, Physics Letters B, 2012. <https://doi.org/10.1016/j.physletb.2012.08.020> — retrieved 2026-08-21. D. McConnell et al., “The Rapid ASKAP Continuum Survey I: Design and first results”, Publications of the Astronomical Society of Australia, 2020. <https://doi.org/10.1017/pasa.2020.41> — retrieved 2026-08-21.

Modelling the world in cells (elaboration VC2S10H02 . E03). Not every advance needs a giant instrument; some need a giant model. A **computer model** of the climate divides the atmosphere and the ocean into boxes called cells. For each cell the computer keeps score of energy, air and water, and the rules of physics say how each cell exchanges them with its neighbours and with the cell above and below. The computer then steps every cell forward in time — a few minutes at a time — and the weather, and over longer runs the climate, appear. The same kind of modelling is used to track pollution as it spreads through air and water. The science supplies the rules; the technology — computers fast enough to step billions of cells — supplies the answer; and the models are checked, like all science, against what actually happens (Subtopic 1A). New kinds of computer, including **quantum computers** — machines that use the strange physics of atoms to run certain calculations in a new way — may one day step the loop faster still.

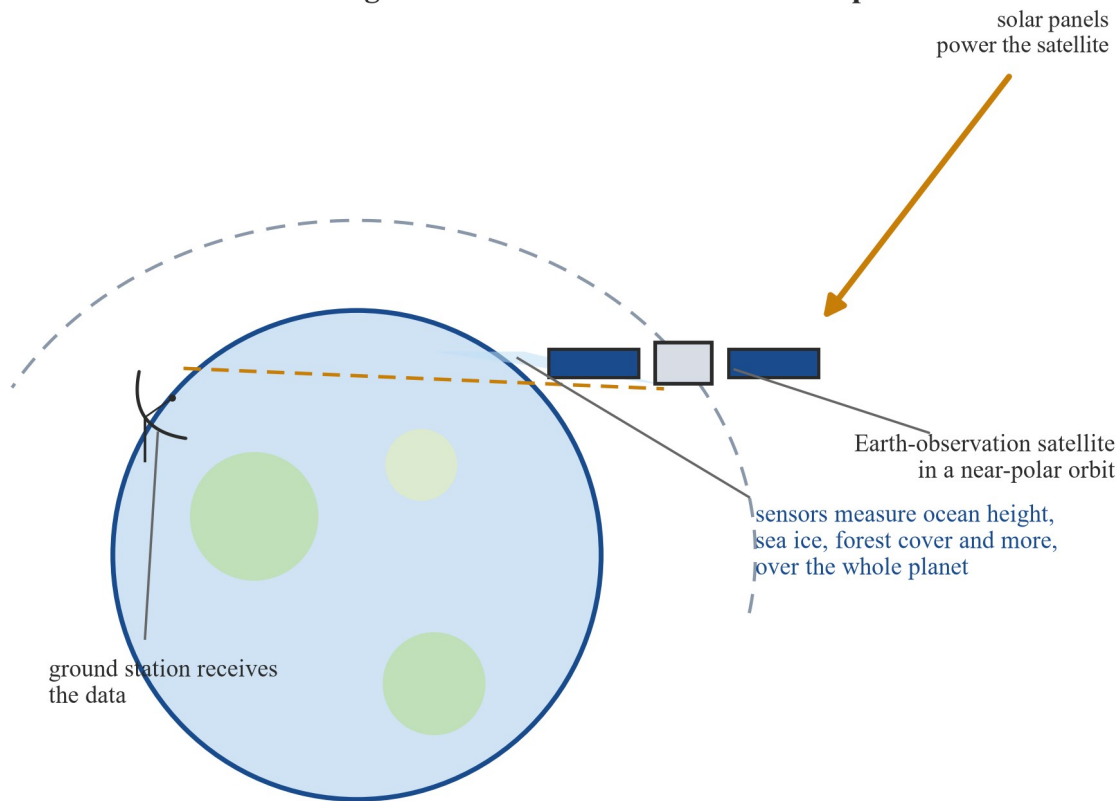


A computer steps every cell forward in time: energy, air and water moving between cells — that is how weather and climate forecasts are made

