Course Companion

International Baccalaureate · IB Diploma · Design Technology · SL

Every topic handout in one volume

全部专题讲义合集

exercises.lol

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Design in theory

International Baccalaureate · IB Diploma · Design Technology · SL

Scope and prerequisites

This handout teaches Design in theory for the course first assessed in 2027: how designers work through a design process, how they research and involve users, how ergonomics and anthropometric data make products fit people, how physiological, psychological and cognitive factors affect use, and how a design specification turns needs into measurable requirements. It is written for both SL and HL students.

Prerequisites: percentages, the mean and the idea of a normal distribution from mathematics. Unit 2 (Design in practice) and unit 4 (the design project) use these ideas.

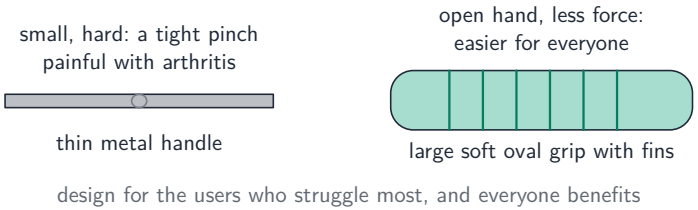
Design processes

A peeler for sore hands

In the late 1980s, Sam Farber watched his wife Betsey, who had arthritis in her hands, struggle to hold an ordinary metal vegetable peeler. He worked with a design consultancy to watch many people, young and old, with and without arthritis, using kitchen tools. The result, launched in 1990, was a range of 15 tools with large, soft, oval rubber handles with fins that the thumb and fingers could grip. They were easier for people with arthritis, and also more comfortable for everyone else. The OXO Good Grips range became one of the most famous examples of **inclusive design**: start with users who find a task hardest, and the result often works better for all.



Vegetable peelers: the same task, solved with different handle shapes, grips and blade angles

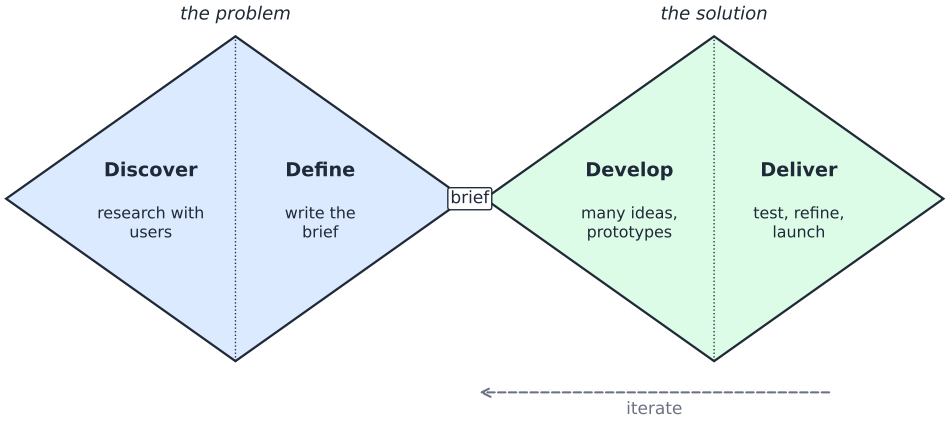


Design for those who struggle most

The design cycle

Design is a process of solving problems for people, and it is **iterative** 迭代: designers move back and forth between stages as they learn. A common model, the **design cycle** 设计循环, has four stages:

1. **Inquiring and analysing**: understand the problem, the users and the context; research existing products; write a design brief.
2. **Developing ideas**: write a specification; generate a wide range of ideas; develop and choose one.
3. **Creating the solution**: plan and make models and prototypes.
4. **Evaluating**: test the solution against the specification with users, and suggest improvements.



The double diamond design process

The **double diamond** 双钻模型 shows that design alternates between two kinds of thinking:

- **Divergent thinking** 发散思维 opens up many possibilities: wide research, many ideas, no judgement yet.
- **Convergent thinking** 收敛思维 narrows down: choosing the real problem, selecting the best idea.

The first diamond is about finding the right problem (discover, define); the second about finding the right solution (develop, deliver).

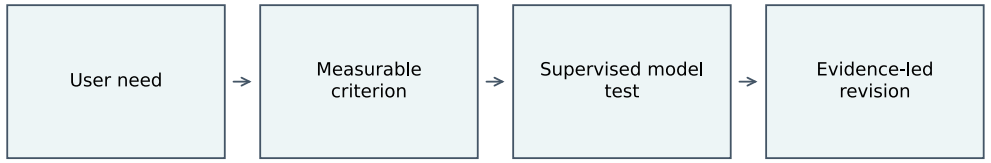
Design thinking 设计思维 describes a similar process in five modes: **empathise** (understand users' feelings and needs), **define** (state the problem from the user's point of view), **ideate** (generate ideas), **prototype** (make quick, cheap models) and **test** (learn from users). Its main message is to understand people deeply before designing for them, and to test early and often.

Design brief and specification

- A **design brief** 设计简报 is a short statement of the problem, the target users and the context: "Design a kitchen utensil that people with reduced grip strength can use safely and comfortably."
- A **design specification** 设计规格 is a list of requirements the solution must meet. Each requirement should be **measurable**, so it can be tested.

Vague	Measurable
"The handle should be comfortable"	"At least 8 of 10 test users with arthritis rate the grip 4 or 5 out of 5 after 5 minutes of use"
"It must be strong"	"The handle must withstand a 100 N bending load without permanent damage"
"Cheap"	"Manufacturing cost below ¥15 per unit at 10 000 units"

Specifications usually cover function, users, ergonomics, aesthetics, materials, size, safety, cost, environment and manufacture.



Turn a user need into a measurable criterion, test a model against it, then revise from the evidence

Worked example. A handle is gripped with a force of about 40 N in normal use. The designer applies a **factor of safety** 安全系数 of 2.5 to allow for misuse, variation in materials and wear. The specification test load = 40 × 2.5 = 100 N. The factor of safety is a design judgement that must be justified; it does not replace a proper safety review.

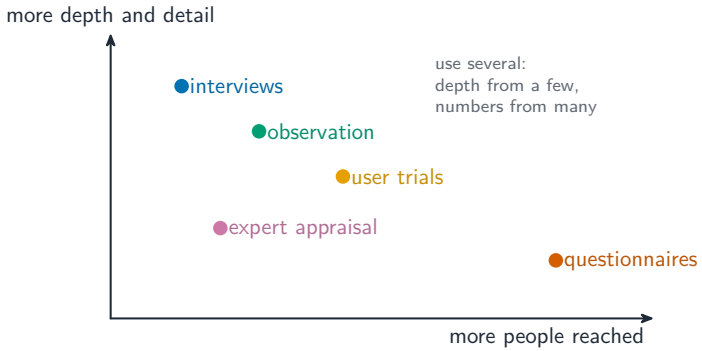
Researching and involving users

User-centred design

User-centred design 以用户为中心的设计 involves users at every stage, not only at the end. Designers ask: who will use it, for what, where, and what makes it hard for them?

Research method	Description	Strength	Limitation
Observation	Watching people use products in real settings	Shows what people really do, including problems they do not mention	Time-consuming; people may act differently when watched
Interviews	Talking with users in depth	Rich detail about needs and feelings	Small numbers; leading questions bias answers
Questionnaires	Fixed questions to many people	Quick; numerical data to compare	Little depth; people may not answer honestly
User trials	Users try a product or model on set tasks	Direct evidence of problems; measurable	Artificial setting; needs a model
Expert appraisal	Specialists (such as occupational therapists) judge a design	Fast; uses expert knowledge	Experts are not the real users
Personas	Invented but realistic profiles of typical users	Keeps the team focused on real needs	Can become stereotypes if not based on research

Research must be ethical: users give informed consent, take part voluntarily, can stop at any time, and their data are kept anonymous. Collect only the measurements and information you need.



Depth from a few, numbers from many

Inclusive design

Inclusive design 包容性设计 (also called universal design) aims to make products usable by as many people as possible, including older people, children, left-handed people and people with disabilities, without the need for special adaptation. Its principles include:

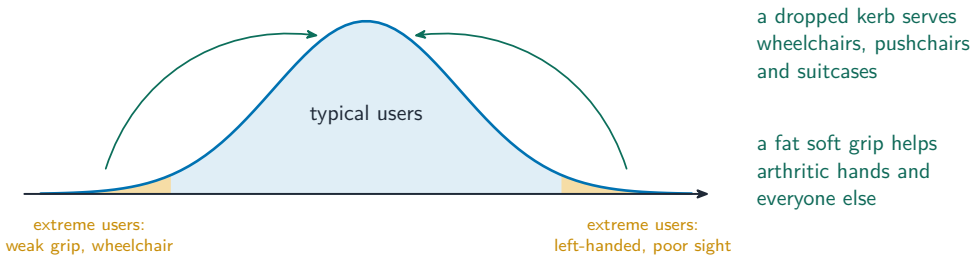


A kerb ramp with tactile paving: designed for wheelchair users, it also helps people with prams, trolleys and suitcases

- **equitable use**: useful to people with different abilities;
- **flexibility in use**: left- or right-handed use, different speeds;
- **simple and intuitive use**: easy to understand regardless of experience or language;

- **perceptible information**: information given in more than one way (colour, symbol, sound, touch);
- **tolerance for error**: mistakes have small, reversible consequences;
- **low physical effort**: little force or tiring posture;
- **size and space for approach and use**: room for wheelchairs, walking aids and different body sizes.

Examples include dropped kerbs (useful for wheelchairs, pushchairs and suitcases), lever door handles and subtitles. Designing for "extreme users" often improves a product for everyone, as the OXO peeler shows.



Design for the extremes and the middle benefits

Ergonomics and anthropometrics

Fitting products to people

Ergonomics 人体工学 is the study of how people interact with products, tasks and environments, so that designs are safe, comfortable, efficient and easy to use. It includes three groups of factors:

- **physiological**: the body's size, strength, comfort and fatigue (anthropometrics and biomechanics);
- **psychological**: how people perceive and respond to light, sound, colour, texture and temperature;
- **cognitive**: how people understand, remember and decide.

Anthropometric data

Anthropometrics 人体测量学 is the measurement of the human body. **Anthropometric data** 人体测量数据 give dimensions for a defined population, such as adults in China or children aged 8.

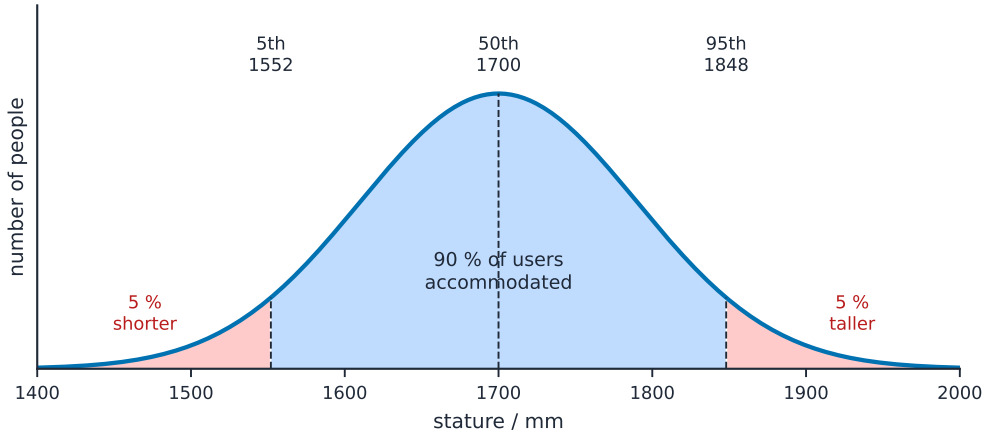


Measuring arm span: anthropometric tables are built from thousands of measurements like this one

- **Static data** 静态数据 are measured in fixed postures: stature, sitting height, hand length.
- **Dynamic data** 动态数据 are measured during movement: reach, range of joint movement.

Data must suit the **target population**: dimensions differ with age, sex, nationality and generation, and data should state how they were measured (posture, clothing, shoes).

Percentiles



Designing from the 5th to the 95th percentile accommodates 90 % of users

Most body dimensions follow a **normal distribution** 正态分布. A **percentile** 百分位数 is the value below which a given percentage of the population falls: 5 % of people are shorter than the 5th percentile stature. Designers often aim to accommodate the 5th to 95th percentile range, which includes 90 % of the population.

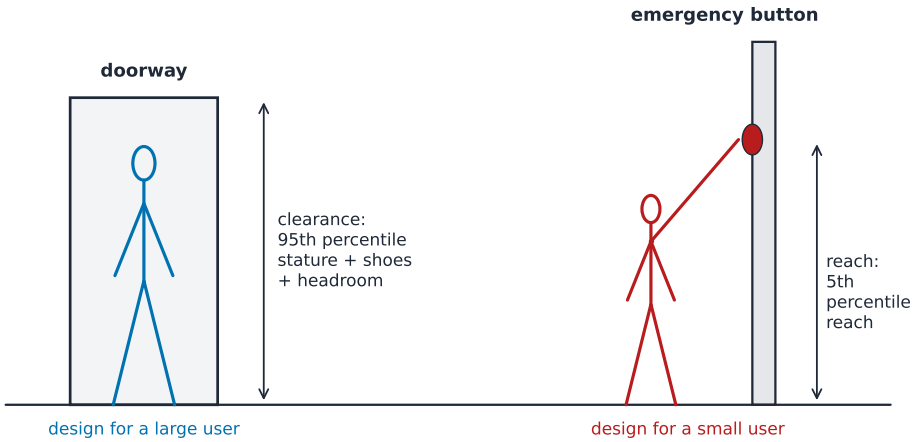
For a normal distribution, the 5th and 95th percentiles lie 1.645 standard deviations below and above the mean.