A grid of cells in two blocks. The upper block of three rows is labelled atmosphere divided into cells; the lower block of two rows is labelled ocean divided into cells; a ground line sits between them. An orange arrow labelled sunlight in enters from the top left and a red arrow labelled infrared radiation out leaves at the top right; small arrows between cells show energy, air and water moving between cells. Caption: a computer steps every cell forward in time — that is how weather and climate forecasts are made.

Satellites: instruments above the atmosphere (elaboration VC2S10H02 . E04). Some measurements only work from space. Earth-observation satellites in near-polar orbits carry sensors that measure ocean height and ocean temperature, sea ice, forest cover and ice sheets, over the whole planet, day after day — data no ground station could ever collect. The satellite record of ocean height, kept since 1993, is one of the clearest measures of a warming world: the IPCC’s 2021 assessment reports that global sea level rose about 20 cm between 1901 and 2018, and that the rate of rise has quickened — about 1.3 mm per year over 1901–1971, 1.9 mm per year over 1971–2006, and 3.7 mm per year over 2006–2018. The science of climate needed the satellite technology; the flood of satellite data, in turn, keeps sharpening the climate models of the previous case.

Satellites: global instruments above the atmosphere

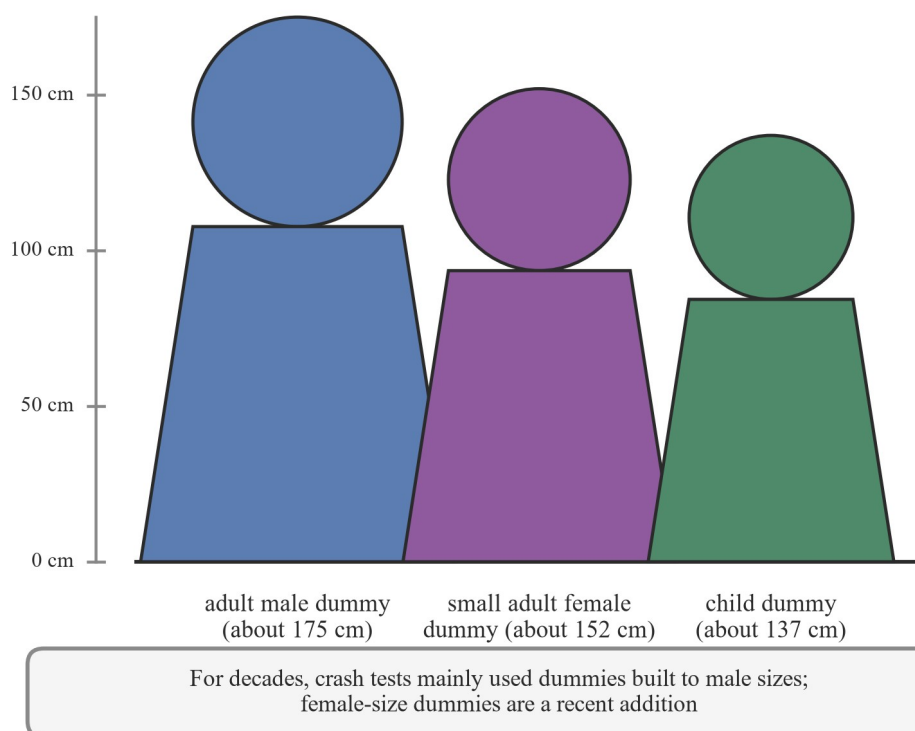


The Earth with a satellite on a dashed near-polar orbit above it. The satellite has two solar panels, labelled: solar panels power the satellite. A sensor beam reaches the surface, labelled: sensors measure ocean height, sea ice, forest cover and more, over the whole planet. A dashed line runs from the satellite to a ground station on the Earth, labelled: ground station receives the data. Caption: satellites — global instruments above the atmosphere.