> **Worked example.** An adult population has mean stature 1700 mm and standard deviation 90 mm.

- 95th percentile $= 1700 + 1.645 \times 90 \approx 1848$ mm.
- 5th percentile $= 1700 - 1.645 \times 90 \approx 1552$ mm.

Designing for the **mean** alone is a common mistake: a door 1700 mm high would hit the heads of half the population.

Reach, clearance and adjustability



Clearance uses a large user; reach uses a small user

Design problem	Which user limits it	Percentile	Example
Clearance 间隙 (space to pass through or fit in)	The largest users	95th (or 99th for safety)	Door height, legroom, seat width
Reach 可达范围	The smallest users	5th (or 1st)	Shelf height, emergency stop button, light switch
Fit to body	The whole range	5th to 95th	Chair seat height, helmet size

> **Worked example.** For the population above:

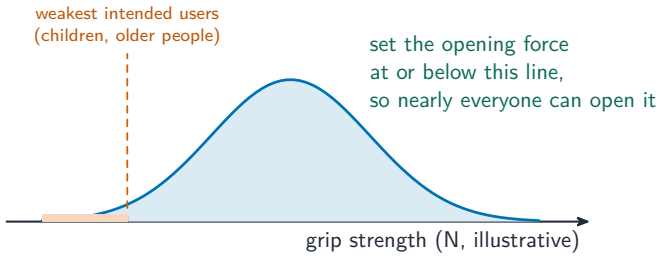
- Doorway: 95th percentile stature 1848 mm + 30 mm for shoes + about 100 mm headroom $\approx$ 1980 mm, so a standard 2000 mm door is suitable.
- Emergency stop button: the population's standing vertical reach has mean 1950 mm and SD 100 mm. 5th percentile reach $= 1950 - 1.645 \times 100 \approx 1786$ mm. Placing the button below about 1780 mm lets 95 % of standing adults reach it; lower still is needed for wheelchair users and children.

When one size cannot fit the range, designers use **adjustability** (an adjustable office chair or car seat), **a range of sizes** (shoes, helmets, clothing), or design for the **extremes** (both tall and short users can use a lever placed at a middle height).

Percentiles are not additive: a person with a 95th percentile stature does not have 95th percentile arms and legs, so there is no "95th percentile person". Each dimension must be chosen separately for the task.

Physiological factors

- **Comfort and fatigue**: poor posture, repetitive movements and holding loads cause discomfort, fatigue and injury, such as repetitive strain injury from keyboards.
- **Strength**: the force needed to open, turn or lift must suit the weakest intended users, such as children or older people opening a jar.
- **Biomechanics**: handle diameters, grip shapes and the angle of tools reduce stress on joints.



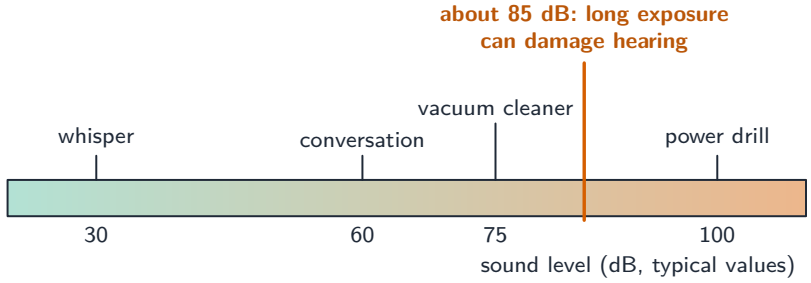
Size the force for the weakest intended user

Psychological factors

People respond to their surroundings and to a product's sensory qualities:

Factor	Effect	Example
Light	Too little causes errors and eye strain; glare causes discomfort	Offices about 300 to 500 lux; task lighting for detailed work
Sound	Noise distracts and long exposure above about 85 dB can damage hearing	Quiet appliances; warning sounds that stand out
Colour	Colours carry meanings (red for danger or stop) and affect mood	Red emergency buttons; calm colours in hospitals
Texture and temperature	Affect comfort and perceived quality	Soft-touch grips; cold metal handles feel unpleasant
Smell and taste	Signal freshness or danger	Gas suppliers add a smell to natural gas

These responses vary between people and cultures, so they need testing with real users.



Above about 85 dB, long exposure harms hearing

Cognitive ergonomics

Designing for the mind

Cognitive ergonomics 认知工效学 is about how people perceive, understand, remember and decide when using products, especially interfaces. Don Norman, in *The Design of Everyday Things*, described key principles:



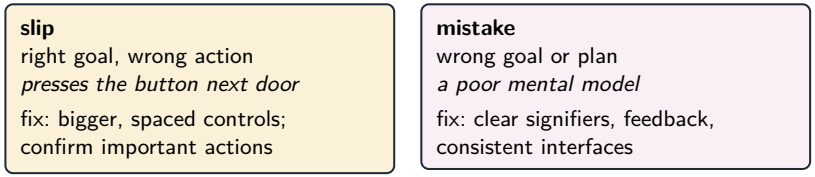
Affordance and signifier

Principle	Meaning	Good example	Bad example
Affordance 示能	What actions a design allows	A flat plate on a door affords pushing	A pull handle on a push door
Signifier 意符	A signal showing where and how to act	An arrow or a "push" label	Hidden touch controls
Mapping 映射	The link between controls and their effects	Cooker knobs arranged like the burners	Four knobs in a row for a square of burners
Feedback 反馈	Showing that an action has worked	A click, a light or a progress bar	A button that does nothing visible
Constraints 约束	Limiting possible actions to prevent errors	A keyed connector that fits only in the correct orientation	A plug that can be inserted wrongly
Consistency	Similar things work in similar ways	Standard icons for save and delete	Different layouts in every screen

A **mental model** 心智模型 is a user's understanding of how something works. Good designs match the user's mental model, so people can predict what will happen. A door that people regularly push when they should pull (a "Norman door") is a design failure, not a user failure.

Human error

- A **slip** is when someone intends the right action but does something else, such as pressing the button next to the right one. Slips are reduced by larger, well-spaced controls and confirmation for important actions.
- A **mistake** is when someone has the wrong goal or plan, often because of a poor mental model. Mistakes are reduced by clear signifiers, feedback and simple, consistent interfaces.



Slip or mistake

Information overload 信息过载 happens when too much information is presented at once. Miller's traditional estimate is about 7 ± 2 chunks in short-term recall; capacity depends on the task and how information is grouped, so good interfaces group information, show only what is needed and use recognition (menus, icons) rather than recall. Each extra choice also makes decisions slower (Hick's law).

Practice

1. Describe the four stages of the design cycle and explain why design is iterative.
2. Distinguish between divergent and convergent thinking, with an example of each in designing a school bag.
3. Rewrite these specification points so they can be tested: "light", "easy to clean", "suitable for children".
4. A shelf bracket carries a normal load of 150 N. Using a factor of safety of 3, calculate the test load, and explain why a factor of safety is used.
5. Compare observation and questionnaires as methods of user research for a new bus ticket machine.
6. Explain why designers involve "extreme users", using the OXO peeler as an example.
7. Outline four principles of inclusive design, with an example of each.
8. Distinguish between static and dynamic anthropometric data, with an example of each.
9. A population has mean sitting height 900 mm and SD 40 mm. Calculate the 5th and 95th percentiles.
10. Explain which percentile you would use for: the height of a car roof above the seat, the distance to a car's handbrake, the width of a cinema seat.
11. Explain why there is no "95th percentile person".
12. Suggest three ways designers can accommodate a wide range of body sizes, with an example of each.
13. Explain how lighting and noise could be designed in a school workshop.
14. Explain affordance, mapping and feedback, using the controls of a microwave oven.
15. A user repeatedly pulls a door that must be pushed. Explain why this is a design problem and how to fix it.
16. Distinguish between a slip and a mistake, and suggest how a design could reduce each.
17. Evaluate designing a product for the 50th percentile user.

Answers.

1. Inquiring and analysing (understand the problem, users and context; write a brief); developing ideas (specification, many ideas, choose one); creating the solution (models and prototypes); evaluating (test against the specification with users). It is iterative because testing reveals new needs and problems, so designers return to earlier stages and improve the design several times.
2. Divergent thinking opens up many possibilities without judging, such as sketching 30 different ways of carrying books. Convergent thinking narrows down, such as using the specification to choose the best two ideas to develop.
3. Light: "mass below 800 g when empty". Easy to clean: "all surfaces can be wiped clean with a damp cloth in under 1 minute; no gaps narrower than 5 mm". Suitable for children: "usable by children aged 6 to 10: grip diameter 25 to 30 mm; opening force below 10 N; no parts small enough to swallow".
4. Test load $= 150 \times 3 = 450$ N. A factor of safety allows for misuse, overloading, variation in materials and manufacture, wear and uncertainty in loads, so the product does not fail in use.
5. Observation shows real behaviour and problems users may not mention (confusion over buttons, queues) but takes time and people may act differently when watched. Questionnaires reach many users quickly and give numbers to compare, but give little depth and rely on honest, accurate answers; they cannot show problems users do not notice.
6. Extreme users (such as people with arthritis) find the task hardest, so they reveal problems that average users tolerate. Solving their problems usually improves the product for everyone: the OXO peeler's large, soft handle helps people with arthritis and is more comfortable for all.
7. Equitable use: a dropped kerb for wheelchairs and pushchairs. Flexibility in use: scissors usable left- or right-handed. Simple and intuitive: icons instead of text instructions. Perceptible information: a pedestrian crossing that beeps as well as showing a green figure. (Also tolerance for error, low physical effort, size and space.)

8. Static data are measured in fixed postures, such as stature or hand width. Dynamic data are measured during movement, such as arm reach or the range of movement of the wrist.
9. 5th $= 900 - 1.645 \times 40 \approx 834$ mm; 95th $= 900 + 1.645 \times 40 \approx 966$ mm.
10. Car roof: clearance, so 95th (or higher) percentile sitting height. Handbrake: reach, so 5th percentile arm reach. Cinema seat width: clearance, so 95th percentile hip breadth.
11. Body dimensions are not perfectly correlated: a person with 95th percentile stature may have average arms or narrow hips. Each dimension must be chosen separately for the task, so designing for a "95th percentile person" in every dimension would fit almost no one.
12. Adjustability: an office chair with adjustable seat height. A range of sizes: bicycle helmets in S, M and L. Design for the extremes: a lever placed where short users can reach and tall users can still use it.
13. Lighting: good general light (about 500 lux) plus task lights at machines, without glare, so users see clearly and make fewer errors. Noise: quieter machines, sound-absorbing panels, separate noisy machines, and hearing protection where noise is high, because long exposure above about 85 dB can damage hearing and noise distracts.
14. Affordance: buttons that look pressable and a door handle that looks pullable. Mapping: the time controls arranged in order (minutes, seconds) and a dial turned clockwise to increase time. Feedback: a beep when a button is pressed, a display of the time and a light inside when it runs.
15. The door's design gives the wrong signal: a pull handle affords pulling, so users' mental model says "pull". The design does not match the action. Fix: replace the handle on the push side with a flat push plate, and add a clear signifier such as "push".
16. A slip: the right intention but the wrong action, such as pressing the wrong button; reduce it with larger, well-spaced controls and confirmation for important actions. A mistake: the wrong goal or plan from a poor mental model; reduce it with clear signifiers, feedback and simple, consistent controls.
17. A 50th percentile design suits the middle of the population only: for clearance, half the users are too big; for reach, half cannot reach. It may be acceptable where dimensions do not matter much or where the product is adjustable around the mean, but usually designers should use the 5th or 95th percentile, adjustability or a range of sizes. Designing for the average fits almost no one well.

Exam tips

- Write specification points as measurable requirements with numbers and units.
- Use 95th percentile (large users) for clearance and 5th percentile (small users) for reach, and explain why.
- Show percentile calculations: mean $\pm$ 1.645 $\times$ standard deviation.
- Name the ergonomic factor (physiological, psychological or cognitive) and give a product example.
- Use Norman's terms (affordance, signifier, mapping, feedback, constraints) precisely.
- When evaluating a research method, give one strength and one limitation in the context of the product.

Design in practice

International Baccalaureate · IB Diploma · Design Technology · SL

Scope and prerequisites

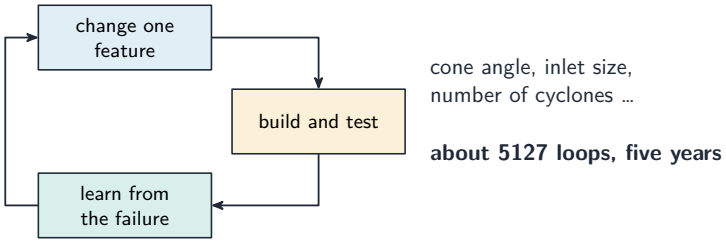
This handout teaches Design in practice for the course first assessed in 2027: how designers use models and prototypes to test ideas, how materials are described by their properties and chosen for a product, how products are made by wasting, forming, additive and joining processes, how the scale of production changes cost and method, and how tolerances, quality control and testing make sure each product works. It is written for both SL and HL students.