IPCC, “Climate Change 2021: The Physical Science Basis — Summary for Policymakers” (Sixth Assessment Report, Working Group I), 2021. <https://www.ipcc.ch/report/ar6/wg1/> — retrieved 2026-08-21.

Crash-test dummies: whose body is the standard? (elaboration VC2S10H02 . E05). Science about crashes comes, in part, from crashing cars with **dummies** — instrumented bodies built to human size and weight — inside. For decades the standard dummy was built to the 50th-percentile man — the height and weight of a middle-sized man — and it has been the reference dummy since 1976. A smaller “female” dummy added in 2003 was a scaled-down version of the male design, built to a small body rather than to the average woman. That choice had a scientific cost: a 2019 study of real crashes found that, in front-on crashes, belted women were at greater risk of injury than belted men in similar crashes at similar speeds — a difference the male-shaped testing had never been built to find. In 2023 a Swedish team led by Dr Astrid Linder presented the first dummy built to the average female body, so that cars can at last be tested against it. The case is the loop again, with a lesson attached: when the instruments carry a bias, the science they produce carries the same bias, and better engineering of the instruments corrects the science.

Crash-test dummies come in different sizes

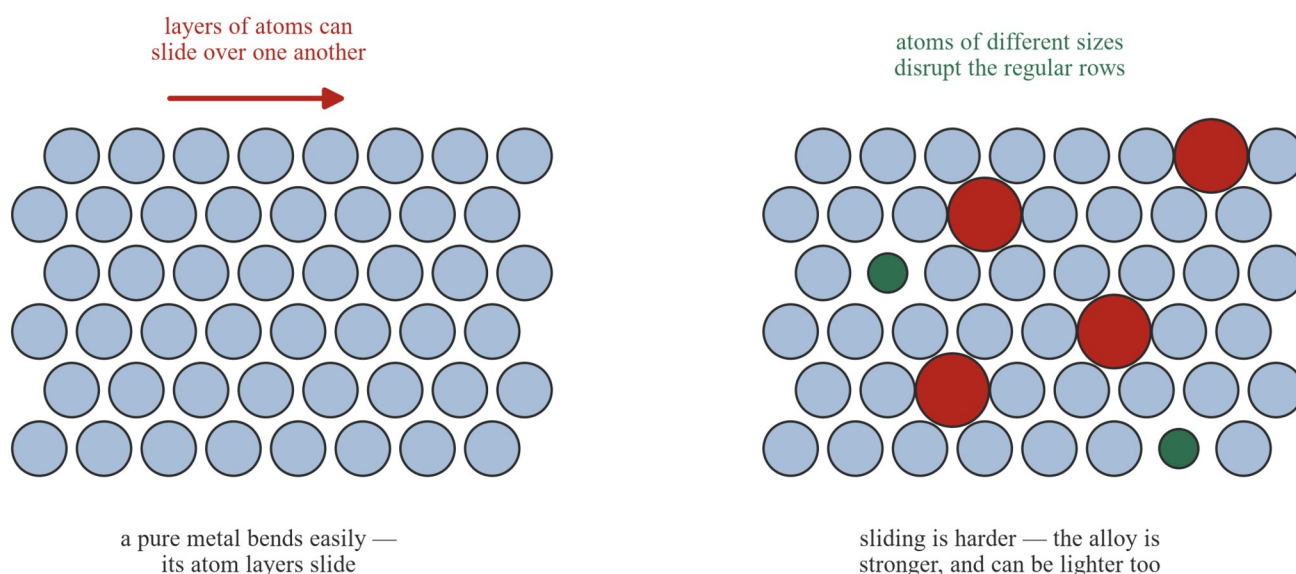


Three human figures side by side against a height ruler marked 0, 50, 100 and 150 cm: an adult male dummy (about 175 cm), a small adult female dummy (about 152 cm) and a child dummy (about 137 cm). A note below says: for decades, crash tests mainly used dummies built to male sizes; female-size dummies are a recent addition.