Prerequisites: unit 1 (Design in theory), especially the design cycle and measurable specifications; rearranging a formula; percentages and units such as newtons and millimetres from mathematics and physics.

Modelling and prototyping

5127 prototypes

In 1978 James Dyson was annoyed that his vacuum cleaner lost suction as its bag filled with dust. He had seen a sawmill use a cyclone, a spinning column of air, to separate sawdust from air, and wondered whether a small cyclone could replace the bag. Over about five years he built 5127 prototypes in his shed, changing one feature at a time: the cone angle, the inlet size, the number of cyclones. Most failed, but each failure taught him something. The idea that "design is iteration" could not have a clearer example: the final product came from thousands of small tests, not from one perfect drawing.



Design is iteration

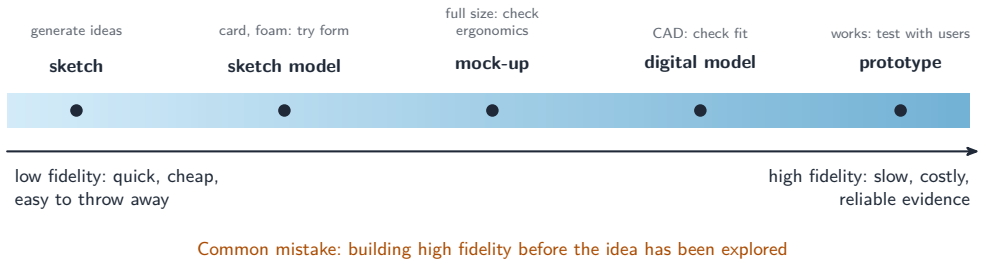
Why designers model

A **model** 模型 represents selected features of a design so that designers can explore, communicate or test an idea before committing time and money to the final product. Every model includes some features and leaves others out, so the first question about any model is: what is it for?

- **Communicate**: show clients, users or a team what the idea looks like.
- **Explore**: try out shape, size and arrangement quickly.
- **Test**: check function, strength, fit or usability against the specification.

Kinds of model

Model	What it is	Typical use
Sketch and drawing	Freehand or technical drawings, 2D or 3D	Generating and communicating ideas quickly
Sketch model	Quick 3D model in card, foam or tape	Exploring form, size and arrangement
Mock-up 实物模型	Full-size model of the outside, often non-working	Checking ergonomics and appearance
Scale model 比例模型	Accurate model larger or smaller than real life	Buildings, vehicles, products too big or small to make full size
Digital model	3D computer model	Visualising, checking fit, preparing for manufacture
Prototype 原型	A working or partly working version of the product	Testing function and use with real users



Fidelity rises from sketch to prototype; build high fidelity only once the idea has been explored

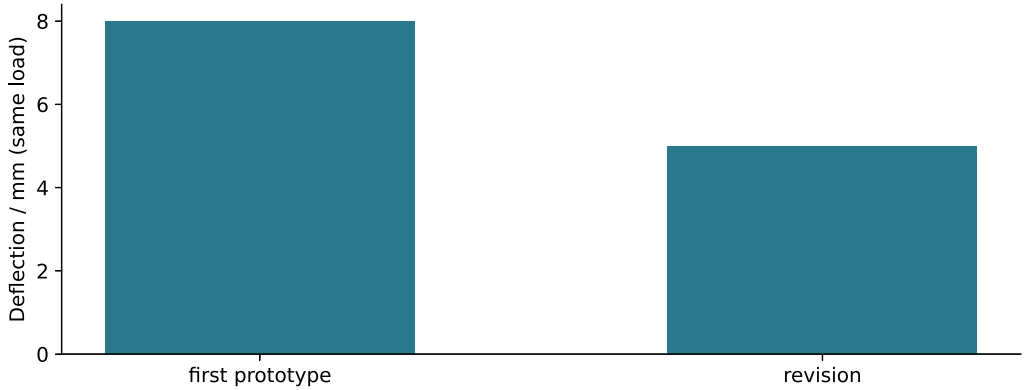
Fidelity 保真度 describes how closely a model matches the final product. A **low-fidelity** model (paper, card, foam) is quick and cheap, so designers can make many and are happy to change or throw them away; it suits early ideas. A **high-fidelity** model looks and works almost like the final product; it is slow and expensive but gives more reliable evidence for user testing and manufacture. A common mistake is to build high-fidelity models too early, before the idea has been explored.

Prototypes

Prototypes are made for different purposes:

- A **proof of concept** 概念验证 tests whether the main principle works at all (Dyson's first cyclone made of cardboard and tape).
- A **looks-like** prototype shows the final appearance but may not work.
- A **works-like** prototype works but may look rough.
- A **user-testing** prototype is good enough for users to try in realistic conditions.

Testing a prototype produces evidence that leads to changes. This is **iteration** 迭代: designers revise the design based on evidence, and test the revision against the same success criteria.



Deflection falls from 8 mm to 5 mm under the same load: a 3 mm, 37.5 % reduction

A shelf prototype deflects (bends) 8 mm under a test load. The revision, with a deeper section, deflects 5 mm under the same load, at the same span and in the same conditions.

$$\text{percentage reduction} = \frac{8-5}{8} \times 100 = 37.5\ \%$$

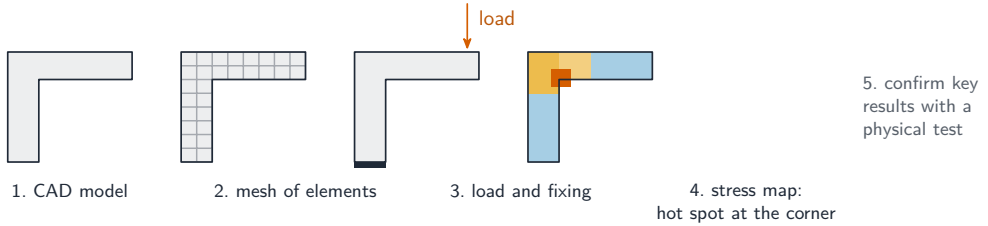
The test supports the claim that the revision is stiffer. It does not prove the shelf is strong enough or will last: deflection, strength and fatigue are different properties, and the comparison is fair only if one thing changed.

Computer modelling

Computer-aided design 计算机辅助设计 (CAD) software builds accurate 2D drawings and 3D models.

- **Advantages:** easy to edit and copy; precise dimensions; parts can be checked for fit before anything is made; realistic renderings for clients; files can be shared worldwide and sent straight to machines.
- **Limitations:** software and training cost; a screen cannot show how a product feels in the hand; it is easy to make something that looks perfect but cannot be manufactured.

Virtual prototyping 虚拟原型 tests a design in the computer. In **finite element analysis** 有限元分析 (FEA), the software divides a part into thousands of small elements and calculates the stress in each under a load, showing where the part might bend or break. **Simulation** 仿真 can also model air flow, heat or the motion of moving parts. Virtual tests save materials and time, but they are only as good as the model and the data put into it, so important results are still checked with physical tests.



FEA finds the hot spot before anything is made

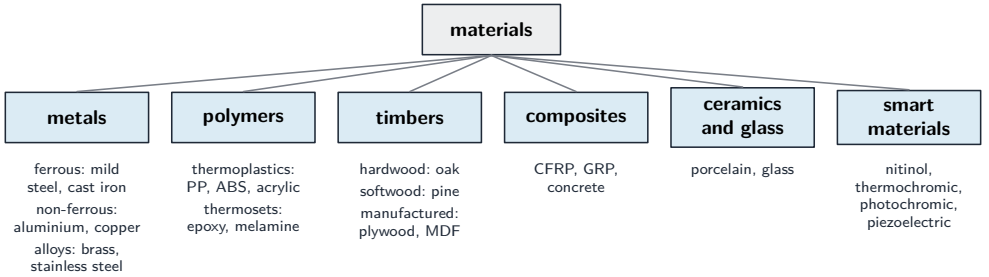
Materials and their properties

Material groups

Group	Examples	Typical properties
Metals: ferrous (contain iron)	Mild steel, stainless steel, cast iron	Strong, stiff, ductile; most rust unless protected
Metals: non-ferrous	Aluminium, copper, brass	Lighter or better conductors; resist corrosion
Polymers: **thermoplastics** 热塑性塑料	Polypropylene, ABS, acrylic	Soften when heated and can be reshaped and recycled
Polymers: **thermosetting polymers** 热固性塑料	Epoxy resin, melamine	Set permanently by curing; many resist heat; hard to recycle
Timbers	Oak (hardwood), pine (softwood), plywood and MDF (manufactured boards)	Renewable, good strength for their weight, vary with grain
Composites 复合材料	Carbon-fibre reinforced polymer, glass-reinforced plastic, concrete	Two or more materials combined to get better properties
Ceramics and glass	Porcelain, glass	Hard, heat resistant, brittle



Carbon-fibre weave: a composite, stiff strong fibres held in a resin matrix



The main material groups and examples of each

An **alloy** 合金 is a mixture of a metal with other elements to improve its properties: brass is copper and zinc; stainless steel is steel with chromium, which forms a protective oxide layer and improves corrosion resistance; it can still corrode.

Smart materials 智能材料 change a property in response to a change in their surroundings, and change back:

- **Shape memory alloys** such as nitinol return to a set shape when heated (glasses frames, medical stents).
- **Thermochromic** pigments change colour with temperature (baby spoons, mugs).
- **Photochromic** materials darken in bright light (sunglasses lenses).
- **Piezoelectric** materials produce a voltage when squeezed, or move when a voltage is applied (gas lighters, buzzers).

Physical and mechanical properties

Physical properties describe what a material is like: **density** 密度 (mass per unit volume), thermal conductivity, electrical conductivity, melting point and appearance.

Mechanical properties describe how a material reacts to forces:

Property	Meaning	Example
Tensile strength 抗拉强度	The maximum engineering stress reached in a tensile test	Steel cable
Stiffness 刚度	Resistance to elastic bending or stretching	Steel beam bends less than a polymer beam
Hardness 硬度	Resistance to scratching and wear	Ceramic tiles, tool steel
Toughness 韧性	Ability to absorb energy without breaking (resisting cracks)	Polycarbonate safety glasses
Ductility 延展性	Can be stretched into wire without breaking	Copper

Property	Meaning	Example
Brittleness 脆性	Breaks suddenly with little deformation	Glass, cast iron
Elasticity 弹性	Returns to its original shape when the force is removed	Rubber band
Plasticity 塑性	Keeps its new shape after the force is removed	Clay, hot metal

Strength and stiffness are often confused. Strength is about when a material **breaks**; stiffness is about how much it **bends** before then. A glass rod is stiff but not tough; a nylon rope is strong but not stiff.

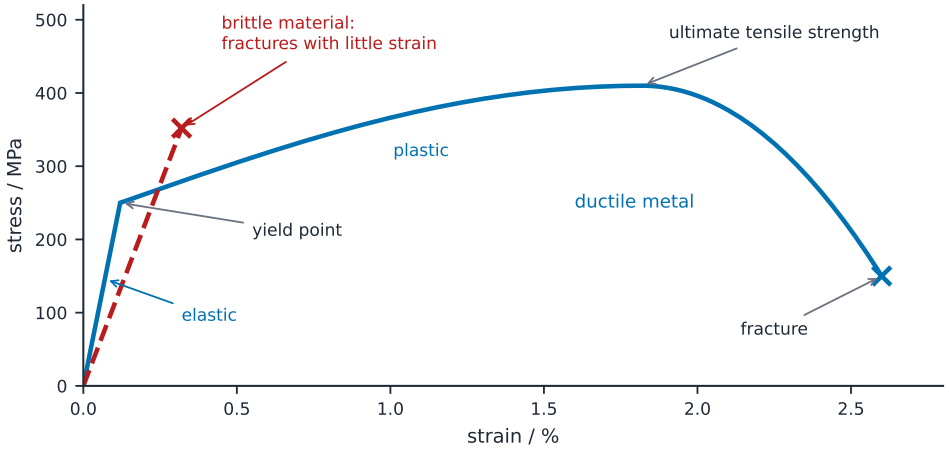
Stress, strain and stiffness

When a force pulls on a bar, the **stress** 应力 is the force per unit area of cross-section, and the **strain** 应变 is the extension divided by the original length:

$$\text{stress} = \frac{F}{A} \qquad \text{strain} = \frac{\Delta l}{l}$$

Stress in N/mm^2 is the same as megapascals (MPa). Strain has no units. Within the linear elastic region, stress divided by strain is constant: this is **Young's modulus** 杨氏模量, a measure of stiffness.

$$E = \frac{\text{stress}}{\text{strain}}$$



Stress-strain graphs for a ductile metal and a brittle material

On the graph, the steep straight part is the **elastic** region: remove the force and the material returns to its shape. After the **yield point** the material deforms plastically and permanently. The highest point is the **ultimate tensile strength**. A ductile metal stretches a long way before it fractures; a brittle material breaks soon after its elastic region, with almost no warning.

> **Worked example.** A steel tie rod has cross-sectional area 50 mm^2 and length 500 mm. A load of 10 000 N stretches it by 0.5 mm.

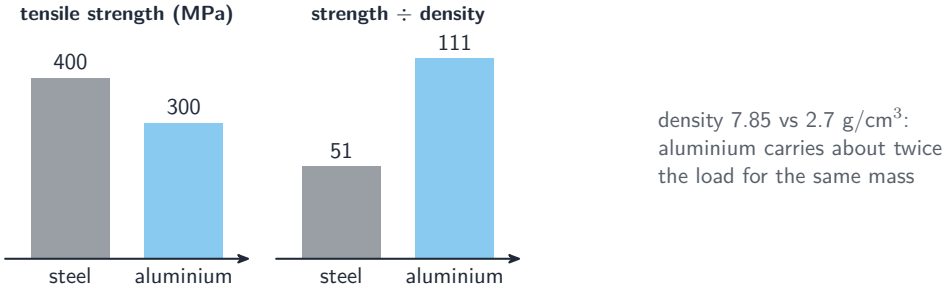
- Stress $= 10\,000 \div 50 = 200\ \text{N/mm}^2 = 200$ MPa.
- Strain $= 0.5 \div 500 = 0.001$.
- Young's modulus $= 200 \div 0.001 = 200\,000$ MPa $= 200$ GPa, typical of steel.
- If the steel yields at 250 MPa, the factor of safety against yielding is $250 \div 200 = 1.25$, which is low for a product that people depend on.

Choosing a material

Designers rarely choose a material for one property. They balance:

- **Function**: the mechanical and physical properties the product needs.
- **Manufacture**: can it be made in the shape needed, at the quantity needed?
- **Cost and availability**: price per kilogram, stock forms (sheet, bar, tube, granules).
- **Aesthetics**: colour, texture, finish.
- **Environment**: energy to produce, recyclability, toxicity (unit 3).

When mass matters, compare **strength-to-weight ratio** 强度重量比: strength divided by density. An aluminium alloy with tensile strength 300 MPa and density 2.7 g/cm^3 has $300 \div 2.7 \approx 111$; a steel with tensile strength 400 MPa and density 7.85 g/cm^3 has $400 \div 7.85 \approx 51$. The steel is stronger, but the aluminium carries about twice as much load for the same mass, which is why it is used in bicycle frames and aircraft.



Stronger is not the same as stronger per kilogram

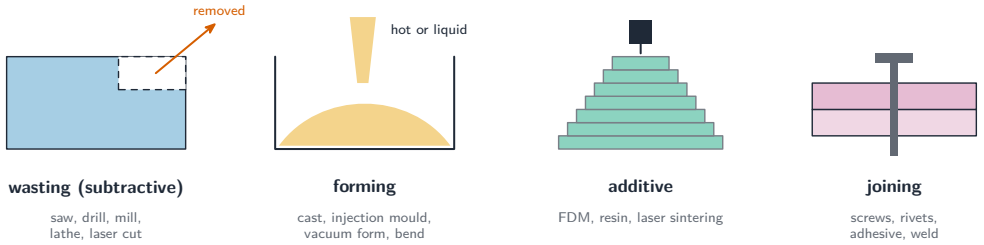
Manufacturing processes

Four families of process

Family	How it works	Examples
Wasting 切削加工 (subtractive)	Material is removed from a larger piece	Sawing, drilling, milling, turning on a lathe, laser cutting
Forming 成型	Material is shaped without removing it, often when hot or liquid	Casting, **injection moulding** 注塑成型, **vacuum forming** 真空成型, extrusion, bending, forging
Additive manufacturing 增材制造	The part is built up layer by layer from a digital model	Fused deposition modelling (FDM) printing, resin printing, laser sintering of powder
Joining	Separate parts are fixed together	Screws, bolts and rivets; adhesives; welding, brazing and soldering; joints in wood



An injection-moulding machine: molten plastic is forced into a steel mould, so each extra part costs very little once the mould is paid for



Remove, reshape, build up or fix together: the four families of manufacturing process

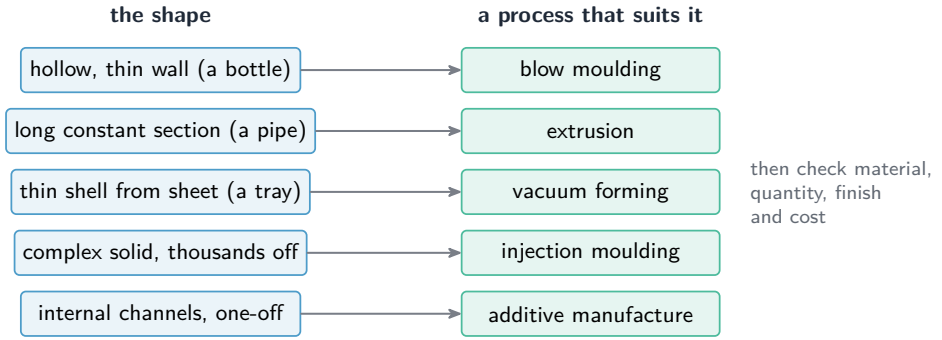
Computer-aided manufacture 计算机辅助制造 (CAM) uses the CAD model to control machines such as **computer numerical control** 计算机数控 (CNC) routers, lathes, laser cutters and 3D printers. CAD/CAM gives accurate, repeatable parts and makes it easy to change a design, but machines are expensive and still need skilled set-up.

Joining methods are **permanent** (welding, rivets, adhesives) or **temporary** (screws, bolts, clips). Temporary joints make repair and recycling easier.

Choosing a process

The right process depends on:

- the material (thermoplastics can be injection moulded and vacuum formed; thermosets cannot be remelted);
- the shape (hollow parts suit blow moulding; long constant sections suit extrusion; complex internal shapes suit additive manufacture);
- the quantity (a mould is worth making only for many parts);
- the accuracy and surface finish needed;
- the cost, waste and energy.



The shape narrows the process; the rest decides

Additive manufacturing usually needs no dedicated mould, though setup, supports

and finishing still cost money and can make shapes that are impossible to machine, so it suits prototypes, one-off parts and customised products such as dental aligners. But it is slow per part, so for large numbers forming processes become cheaper.

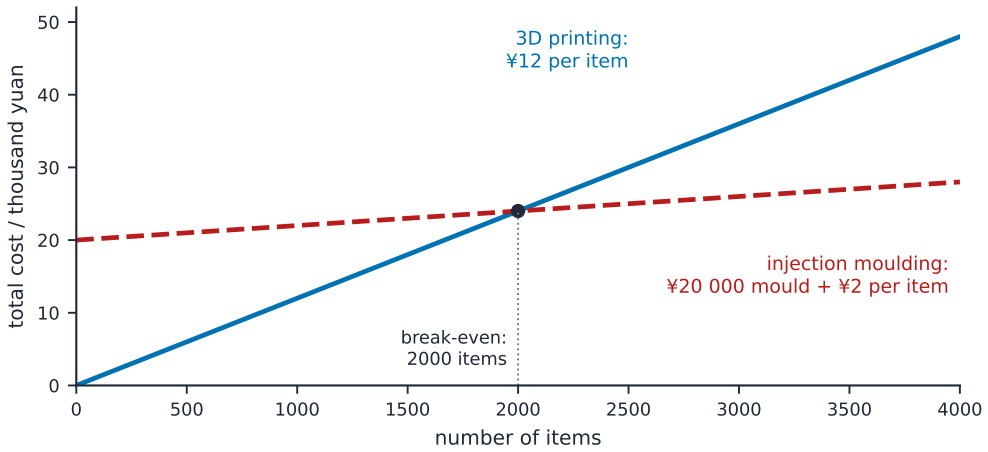
Scales of production

Scale	Description	Example
One-off production 单件生产	A single product made to order, by skilled workers	A wedding dress, a bridge, a prototype
Batch production 批量生产	A set number of identical products, then the line changes	Bread, school furniture, seasonal clothing
Mass production 大规模生产	Large numbers on an assembly line, often automated	Cars, phones, ballpoint pens
Continuous flow	Runs 24 hours a day without stopping	Oil refining, steel, paper



A car assembly line: mass production spreads tooling costs over many identical units, each worker or robot repeating one stage

As the scale increases, the cost per item falls because the fixed costs (tooling, moulds, set-up, machines) are shared between more items, and automation reduces labour per item. But the investment is large and the product is hard to change. **Mass customisation** 大规模定制 combines mass production with choice: buyers choose colours, sizes or features online, and flexible automated production makes their version.



Break-even between 3D printing and injection moulding

> **Worked example.** A phone stand can be 3D printed for ¥12 per item, or injection moulded for ¥2 per item after a ¥20 000 mould is made. At the break-even number of items, n, the total costs are equal:
>
> $$12n = 20\,000 + 2n \quad \Rightarrow \quad n = \frac{20\,000}{12 - 2} = 2000$$
>
> For fewer than 2000 stands, 3D printing is cheaper; for more, injection moulding is cheaper. For 10 000 stands, printing costs ¥120 000 but moulding costs ¥20 000 + ¥20 000 = ¥40 000.

Production systems

- **Automation** 自动化 uses machines and robots for repetitive work: consistent quality, fast, works around the clock, but expensive to set up and it changes the jobs people do.
- **Just-in-time** 准时制 (JIT) production orders parts to arrive only when needed, so little money is tied up in stock and storage space is small; but a single late delivery can stop the whole line.
- **Just-in-case** production keeps stock in reserve: safer when supplies are uncertain, but costly to store.
- **Lean production** 精益生产 aims to remove every kind of waste: overproduction, waiting, transport, extra processing, stock, movement and defects.

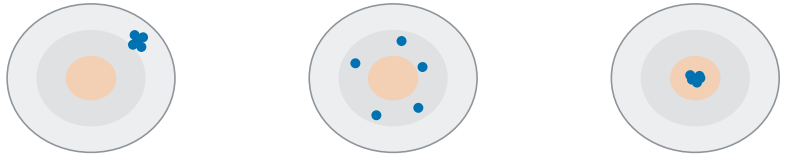
Tolerances, quality and testing

Why parts vary

No process makes every part exactly the same. Two parts can each look correct on a drawing yet fail to fit together if variation has not been allowed for. Designers therefore give each important dimension a **nominal size** 公称尺寸 and a **tolerance** 公差: the allowed range of variation. A hole drawn as 10.0 ± 0.2 mm is acceptable anywhere from 9.8 mm to 10.2 mm.



Vernier calipers measure a part to 0.02 mm: every batch varies a little, so a drawing states the tolerance it must stay inside



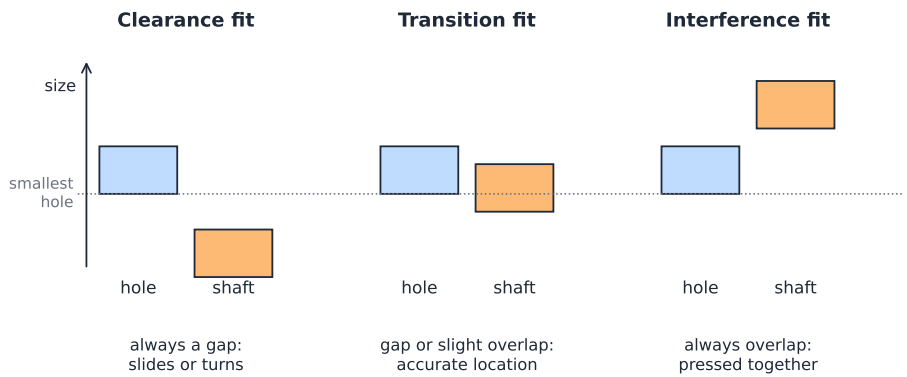
Accuracy and precision

Two words describe measurements and manufacture:

- **Accuracy** 准确度: how close a result is to the true or intended value.
- **Precision** 精密度: how close repeated results are to each other.

A machine can be precise but inaccurate: every part is 0.3 mm too big, by the same amount. That is easier to correct (adjust the setting) than a machine that is imprecise, whose parts are scattered.

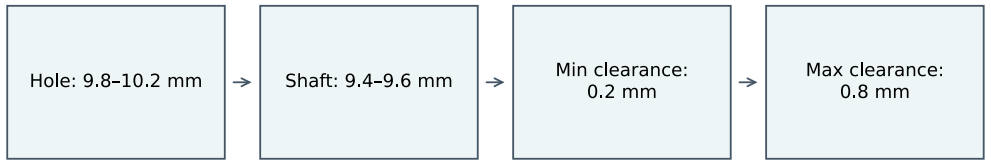
Fits



Clearance, transition and interference fits

When a shaft goes into a hole, the tolerances decide the **fit** 配合:

- **Clearance fit** 间隙配合: there is always a gap, so the shaft slides or turns (a wheel on an axle).
- **Transition fit** 过渡配合: there may be a small gap or a small overlap; used for accurate location.
- **Interference fit** 过盈配合: the shaft is always bigger than the hole, so the parts are pressed or shrunk together and held by friction (a bearing in a housing).



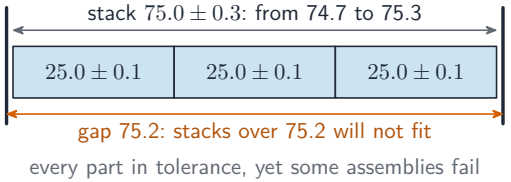
Minimum clearance = smallest hole − largest shaft = 0.2 mm; maximum = largest hole − smallest shaft = 0.8 mm

> **Worked example.** A hole is 10.0 ± 0.2 mm (9.8 to 10.2 mm). A shaft is 9.5 ± 0.1 mm (9.4 to 9.6 mm).

- Minimum **clearance** 间隙 = smallest hole − largest shaft = 9.8 − 9.6 = 0.2 mm.
- Maximum clearance = largest hole − smallest shaft = 10.2 − 9.4 = 0.8 mm.
- Both are positive, so every pair has a gap: a clearance fit. The calculation assumes perfectly round parts at one temperature; it says nothing about strength.