J. Forman et al., “Automobile injury trends in the contemporary fleet: Belted occupants in frontal collisions”, *Traffic Injury Prevention*, 2019. <https://doi.org/10.1080/15389588.2019.1630825> — retrieved 2026-08-21. A. Carlsson, J. Davidsson, A. Linder and M. Y. Svensson, “Design and Evaluation of the Initial 50th Percentile Female Prototype Rear Impact Dummy, BioRID P50F”, *Frontiers in Bioengineering and Biotechnology*, 2021. <https://doi.org/10.3389/fbioe.2021.687058> — retrieved 2026-08-21.

Stronger and lighter: the science of alloys (elaboration VC2S10H02 .E06). A pure metal is a regular stack of atoms, and its flat layers can slide over one another — which is why pure metals bend easily. An **alloy** — a metal with atoms of other elements mixed in — breaks the pattern: the foreign atoms are bigger or smaller than the host atoms, so they disrupt the regular rows and the layers cannot slide so freely. The alloy is stronger, and because the mixed-in atoms can be light ones, it can be lighter too. Super-strong, lighter alloys are exactly what engineering keeps asking science for: lighter aircraft and vehicles burn less fuel, and strong, light, body-friendly alloys such as titanium alloys are used in artificial hips and knees. The science of atomic structure (Subtopic 10C) explains the strength; engineering turns the explanation into materials.

Why alloys are stronger (a model at the atom level)



Two panels of atom rows. Left: a pure metal, regular rows of same-sized atoms with an arrow showing that layers of atoms can slide over one another; caption: a pure metal bends easily — its atom layers slide. Right: the same rows with a few larger and a few smaller foreign atoms in them, caption: atoms of different sizes disrupt the regular rows, so sliding is harder — the alloy is stronger, and can be lighter too.

The loop, once more. Every case above is the same sentence in different clothes: advances in technologies enabled advances in science — the satellite record, the black-hole image, the gravitational-wave detection, the crash data — while science contributed to developments in technologies and engineering — the implant, the spray, the wireless maths, the alloy, the model. Examining that relationship, case by case, is precisely the skill the achievement standard names.

Activities

Activity 1 — Map an Australian advance onto the loop (elaboration VC2S10H02 .E01). Choose one of the four Australian cases — cochlear implant, bionic eye, spray-on skin, wi-fi maths. Copy the four boxes of the loop diagram for your case, and in each box write one sentence about your case: what scientific knowledge it used, what tool or device that knowledge made possible, what new observations or data the device produced, and what sharper theories or new questions followed. Finish with one sentence answering: in your case, which way around the loop did the advance start, and how do you know?

Activity 2 — One instrument, three kinds of work (elaboration VC2S10H02 .E02). Take ASKAP or LIGO. In three columns headed *science*, *technology* and *engineering*, list three items for your instrument under each heading — for example under engineering for LIGO: mirrors hung so that almost no vibration reaches them. Then write two sentences: one stating what the instrument has let science find out, and one stating what science had to know before the instrument could be built. No physical hazards are involved; this is a desk activity using the diagrams in this subtopic.

Activity 3 — A fair test for every body (elaboration VC2S10H02 .E05). The crash-dummy case says that an instrument can carry a bias, and the science it produces can carry the same bias. (a) Using the dummy diagram and the 2019 crash study, explain in three sentences how a male-shaped standard dummy biased what crash science knew. (b) Propose two design criteria — two things the dummy must represent — that an average-female dummy should meet, and say what each criterion would let scientists measure for the first time. (c) Name one other instrument or data set in this subtopic and state one way its design could hide a bias of its own.