Tolerance stacking

When parts are placed end to end, their tolerances add up: this is **tolerance stacking** 公差累积. Three spacers, each 25.0 ± 0.1 mm, make a stack of 75.0 ± 0.3 mm, anywhere from 74.7 mm to 75.3 mm. If the stack must fit in a 75.2 mm gap, some assemblies will not fit, even though every single part is within its tolerance. Designers reduce stacking by using fewer parts, tighter tolerances on the critical parts, or adjustable parts.



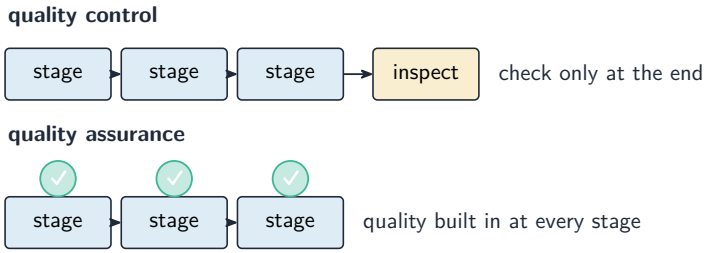
Tolerances add up

Tighter tolerances are not always better: they need slower, more precise processes and more inspection, and more parts are rejected, so cost rises. A good designer specifies tight tolerances only where the function needs them.

Quality control and quality assurance

- **Quality control** 质量控制 (QC) checks products during and after manufacture and rejects or reworks those that do not meet the specification: inspection, measurement, testing samples.
- **Quality assurance** 质量保证 (QA) is the whole system that prevents faults in the first place: trained staff, agreed procedures, calibrated equipment, checks on suppliers, records and audits. International standards such as ISO 9001 describe QA systems.

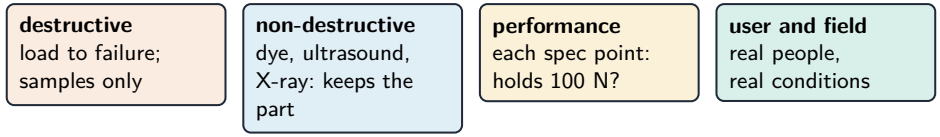
QC finds faults; QA aims to stop them happening. In mass production it is often impossible to check every part, so **sampling** checks a few from each batch, and the results are tracked over time to spot a process that is drifting before it makes bad parts.



QC inspects the output; QA builds quality into the process

Testing

- **Destructive testing** 破坏性试验 loads a sample until it fails, such as a tensile test. It gives the strength, but the sample is destroyed, so only samples can be tested.
- **Non-destructive testing** 无损检测 checks a part without damaging it: visual inspection, dye penetrant to show surface cracks, ultrasound or X-rays to find hidden flaws. It is used for safety-critical parts such as aircraft wings and welds.
- **Performance testing** checks the product against each point of its specification: does the shelf hold 100 N? Does the hinge survive 10 000 openings?
- **User trials** 用户试用 and **field trials** put prototypes or products in the hands of real users in real conditions.



Four kinds of test

In the workshop: Make low-risk models under school rules. Load tests and machines need teacher supervision, guards and eye protection. Record the material, dimensions, process and test method, and change one variable at a time so that the test is fair.

Practice

1. Explain why James Dyson's 5127 prototypes are an example of iteration.
2. Distinguish between a mock-up, a scale model and a prototype, with an example of each.
3. Explain why designers use low-fidelity models early in a project and high-fidelity models later.
4. Outline two advantages and two limitations of CAD compared with physical modelling.

5. A bracket deflects 12 mm. A revision deflects 9 mm under the same load and conditions. Calculate the percentage reduction and state one thing the result does not prove.
6. Distinguish between strength and stiffness, and between toughness and hardness.
7. Distinguish between thermoplastic and thermosetting polymers, and give one product made from each.
8. Name a smart material and describe one product use.
9. A wire of cross-sectional area 2 mm^2 and length 1500 mm carries 400 N and stretches 1.5 mm. Calculate the stress, the strain and Young's modulus.
10. Using the stress-strain graph, describe how a ductile metal and a brittle material behave as the load increases.
11. A titanium alloy has strength 900 MPa and density 4.5 g/cm^3. A steel has strength 500 MPa and density 7.8 g/cm^3. Compare their strength-to-weight ratios and suggest a product for the titanium alloy.
12. Describe one wasting, one forming and one additive process, with a suitable product for each.
13. Batch production of a chair needs a ¥9000 set of jigs and then ¥150 per chair. A one-off workshop charges ¥450 per chair. Find the number of chairs at which the costs are equal.
14. Compare one-off, batch and mass production in terms of cost per item, flexibility and the skill of workers.
15. Evaluate just-in-time production for a car manufacturer.
16. A hole is 12.0 to 12.4 mm and a shaft is 11.5 to 11.8 mm. Calculate the minimum and maximum clearance and name the type of fit.
17. Four plates, each 5.0 ± 0.05 mm thick, are stacked. Find the range of total thickness, and explain why this matters.
18. Distinguish between quality control and quality assurance, and between destructive and non-destructive testing.

Answers.

1. Each prototype tested one change (cone angle, inlet size, number of cyclones). The results showed what worked and what failed, and Dyson revised the design and tested again. The final design came from repeated cycles of testing, evidence and revision, which is iteration.
2. A mock-up is a full-size, usually non-working model of the outside, such as a foam model of a new kettle to check grip and appearance. A scale model is an accurate model at a different size, such as a 1:100 model of a building. A prototype is a working or partly working version, such as a working kettle tested by users.
3. Early on, the problem and ideas are still changing, so cheap, quick low-fidelity models let designers explore many ideas and throw them away without loss. Later, decisions need reliable evidence about appearance, function and use, which a suitable high-fidelity model can provide, and the extra cost is worth it once the design is nearly fixed.
4. Advantages: precise and easy to edit; parts checked for fit before making; renderings for clients; files sent straight to CAM machines. Limitations: cost of software and training; cannot show feel, weight or real ergonomics; a design can look perfect on screen but be impossible to manufacture.
5. Reduction $= (12 - 9) \div 12 \times 100 = 25\ \%$. It does not prove the bracket is strong enough, will survive repeated loading (fatigue) or is safe for all users; it shows only greater stiffness in that test.
6. Strength is the stress a material can take before it breaks; stiffness is its resistance to bending or stretching elastically. Toughness is the ability to absorb energy and resist cracks; hardness is resistance to scratching and wear. Glass is hard but not tough.
7. Thermoplastics soften when heated and can be reshaped and recycled, such as acrylic for a display stand or polypropylene for a lunch box. Thermosetting polymers set permanently by curing (with heat or a chemical hardener) and cannot be remelted, such as melamine for kitchen worktops or epoxy for adhesives.
8. For example, nitinol, a shape memory alloy: bendable glasses frames that return to shape, or a medical stent that expands in the body. (Thermochromic pigment on a baby spoon that changes colour when food is too hot is also correct.)
9. Stress $= 400 \div 2 = 200$ MPa. Strain $= 1.5 \div 1500 = 0.001$. Young's modulus $= 200 \div 0.001 = 200\,000$ MPa $= 200$ GPa.
10. The ductile metal first deforms elastically (straight, steep line), then yields and deforms plastically and permanently, reaches its ultimate tensile strength and fractures after a large strain, giving warning by stretching. The brittle material stays elastic and then fractures suddenly at a small strain with almost no plastic deformation.
11. Titanium: $900 \div 4.5 = 200$. Steel: $500 \div 7.8 \approx 64$. The titanium alloy is about three times better per unit mass, so it suits a product where mass matters, such as an aircraft part, a racing bicycle frame or a hip implant.
12. Wasting: turning a steel shaft on a lathe, or laser cutting acrylic parts for a phone stand. Forming: injection moulding a polypropylene bottle cap, or vacuum forming a polystyrene food tray. Additive: 3D printing a customised prosthetic hand or a prototype housing.
13. $9000 + 150n = 450n$, so $300n = 9000$ and $n = 30$ chairs. Above 30 chairs batch production is cheaper.
14. One-off: highest cost per item, very flexible, highly skilled workers. Batch: medium cost per item, can change product between batches, skilled and semi-skilled workers. Mass: lowest cost per item because fixed costs are shared, least flexible, many workers do simple repeated tasks or supervise machines.
15. JIT reduces money tied up in stock and storage space, and reveals quality problems

quickly, which suits a car factory with thousands of parts. But the line depends on every supplier delivering on time: a strike, accident or shortage of one part can stop production, as happened to car makers during the chip shortage. It works best with reliable, nearby suppliers and some safety stock for critical parts.

16. Minimum = 12.0 − 11.8 = 0.2 mm. Maximum = 12.4 − 11.5 = 0.9 mm. Both are positive, so it is a clearance fit.
17. Total = 20.0 ± 0.2 mm, from 19.8 mm to 20.2 mm. Tolerances stack, so even when every plate is within tolerance the assembly may not fit a space designed for 20.0 mm; designers must allow for the worst case.
18. QC inspects and tests products and rejects faulty ones; QA is the whole system (procedures, training, calibration, supplier checks) that prevents faults. Destructive testing breaks a sample to find properties such as strength, so only samples are tested; non-destructive testing (visual, dye penetrant, ultrasound, X-ray) checks a part without damage, so every critical part can be checked.

Exam tips

- Say what a model is **for** and what it leaves out before judging it.
- Keep strength, stiffness, toughness and hardness separate, and give an example material for each.
- Show stress, strain and Young's modulus calculations with units: $\mathrm{N/mm^2}$ is the same as MPa, and strain has no units.
- Justify a material or process with several factors: function, manufacture, quantity, cost and environment.
- For break-even, set the two total-cost expressions equal and solve; then say which method is cheaper on each side.
- For fits, minimum clearance = smallest hole − largest shaft; maximum = largest hole − smallest shaft. A negative value means interference.
- Remember QC finds faults, QA prevents them.

Design in context

International Baccalaureate · IB Diploma · Design Technology · SL

Scope and prerequisites

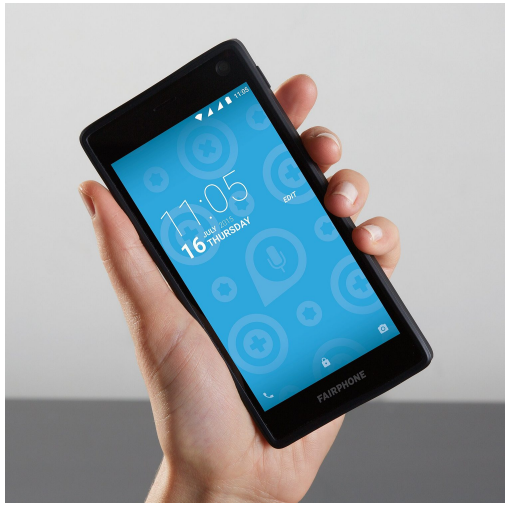
This handout teaches Design in context for the course first assessed in 2027: how designers judge the environmental, social and economic impact of a product over its whole life, how circular design keeps products and materials in use, how innovations reach and spread through a market, how cost, price and intellectual property shape commercial decisions, and how designers act responsibly towards users, workers and society. It is written for both SL and HL students.

Prerequisites: unit 1 (Design in theory) and unit 2 (Design in practice), especially materials, processes, scales of production and break-even; percentages and solving a linear equation from mathematics.

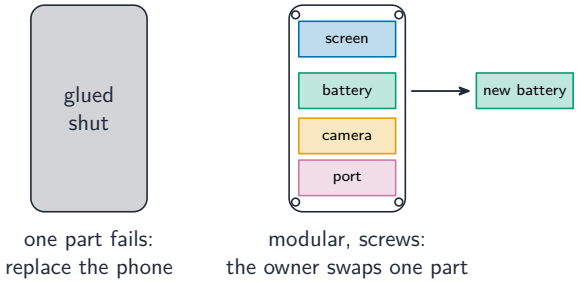
Sustainability and the life cycle

A phone you can open with a screwdriver

Most smartphones are glued together, so a broken screen or a tired battery often means buying a new phone. In 2013 a Dutch social enterprise, Fairphone, began selling a phone designed the other way round. Its later models are modular: the battery, screen, camera and charging port can each be replaced by the owner with a single small screwdriver, and spare parts are sold for years. The company also traces where its tin, tungsten and gold come from, to avoid minerals that pay for armed conflict, and pays extra to improve factory workers' wages. A Fairphone is not the cheapest or the fastest phone, but it shows how one product can be designed around its whole life, from the mine to the recycling plant.



A phone designed for repair: its back opens with a screwdriver, and the battery, camera and screen come out as separate modules



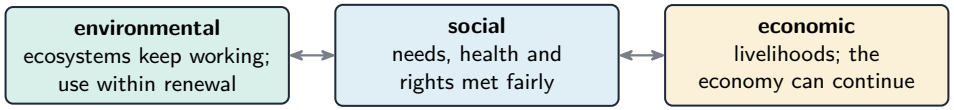
Glued or modular

Three kinds of sustainability

Sustainability 可持续性 means meeting the needs of people today without damaging the ability of future generations to meet theirs. Designers think about three linked kinds, often called the **triple bottom line** 三重底线:

- **Environmental**: resources, energy, pollution, waste and effects on ecosystems.
- **Social**: the health, safety, rights and wellbeing of users, workers and communities.
- **Economic**: a product must be affordable to buy and profitable to make, or it will not last.