Activity 4 — Model a model (elaboration VC2S10H02 .E03). Using a spreadsheet, build a two-cell model: cell A and cell B each hold a number (start with A = 100, B = 0). At each step, move one-tenth of the difference from the larger cell to the smaller one, and step ten times. Record the value in each cell at every step and graph both against step number. Answer: (a) what happens to the difference between the cells as the steps run on; (b) how this two-cell exchange is like, and unlike, the climate model in the diagram (one like and one unlike, one sentence each). No physical hazards are involved; use school-approved software.

Worked examples

Example 1 — scaffolded

The IPCC figures for the rate of sea-level rise are: 1.3 mm per year over 1901–1971, 1.9 mm per year over 1971–2006, and 3.7 mm per year over 2006–2018. (a) Calculate the total rise over 1971–2006, in mm. (b) Express your answer to (a) in cm, to one decimal place. (c) How many times faster was the rate over 2006–2018 than the rate over 1901–1971? Give your answer to one decimal place.

Working	Comment
(a) $2006 - 1971 = 35$ years; rise = rate $\times$ time = 1.9×35 = 66.5 mm	A rate is an amount per year, so amount = rate $\times$ number of years. Units: mm per year $\times$ years = mm.
(b) $66.5 \text{ mm} \div 10 = \mathbf{6.7 \text{ cm}}$ (1 d.p.)	10 mm in every cm; 6.65 rounds to 6.7.
(c) $3.7 \div 1.3 = 2.846... \approx \mathbf{2.8 \text{ times faster}}$	Comparing two rates is a division, not a subtraction.

The answer to (c) is the scientific point: the rate of rise has not stayed the same, it has nearly tripled since 1901–1971. That quickening is part of what the satellite record was built to measure.

Example 2 — scaffolded

Sort the cochlear implant into the three kinds of work. For each item below, state whether it is *science*, *technology* or *engineering*, giving the one-line reason. (a) Knowing that the cochlea normally turns vibrations into nerve signals. (b) The electrode array, thin and flexible enough to thread into the cochlea without damaging it. (c) The implant as a working device fitted to a patient. (d) Finding, from fitted implants, that the auditory nerve can carry an electrical signal the brain reads as sound.

Working	Comment
(a) Science	Tested knowledge about how the ear works — knowledge, not a tool.
(b) Engineering	Designing and building a part to be safe, reliable and useful.
(c) Technology	The built device itself, made possible by the knowledge in (a).
(d) Science	A new observation the device produced — knowledge flowing back from the technology.

Notice (d): the loop does not end when the device works. The fitted implant became an instrument for studying the nerve, so the technology fed the science in return — the second arrow of the content description.

Example 3 — unscaffolded

LIGO's arms are each 4 km long. Light travels at about 300 000 000 m/s. (a) Calculate the time light takes to travel once down one arm. Give your answer in seconds, in the form 0.000 0... (b) Write the same time as "...millionths of a second". (c) Explain, in two sentences, why LIGO needs two arms at right angles rather than one.

- (a) time = distance $\div$ speed = $4000 \text{ m} \div 300\,000\,000 \text{ m/s} = 0.000\,013\,3 \text{ s}$ (to 3 s.f.).
 (b) 0.000 013 3 s is about 13 millionths of a second.

- (c) A gravitational wave stretches space one way and squeezes it the other, so while one arm gets longer the other gets shorter. With two arms at right angles, the two returning beams disagree by exactly that difference, and the detector can see it; a single arm would have nothing to compare itself against.

Example 4 — unscaffolded

Two claims to examine, using this subtopic. (a) “An alloy is stronger than its pure metal because the foreign atoms are stronger than the host atoms.” Evaluate the claim. (b) “The average-female dummy changes the engineering of dummies, but it cannot change the science of crashes.” Evaluate the claim.