A sustainable design balances all three. A product that is green but too expensive for anyone to buy, or cheap because workers are exploited, is not sustainable.



Brundtland (1987): meet present needs without compromising the ability of future generations to meet their own

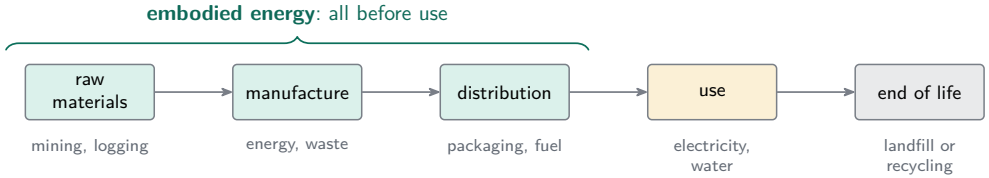
The triple bottom line

The product life cycle and its stages

Every product passes through five life-cycle stages, and each has an environmental impact:

Stage	Examples of impact
Raw materials	Mining, drilling, logging; energy and water use; habitat loss
Manufacture	Energy, waste, emissions, chemicals
Distribution	Packaging; fuel for ships, lorries and planes
Use	Electricity, fuel, water, consumables, repairs
End of life	Landfill, burning, reuse or recycling

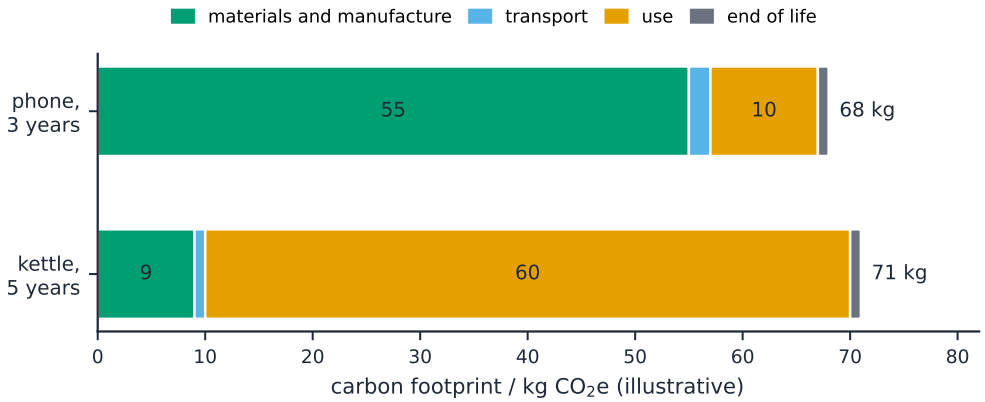
Embodied energy 内含能量 is the total energy used to extract, process, make and transport a product before it is used. A **carbon footprint** 碳足迹 is the total greenhouse gas emissions caused by a product, given in kilograms of carbon dioxide equivalent (kg CO_2e).



Embodied energy is spent before the product is used

Life cycle assessment

A **life cycle assessment** 生命周期评估 (LCA) measures the environmental impact of a product at every stage, from raw materials to disposal. It is often called **cradle to grave**. An LCA tells designers where the biggest impact is, so they know where design changes will help most.



Where the footprint comes from depends on the product (invented round numbers for teaching)

Worked example. Use the illustrative values above.

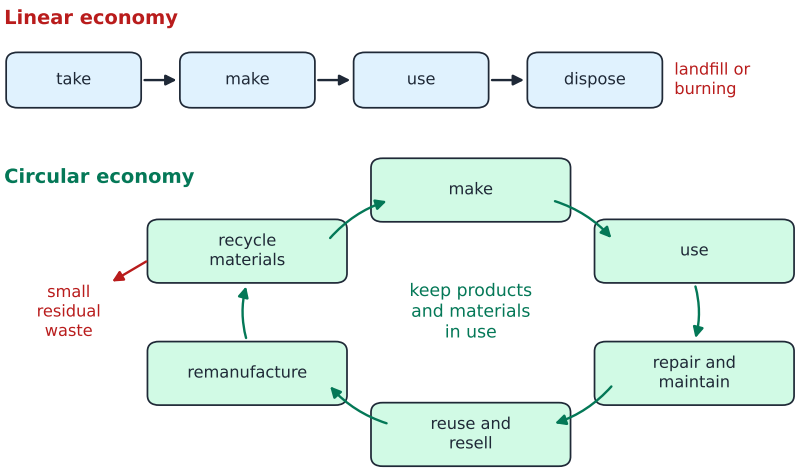
- Phone: materials and manufacture are $55 \div 68 \times 100 \approx 81$ % of the total. The best design choice is to make the phone last longer. If a replacement battery with a footprint of 5 kg CO_2e keeps it in use for 6 years instead of 3, the footprint per year falls from $68 \div 3 \approx 23$ kg to $(68 + 5 + 10) \div 6 \approx 14$ kg, because 3 extra years of use add about 10 kg.
- Kettle: use is $60 \div 71 \times 100 \approx 85$ %. The best choices reduce energy in use: better insulation, a clear water-level window so people boil only what they need, and an automatic switch-off.

The same "green" idea does not fit every product: recycled plastic in the kettle's case would change its total footprint very little.

LCAs have **limitations**: they need a lot of data, they depend on assumptions (how long is the product used? where does the electricity come from?), the boundaries of the study can be chosen to favour a product, and different impacts (carbon, water, toxicity) are hard to compare with each other.

Designing for a circular economy

Linear and circular



Linear and circular economies

In a **linear economy** 线性经济, materials flow one way: take, make, use, throw away. In a **circular economy** 循环经济, products and materials are kept in use for as long as possible at their highest value, and waste is designed out. **Cradle to cradle** 从摇篮到摇篮 design aims for every material to become the raw material for something new, either returned safely to nature or recycled into new products.

The inner loops of the circle save most: repairing a product keeps all its embodied energy, while recycling it saves only the material and needs energy to reprocess.

The six Rs

Designers use the **six Rs** as a checklist:



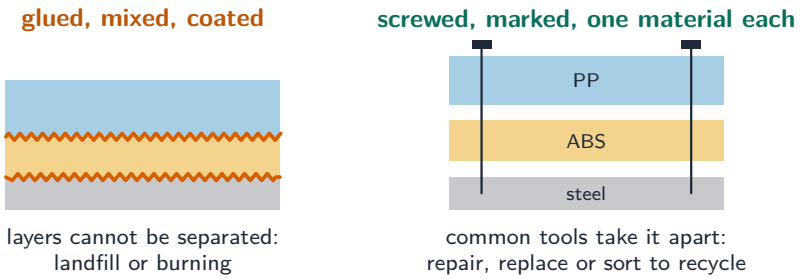
The six Rs

- **Rethink**: is there a better way to meet the need? A shared tool library instead of every home buying a drill that is used for only a few minutes a year.
- **Refuse**: do not use materials or features that harm the environment, such as unnecessary packaging.
- **Reduce**: use less material and energy, such as thinner walls with ribs for stiffness.
- **Reuse**: use the product again, for the same or a new purpose, such as refillable bottles.
- **Repair**: design products that can be mended, with available spare parts and instructions.
- **Recycle**: reprocess the materials into new products.

Design for disassembly and durability

Design for disassembly 可拆卸设计 makes products easy to take apart so that parts can be repaired, replaced or sorted for recycling:

- screws and clips instead of glue and welding;
- fewer, standard fasteners that need common tools;
- fewer different materials, and parts marked with their material (for example the plastic codes PP or ABS);
- no coatings or mixed materials that cannot be separated.



Screws and material codes make recycling possible

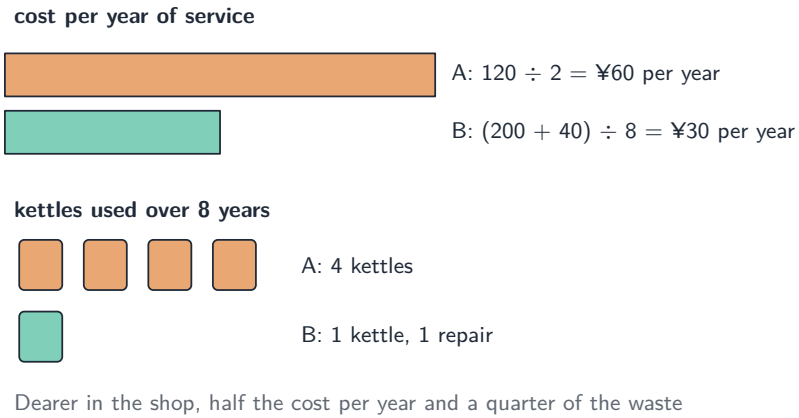
Durability 耐用性 means a product lasts a long time in use: tough materials, protected weak points, and a design that does not quickly look out of date.

Planned obsolescence

Planned obsolescence 计划性淘汰 is designing a product so that it becomes out of date or stops working sooner than it needs to, so that people buy again. From 1925 to the late 1930s the major light-bulb makers agreed to limit bulb life to about 1000 hours. There are several kinds:



Electronic waste: products replaced long before their materials wore out



The repairable kettle costs more in the shop but half as much per year, with a quarter of the waste

- **Functional** obsolescence: parts wear out or cannot be replaced (glued-in batteries).
- **Technological** obsolescence: new technology or software makes the product less useful (an old phone that no longer receives updates).
- **Style** or **perceived** obsolescence: fashion makes a working product look old.

Planned obsolescence can lower prices and drive innovation, but it wastes resources and money. Many countries now have **right to repair** 维修权 laws: makers of some appliances in the European Union must supply spare parts and repair information for up to 10 years.

> **Worked example: cost per year of service.** Kettle A costs ¥120 and lasts 2 years. Kettle B costs ¥200, has a replaceable switch and lasts 8 years with one ¥40 repair.

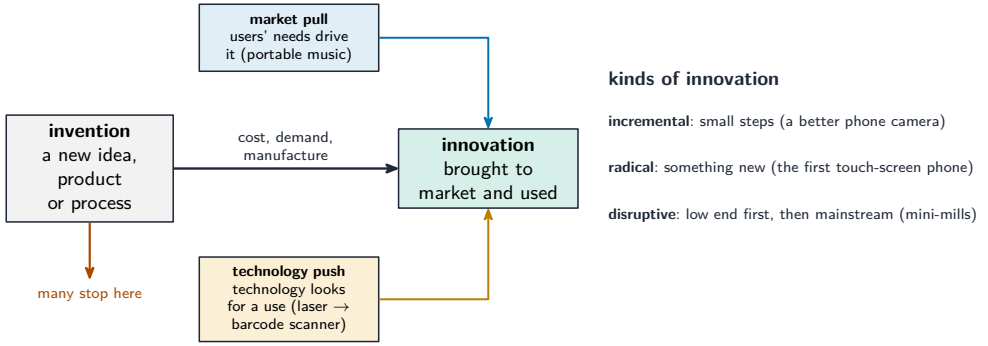
- A: 120 ÷ 2 = ¥60 per year.
- B: (200 + 40) ÷ 8 = ¥30 per year.

B costs more in the shop but half as much per year of use, and sends a quarter as many kettles to waste.

Innovation and markets

Invention and innovation

An **invention** 发明 is a new idea, product or process. An **innovation** 创新 is an invention that has been successfully brought to market and used. Many inventions never become innovations, because they are too expensive, there is no demand or they cannot be manufactured.

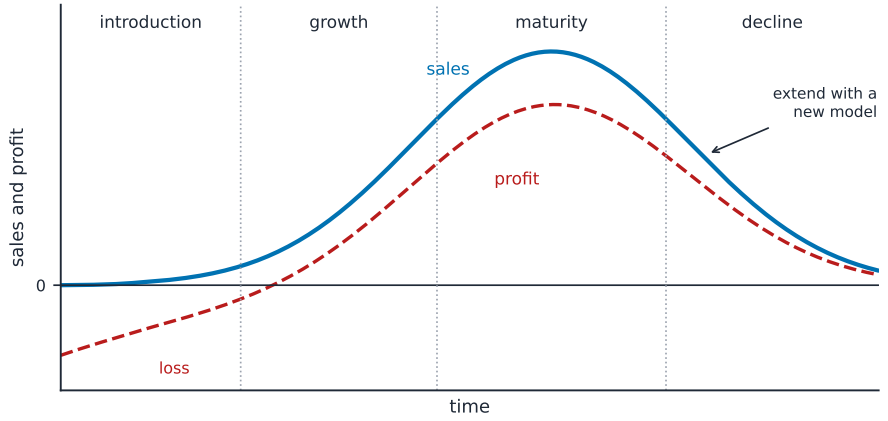


An invention becomes an innovation only when it reaches the market, pulled by users or pushed by technology

- **Incremental innovation** 渐进式创新 makes small improvements to an existing product: a slightly better camera in each new phone.
- **Radical innovation** 突破性创新 is a big change that creates something new: the first smartphone with a touch screen.
- **Disruptive innovation** 颠覆性创新 starts by serving overlooked low-end customers or new users, then improves and moves into the mainstream: steel mini-mills first made low-cost reinforcing bars, then moved into higher-value steel markets.

Innovations start in two ways. In **market pull** 市场拉动, users' needs drive the new product (people wanted to carry their music, so firms made portable players). In **technology push** 技术推动, a new technology leads to products looking for a use (lasers were invented before anyone used them in barcode scanners).

The product life cycle (sales)



Sales and profit through the product life cycle

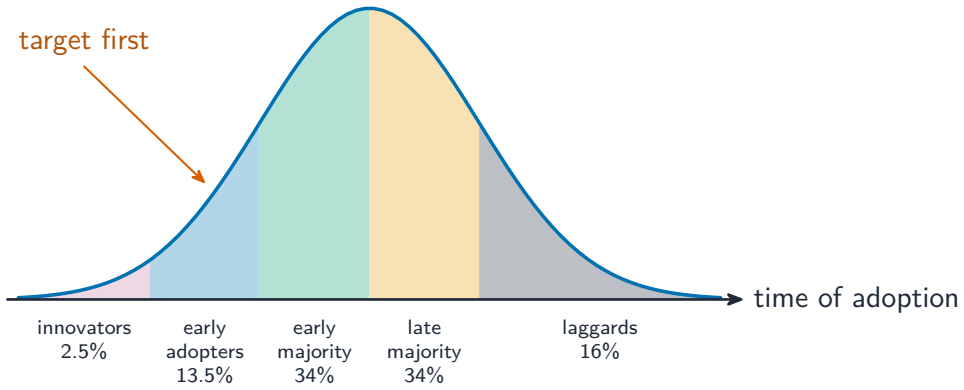
In a market, a product passes through four stages:

1. **Introduction**: low sales and a loss, because development and marketing costs are high.
2. **Growth**: sales rise quickly and the product becomes profitable.
3. **Maturity**: sales level off as the market fills and competitors copy the product.
4. **Decline**: sales fall as newer products replace it.

Firms use **extension strategies** to delay decline: a new model, new features, new colours, a lower price or new markets. Designers must understand that this "life cycle" is about sales, which is different from the environmental life cycle of a single product.

How innovations spread

The **diffusion of innovations** 创新扩散 describes how a new product spreads through a population. Rogers' model divides buyers into five groups:



Rogers' adopter categories

Group	Share	Typical behaviour
Innovators	2.5 %	Take risks, try new things first
Early adopters	13.5 %	Respected opinion leaders, influence others
Early majority	34 %	Adopt once a product is proven
Late majority	34 %	Sceptical, adopt when most others have
Laggards	16 %	Resist change, adopt last or never

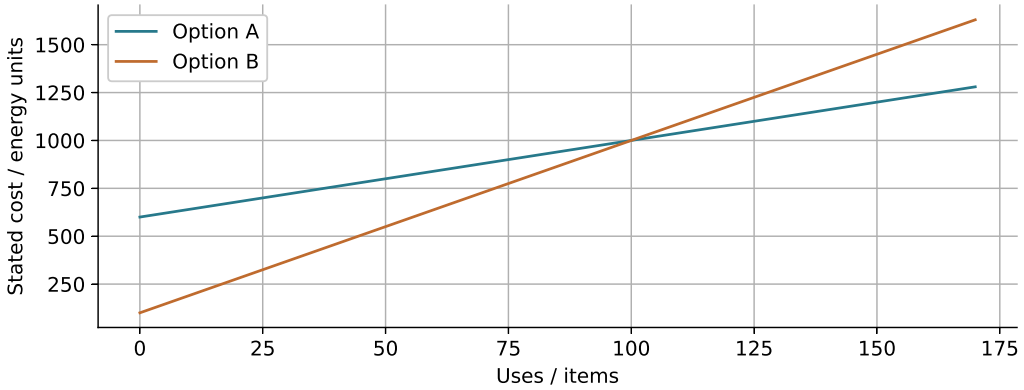
Designers and marketers target the early adopters first, because if they adopt, the majority often follows.

Commercial design: cost and intellectual property

Costs, price and break-even

- **Fixed costs** 固定成本 do not change with the number of items made: moulds, machines, rent, design work.
- **Variable costs** 可变成本 rise with each item made: materials, energy, packaging, labour per item.
- Total cost = fixed costs + variable cost per item × number of items.

Choosing between two production methods is a break-even problem.



Option A (600 + 4n) and option B (100 + 9n) cost the same at n = 100; above that A is cheaper

> **Worked example 1: choosing a method.** Method A costs 600 fixed units plus 4 per item; method B costs 100 plus 9 per item.

$$600 + 4n = 100 + 9n \quad \Rightarrow \quad 500 = 5n \quad \Rightarrow \quad n = 100$$

Below 100 items B is cheaper; above 100, A is cheaper. Quality, waste and end-of-life can still change the choice.

> **Worked example 2: break-even with a selling price.** A firm sells a lamp for ¥70. Fixed costs are ¥20 000 and the variable cost is ¥30 per lamp. Each lamp sold contributes 70 − 30 = ¥40 towards the fixed costs.

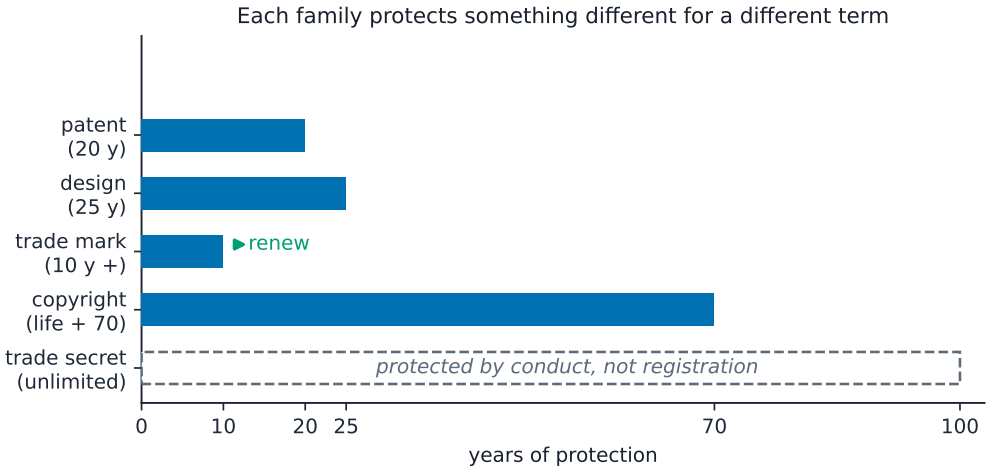
$$\text{break-even} = \frac{\text{fixed costs}}{\text{price} - \text{variable cost}} = \frac{20\,000}{70 - 30} = 500 \text{ lamps}$$

Selling 800 lamps gives a profit of $800 \times 40 - 20\,000 = ¥12\,000$.

Designers affect cost through material choice, the number of parts, the process and the tolerances specified. **Value engineering** 价值工程 looks at every part and asks whether its function could be achieved at lower cost, without lowering quality.

Intellectual property

Intellectual property 知识产权 (IP) gives legal rights over inventions, creative expression, designs and brand identifiers; an idea alone is not automatically protected. It rewards designers for the time and money they spend, and allows them to license their work to others.



Typical protection terms (they vary by country): each kind of IP protects something different for a different length of time

Protection	What it protects	Typical length
Patent 专利	A new invention: how it works	About 20 years, then anyone may use it
Registered design 外观设计	The appearance: shape, pattern, decoration	Up to about 25 years in many countries
Copyright 版权	Original drawings, writing, software, music	The creator's life plus 50 to 70 years; automatic
Trademark 商标	Names, logos and symbols that identify a brand	Renewable for as long as it is used

To get a patent, an invention must be new, involve an inventive step that is not obvious, and be capable of industrial application. Applying makes the invention public, so some firms keep a method secret instead. The opposite approach is **open source** 开源 design, where designs are shared under a licence allowing others to study, modify, make and sell them; Creative Commons licences that ban commercial use or derivatives are not open-source licences, and progress can be faster.

Ethics and responsibility

Responsibility to users and society

Designers make decisions that affect people who never meet them. An ethical designer considers:

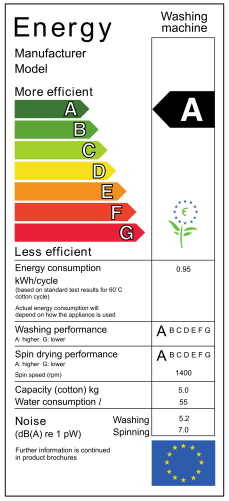
- **Safety**: products must meet safety standards and be safe in foreseeable misuse, not only normal use (unit 1, factor of safety).
- **Workers**: fair wages, safe factories, no child or forced labour anywhere in the supply chain.
- **Materials**: conflict-free minerals, no hazardous substances. The European Union's RoHS rules restrict lead, mercury and other hazardous substances in electronics, and its WEEE rules make producers responsible for collecting and recycling waste electronics.
- **Culture**: products, colours and symbols can mean different things in different cultures; designers should involve people from the culture rather than copy from it.
- **Honesty**: claims such as "eco-friendly" must be supported by evidence. Exaggerated environmental claims are called **greenwashing** 漂绿.

Appropriate technology

Appropriate technology 适用技术 is designed for the place and people who will use it: affordable, made from local materials, repairable with local skills and tools, and needing little energy. Examples include treadle pumps for small farms and rolling water containers that let one person move 50 litres of water at once instead of carrying it on their head. A product that works well in a city with spare parts and reliable electricity may fail completely where neither is available.

Eco-labels and standards

Eco-labels 生态标签 tell buyers that a product meets stated environmental standards, such as the EU Ecolabel, the Energy Star mark for efficient electronics, or the Forest Stewardship Council (FSC) label for timber from responsibly managed forests. Energy labels grade appliances from most to least efficient. Labels help buyers compare products, but each one covers only part of the life cycle: a recycled-content label says nothing about energy in use or the end of life.



An EU energy label: a standard scale lets buyers compare running costs before they choose

Practice

1. Explain what is meant by the triple bottom line, using the Fairphone as an example.
2. Outline the five stages of a product's life cycle and give one environmental impact of each.
3. Distinguish between embodied energy and a carbon footprint.
4. A bicycle has an illustrative footprint of 96 kg CO_2e from materials and manufacture, 4 from transport, 0 from use and 2 from end of life. Calculate the percentage from materials and manufacture, and suggest the most effective design strategy.
5. Explain two limitations of life cycle assessment.
6. Distinguish between a linear and a circular economy, and explain why repair saves more than recycling.
7. Apply the six Rs to the redesign of a school stapler.
8. Suggest four features of design for disassembly in a desk lamp.
9. Distinguish between functional, technological and style obsolescence, with an example of each.
10. Toaster A costs ¥90 and lasts 3 years. Toaster B costs ¥240, lasts 10 years and needs one ¥30 repair. Compare the cost per year.
11. Distinguish between invention and innovation, and between incremental and radical innovation.
12. Explain the difference between market pull and technology push, with an example of each.
13. Describe the four stages of the product life cycle (sales) and suggest two extension strategies for a games console.
14. Explain why designers target early adopters when launching a new product.
15. A method costs 900 fixed units plus 3 per item; another costs 300 plus 6 per item. Find the break-even quantity.
16. A backpack sells for ¥150. Fixed costs are ¥45 000 and the variable cost is ¥60 per bag. Calculate the break-even number of bags and the profit from selling 800 bags.
17. Identify the most suitable form of intellectual property for: a new hinge mechanism, the shape of a chair, a brand logo, a product manual.
18. Evaluate the use of open-source design for a low-cost prosthetic hand.
19. Explain what makes a technology "appropriate", using an example.
20. A company labels its plastic bottle "eco-friendly" because it contains 30 % recycled plastic. Evaluate this claim.

Answers.

1. The triple bottom line considers environmental, social and economic sustainability together. Environmental: Fairphone's repairable modules keep phones in use longer and reduce waste. Social: it traces minerals to avoid conflict sources and improves workers' wages. Economic: it must sell enough phones at a price buyers accept to stay in business.
2. Raw materials: mining uses energy and destroys habitats. Manufacture: energy use and emissions. Distribution: fuel for transport and packaging waste. Use: electricity or fuel consumed. End of life: landfill or pollution from burning, unless reused or recycled.
3. Embodied energy is the total energy used to make and deliver a product before it is used. A carbon footprint is the total greenhouse gas emissions over its life (or a stated part of it), in kg CO_2e. They are related but not the same: energy from renewable sources gives energy with little carbon.
4. Total $= 96 + 4 + 0 + 2 = 102$ kg. Materials and manufacture $= 96 \div 102 \times 100 \approx 94$ %. The most effective strategy is to make the bicycle last as long as possible: durable frame, replaceable wear parts (chain, tyres, brake pads) and easy repair, and to choose lower-impact materials.
5. Any two: it needs large amounts of data that may be unavailable or estimated; results depend on assumptions such as product life and electricity source; the boundaries can be chosen to favour a product; different impacts (carbon, water, toxicity) are hard to combine into one judgement; it is expensive and slow.
6. A linear economy takes materials, makes and uses a product, then throws it away. A circular economy keeps products and materials in use through repair, reuse, remanufacture and recycling, with little waste. Repair keeps the whole product and all its embodied energy in use; recycling recovers only the material and needs energy to reprocess it.