- (a) The claim is wrong about the reason. The strength of an alloy does not come from stronger atoms; it comes from the different sizes of the atoms, which disrupt the regular rows so the layers cannot slide. The atoms themselves are unchanged.
- (b) The claim is wrong. The science of crashes is built on what the dummies measure; while the dummies were male-shaped, the injury data carried that bias, and the 2019 study showed belted women at greater risk than the old testing had suggested. A new instrument corrects the measurements, and better measurements change the science.
-

Practice questions

Scaffolded questions

Question 1 The three kinds of work. (a) State the working meaning this subtopic gives to *science*. (b) State the working meaning this subtopic gives to *technology*. (c) State the working meaning this subtopic gives to *engineering*.

Question 2 Reading the loop. (a) Name the four boxes of the loop diagram in one order around the ring. (b) State the two examples the side notes give, and say which arrow of the content description each one shows.

Question 3 The cochlear implant, in order. (a) Number these parts in the order the signal passes through them: electrode array, microphone and processor, auditory nerve, transmitter coil. (b) State which part does the job the cochlea normally does. (c) State the city and the year of the first multi-channel operation.

Question 4 The wi-fi story. (a) State the problem indoor wireless signals face, in one sentence. (b) State the fix, in one sentence. (c) Name the maths the fix uses, and say where the maths first came from.

Question 5 Big instruments. (a) State what joins the Event Horizon Telescope’s dishes into one Earth-sized telescope. (b) State the length of one LIGO arm and what hangs at its far end. (c) State how many antennas ASKAP has and where it stands.

Question 6 The sea-level record. (a) State the total sea-level rise the IPCC reports for 1901–2018. (b) Copy the three rates with their date ranges, smallest first. (c) State which instrument has kept the ocean-height record since 1993.

Unscaffolded questions

Question 7 The loop, both ways, one case. Explain, in three or four sentences, how the cochlear implant shows both arrows of the content description: science contributing to technology, and technology enabling science.

Question 8 Bionic eye. (a) Name the part of the brain the Gennaris tiles sit on. (b) Explain why the bionic eye can help a person whose eye is damaged but whose brain’s sight centre works. (c) State what the 2020 published tests of the tiles were for.

Question 9 Spray-on skin. (a) State whose cells the spray uses, and one reason that choice matters. (b) Identify one piece of science, one piece of technology and one piece of engineering in the spray-on skin story.

Question 10 Two arms are better than one. A student says LIGO should build one arm 8 km long instead of two arms 4 km long, “because the light would travel further”. Using what a gravitational wave does to space, explain why the two-arm design is the right one.

Question 11 The Higgs and the ring. (a) State what the Higgs boson explains. (b) State two facts about the Large Hadron Collider’s ring from the diagram. (c) Explain in one sentence why the detectors sit at the points where the beams cross.

Question 12 Sea-level arithmetic. Using the IPCC rates: (a) calculate the total rise over 1901–1971, in mm; (b) calculate the total rise over 2006–2018, in mm; (c) the second period is much shorter than the first yet produces over half the rise. Explain why, using the word *rate*.

Question 13 Satellites. (a) Name two things Earth-observation satellites measure. (b) Explain in one sentence why those measurements are better made from orbit than from the ground.

Question 14 Dummies and bias. (a) State what the 50th-percentile man means, in your own words. (b) State why the “female” dummy of 2003 was a poor stand-in for the average woman. (c) Explain how the average-female dummy of 2023 improves the science of crashes, not just the engineering of dummies.

Question 15 Alloys. (a) Explain, using the diagram, why a pure metal bends easily. (b) Explain why adding atoms of a different size makes the metal stronger. (c) Give one reason engineering wants alloys that are lighter as well as stronger.

Question 16 The loop applied to a new case. DNA sequencing went from a project of years to a routine task once fast machines and computers did the reading. State which arrow of the content description that sentence shows, and justify your choice in one further sentence.

Answers

Question 1 (a) tested knowledge about the natural world; (b) the tools and devices that knowledge makes possible; (c) designing and building those tools so they are safe, reliable and useful. **Question 2** (a) new scientific knowledge → new tools and instruments built → new observations and data → sharper theories, new questions → back to the start; (b) ear science → cochlear implants shows science contributing to technology; better telescopes → black-hole images shows technology enabling science. **Question 3** (a) microphone and processor, transmitter coil, electrode array, auditory nerve; (b) the electrode array (driven by the implant) does the cochlea's job; (c) Melbourne, 1978. **Question 4** (a) echoes off walls, ceiling and floor arrive late and scramble the data; (b) the data is split across many narrow channels so each echo can be undone from its own channel; (c) the fast Fourier transform; it was first developed by CSIRO radio-astronomers searching for exploding black holes. **Question 5** (a) atomic clocks and fast computers, with all dishes watching the same object at the same instant; (b) 4 km; a mirror; (c) 36 antennas; at the CSIRO Murchison Radio-astronomy Observatory in Western Australia. **Question 6** (a) about 20 cm; (b) 1.3 mm per year (1901–1971), 1.9 mm per year (1971–2006), 3.7 mm per year (2006–2018); (c) Earth-observation satellites. **Question 7** see solution. **Question 8** (a) the visual cortex; (b) see solution; (c) see solution. **Question 9** (a) the patient's own; the body does not reject them; (b) see solution. **Question 10** see solution. **Question 11** (a) why other particles have mass; (b) any two of: about 27 km around; about 100 m underground; near Geneva; (c) see solution. **Question 12** (a) 91 mm; (b) 44.4 mm; (c) see solution. **Question 13** (a) any two of: ocean height, ocean temperature, sea ice, forest cover, ice sheets; (b) see solution. **Question 14** (a) see solution; (b) see solution; (c) see solution. **Question 15** (a) see solution; (b) see solution; (c) see solution. **Question 16** see solution.

Fully-worked solutions

Question 1 (a) Science builds tested knowledge about the natural world — knowledge checked by the methods of Subtopic 1A. (b) Technology is the tools and devices that such knowledge makes possible. (c) Engineering is the work of designing and building those tools so they are safe, reliable and useful.

Question 2 (a) New scientific knowledge → new tools and instruments built → new observations and data → sharper theories, new questions — and the arrows run both ways. (b) “Knowing how the ear works leads to cochlear implants” shows science contributing to developments in technology. “Better telescopes lead to black-hole images” shows advances in technology enabling advances in science.

Question 3 (a) Sound is picked up first, so: microphone and processor → transmitter coil → electrode array → auditory nerve. (b) The electrode array gives the auditory nerve the pulses the damaged cochlea can no longer give — it does the cochlea's job. (c) Melbourne, 1978, by Graeme Clark's team; the patient was Rod Saunders.

Question 4 (a) Indoors, the same signal arrives by several paths; the late echoes overlap and scramble the data. (b) The data is split across many narrow channels, so each echo can be removed from its own channel. (c) The fast Fourier transform. It came from radio-astronomy: CSIRO astronomers developed it while searching for signals from exploding black holes.

Question 5 (a) Atomic clocks time the dishes while fast computers join their signals, with every dish watching the same object at the same instant — together they act like one Earth-sized telescope. (b) Each arm is 4 km long, and a mirror hangs at the far end. (c) ASKAP has 36 antennas, each a dish 12 m wide, at the CSIRO Murchison Radio-astronomy Observatory in Western Australia.

Question 6 (a) About 20 cm over 1901–2018. (b) 1.3 mm per year over 1901–1971; 1.9 mm per year over 1971–2006; 3.7 mm per year over 2006–2018. (c) Earth-observation satellites, measuring ocean height from orbit since 1993.

Question 7 First arrow: the science of the ear — how the cochlea and the auditory nerve work — contributed to the development of the implant, a technology. Second arrow: the implant, once fitted, became an instrument for studying the nerve in real ears, so the technology enabled new science. One case, both directions — the loop.

Question 8 (a) The visual cortex, at the back of the head. (b) The system does not use the eye at all: the camera replaces the eye, and the tiles send pulses straight to the sight centre. So a damaged eye is bypassed, while a working visual cortex can still turn the pulses into spots of light. (c) The 2020 tests were safety tests of the implanted tiles — the step that has to be passed before human trials can go ahead.

Question 9 (a) The patient's own cells; because they are the body's own, the body does not reject them. (b) Science: what skin cells need to grow and attach (cell biology). Technology: the spray device and the laboratory method of growing the cells. Engineering: making both work reliably, in a hospital, in the time a burn allows.

Question 10 A gravitational wave stretches space one way and squeezes it the other, so the change LIGO measures is a *difference* between two lengths. With two arms at right angles, one arm lengthens while the other shortens, and the two returning beams show the difference. One 8 km arm would stretch and squeeze with the wave and have nothing to compare itself against — the difference, and therefore the signal, would disappear.

Question 11 (a) The Higgs boson explains why other particles have mass. (b) Any two of: the ring is about 27 km around; it sits about 100 m underground; it is near Geneva. (c) The protons collide where the beams cross, so the detectors sit at those points to record what flies out of each collision.

Question 12 (a) $1971 - 1901 = 70$ years; $1.3 \times 70 = 91$ mm. (b) $2018 - 2006 = 12$ years; $3.7 \times 12 = 44.4$ mm. (c) The rate is the rise per year, and the later rate is nearly three times the earlier one (3.7 against 1.3 mm per year). So 12 fast years produce over half of what 70 slow years produced — the rate has quickened, and that quickening is the finding.

Question 13 (a) Any two of: ocean height, ocean temperature, sea ice, forest cover, ice sheets. (b) From orbit, one instrument measures the whole planet, day after day, including ocean and ice no ground station can reach.

Question 14 (a) The 50th-percentile man is a middle-sized man — the height and weight that sit in the middle of all men, so half of men are bigger and half smaller. (b) It was a scaled-down version of the male design, built to a small body (the 5th percentile of women) rather than to the average woman's height, weight and shape — so most women were still not represented. (c) Science is built on what instruments measure. With an average-female dummy, crash tests produce injury data for female bodies for the first time, so the science of crashes learns what male-shaped testing could not see — the 2019 study's greater risk for belted women is exactly the kind of finding such data makes possible.

Question 15 (a) A pure metal is a regular stack of atoms; its flat layers can slide over one another, so the metal bends easily. (b) Foreign atoms of a different size disrupt the regular rows, so the layers cannot slide freely — and a metal whose layers cannot slide is harder to bend: stronger. (c) Lighter aircraft and vehicles burn less fuel, so engineering wants materials that are strong without being heavy.

Question 16 The sentence shows technology enabling science: fast machines and computers (technology) made DNA sequencing routine, and the reading of DNA opened whole areas of biological science that the slow earlier methods could not feed. The direction of the arrow is from the technology to the science, which is the first clause of the content description.

Where this leads: the skill this subtopic builds — examining the relationship between science, engineering and technologies, case by case — is part of the cross-study key science skills every VCE science assesses when it asks how evidence is gathered and what instruments contribute (reference-only for this book; VCE re-teaches its own frameworks and does not assume this content, TOC D9). Inside this book the cases hand tools forward: the nervous-system picture used for the cochlear implant and the bionic eye is developed in Subtopic 8A; the climate models of elaboration .E03 meet the greenhouse account in Subtopic 12C; the atomic structure behind the alloys is Subtopic 10C; and Subtopic 13C's space exploration carries the engineering link back to this subtopic, while Subtopic 1A supplies the checks — replication, publication, peer review, consensus — that every case above ultimately relies on.

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