7. Rethink: could pages be held without metal staples, such as a staple-free crimping stapler? Refuse: no plastic blister packaging. Reduce: less metal by using a ribbed shape. Reuse: refillable with standard staples. Repair: replaceable spring and screwed-together body. Recycle: separable metal and plastic parts, marked with their material.
8. Any four: parts joined with screws and clips instead of glue; standard screws that need one common screwdriver; few different materials; plastic parts marked with their material code; replaceable bulb and switch; cable connected by a plug, not soldered.
9. Functional: parts wear out and cannot be replaced, such as a glued-in battery. Technological: new technology makes it less useful, such as a phone that no longer gets software updates. Style: fashion makes it look old, such as last year's colour of trainers.
10. A: $90 \div 3 =$ ¥30 per year. B: $(240 + 30) \div 10 =$ ¥27 per year. B is slightly cheaper per year, and sends about a third as many toasters to waste over 10 years.
11. An invention is a new idea or product; an innovation is an invention successfully brought to market and used. Incremental innovation is a small improvement to an existing product (a slightly larger battery); radical innovation is a big change that creates something new (the first touch-screen smartphone).
12. Market pull: users' needs drive a new product, such as demand for portable music leading to portable players. Technology push: a new technology leads to new products, such as lasers later used in barcode scanners.
13. Introduction: low sales, loss. Growth: sales rise quickly, profit begins. Maturity: sales level off, competitors arrive. Decline: sales fall. Extension strategies for a console: a slimmer, cheaper model; new games, colours or bundles; a price cut; entering new markets.
14. Early adopters are respected opinion leaders who try new products before most people. If they adopt and recommend a product, the early and late majority are more likely to follow, so the product can spread through the market.
15. $900 + 3n = 300 + 6n$, so $600 = 3n$ and $n = 200$ items.
16. Break-even $= 45\,000 \div (150 - 60) = 45\,000 \div 90 = 500$ bags. Profit from 800 bags $= 800 \times 90 - 45\,000 =$ ¥27 000.
17. Hinge mechanism: patent. Shape of a chair: registered design. Logo: trademark. Manual: copyright.
18. Advantages: anyone can download, make and adapt the design cheaply, such as on a 3D printer, so it reaches people who cannot afford a commercial prosthesis; users and volunteers can improve it quickly. Disadvantages: an open licence does not itself ensure safety or quality; versions may vary and ongoing development needs funding. Makers can earn income from selling products or services. Overall it suits a low-cost, simple device if quality checks and fitting by trained people are included.
19. Appropriate technology suits the place and users: affordable, made from local materials, repairable with local skills and needing little energy. A treadle pump for small farms is powered by the user's legs, needs no fuel and can be repaired locally, so it works where electricity and spare parts are not available.
20. The claim is weak. 30 % recycled content reduces the need for new plastic, but 70 % is still new plastic. The label says nothing about manufacturing energy, transport, whether the bottle is single-use, or what happens at the end of life. "Eco-friendly" is vague and could be greenwashing; a fair claim would state the recycled content and give evidence from a life cycle assessment.

Exam tips

- Use the triple bottom line: give an environmental, a social and an economic point.
- Name the life-cycle stage with the biggest impact before suggesting a design change.
- Repair and reuse keep more value than recycling: say why (embodied energy).
- Do not confuse the product life cycle (sales over time) with the environmental life cycle of one product.
- For break-even, show the equation, solve it, and say which option is better on each side.
- Choose the right form of intellectual property: how it works (patent), how it looks (registered design), the brand (trademark), the drawings or text (copyright).
- Evaluate green claims with evidence, not labels.

Design project

International Baccalaureate · IB Diploma · Design Technology · SL

Scope and prerequisites

This handout teaches how to carry out the design project for the course first assessed in 2027: choosing a real problem, researching it, writing a measurable specification, generating and choosing ideas, developing and testing models and prototypes one change at a time, planning and making safely, evaluating against the specification, and presenting the work honestly. It follows one fictional student project from start to finish. It is written for both SL and HL students. Check the assessment criteria, page limits and deadlines in your school's copy of the current IB guide: this handout teaches the process, not the mark scheme.

Prerequisites: unit 1 (design processes, users, specifications, anthropometrics), unit 2 (models, materials, processes, testing) and unit 3 (sustainability and cost).

Choosing and researching a problem

Bags in the aisle

Mei noticed that in her classroom students put their school bags on the floor beside their desks. People tripped over the straps, and once a teacher fell. The school would not drill into the desks. Mei's design project began with one question: how might students keep their bags off the floor, safely and cheaply, without changing the desks? This handout follows her project. Mei and her data are invented, but every step is one that a real project needs.



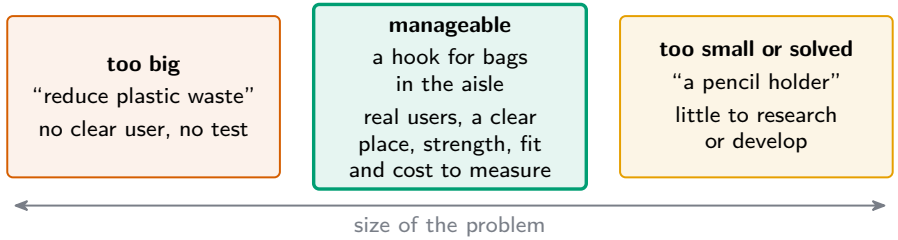
Backpack cubbies at the back of a Japanese classroom: one existing answer to bags in the aisle, worth analysing in your research

What makes a good problem

A good design problem:

- comes from a **real need** of real people, whom you can meet, observe and test with;
- has a clear **context**: who, where, when and why;
- is **manageable** in the time, money, skills and workshop you have;
- can be **tested**: you can measure whether your solution works;
- is **safe** to research, make and test in school.

A problem that is too big ("reduce plastic waste") gives no clear user or test. A problem that is too small or already solved ("a pencil holder") gives little to research or develop. Mei's problem has real users, a clear place, and things to measure: strength, fit, cost and whether the aisle stays clear.



A good problem sits in the middle: real users, a clear place, things to measure

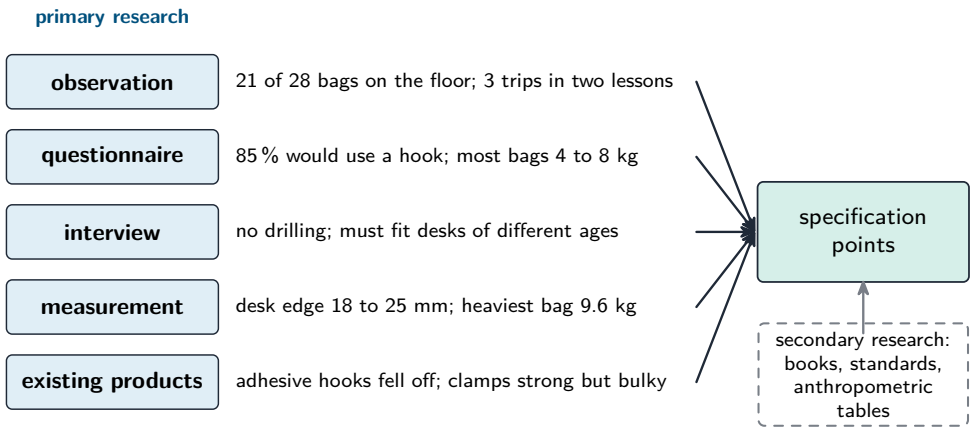
Researching the problem

Research has a purpose: each piece should help you understand the problem or set a specification point. Plan it before you start.

Method	What Mei did	What she learned
Observation	Watched two lessons and counted bags in the aisle	21 of 28 bags on the floor; 3 trips in two lessons
Questionnaire	40 students, five questions	85 % would use a hook; most bags weigh 4 to 8 kg
Interview	The teacher and the school's facilities manager	No drilling; any product must fit desks of different ages
Measurement	Measured desk edges and 30 loaded bags	Desk edge 18 to 25 mm thick; heaviest bag 9.6 kg
Existing products	Analysed three hooks sold online	Adhesive hooks fell off; clamp hooks were strong but bulky

Primary research 一手研究 is data you collect yourself (observation, questionnaires,

interviews, measurements, testing existing products). **Secondary research** 二手研究 uses data others have collected (books, websites, standards, anthropometric tables). Both are useful, but primary research about your own users is usually the most valuable.



Every research method should feed a specification point

Analysing existing products

Product analysis 产品分析 looks closely at existing solutions to learn what works and what does not. A common checklist is ACCESS FM: aesthetics, cost, customer, environment, safety, size, function and materials. Do not just describe the products: say what each one teaches you for your own design. Mei found that adhesive hooks failed because the glue peeled under a heavy bag, so her design would clamp mechanically.

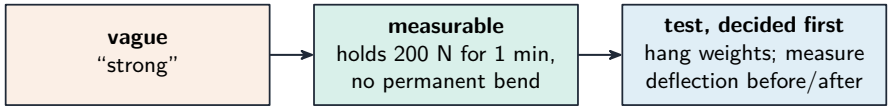
The design brief

The research leads to a **design brief** 设计简报: a short statement of the problem, the users, the context and what the solution must achieve. Mei's brief: "Design a low-cost hook that lets secondary school students hang a school bag of up to 10 kg from the edge of a classroom desk, without tools or damage to the desk, so that aisles stay clear."

Specification and success criteria

Measurable criteria

A **design specification** 设计规格 lists the requirements the solution must meet. Each point should be a **success criterion** 成功标准 that is **measurable** and has a **test method** decided before anything is built. "Strong" cannot be tested; "holds 200 N for 1 minute without permanent bending" can.



justified: heaviest bag 9.6 kg ≈ 94 N, safety factor about 2

From wish to testable criterion

Requirement	Measurable criterion	Justified by	Test method
Strength	Holds 200 N for 1 minute without breaking or permanent bending	Heaviest bag 9.6 kg ≈ 94 N; factor of safety about 2	Hang weights, measure deflection before and after
Fit	Clamps desk edges 18 to 25 mm thick	Measured desks	Fit to test blocks of 18, 21 and 25 mm
Ease of use	Fitted without tools in under 30 seconds	Interview with teacher	Time 10 students
Safety	Sticks out no more than 40 mm from the desk; no sharp edges	Knee clearance, trip observations	Measure; edge check
Cost	Under ¥10 per hook at 500 hooks	School budget	Cost calculation
Environment	Single material, marked for recycling	Unit 3	Inspect

Notice how each criterion comes from research. The 40 mm limit protects knee **clearance** 间隙: a seated student's knees must not hit the hook, so this is a clearance dimension, set for large users, the 95th **percentile** 百分位数. Where a product must be reached, such as a control or a shelf, use small users, the 5th percentile. A single average dimension cannot satisfy every constraint.

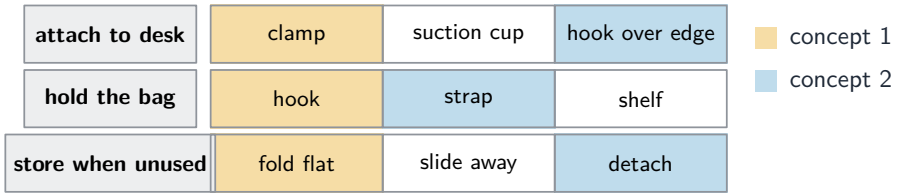
A good criterion can fail

A criterion is useful only if the product could fail it. "Mean comfort rating at least 4 out of 5 across 10 users" can fail; "users like it" cannot. If none of your tests could ever fail, they are not testing anything.

Generating and developing ideas

Generating ideas

Start with **divergent thinking**: many different ideas before choosing.



each path through the chart is one concept: $3 \times 3 \times 3 = 27$ to choose from

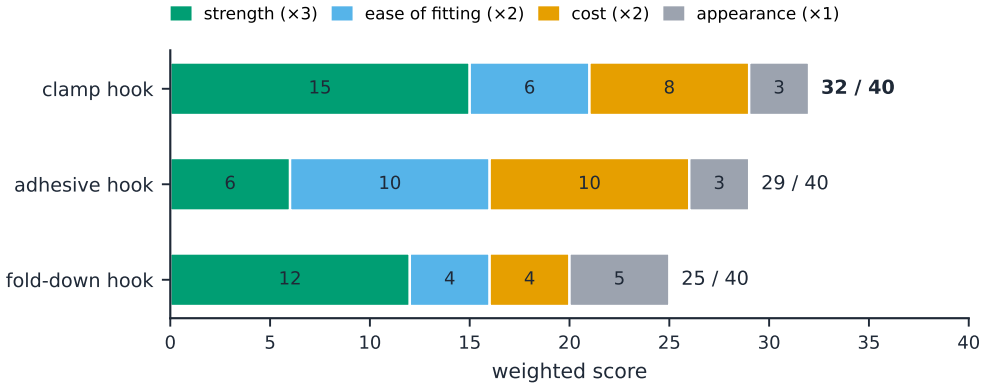
A morphological chart

- **Sketching and annotation**: quick sketches with notes about how each idea works and how it meets the specification.
- **Brainstorming** 头脑风暴: many ideas quickly, without judging.
- **SCAMPER**: substitute, combine, adapt, modify, put to another use, eliminate, reverse.
- **Morphological chart** 形态分析表: list the functions (attach to desk, hold bag, store when not in use) and several ways of achieving each, then combine them.
- **Biomimicry** 仿生设计: borrow solutions from nature, such as a bird's claw gripping a branch.

Annotation turns a sketch into design thinking: label materials, sizes, how it is made and which specification points it meets or fails.

Choosing an idea: the weighted decision matrix

Choosing should be fair and explained. A **weighted decision matrix** 加权决策矩阵 scores each idea against the criteria, with more important criteria given a larger weight.



Mei's weighted decision matrix

> **Worked example.** Weights: strength 3, ease of fitting 2, cost 2, appearance 1. Each idea is scored from 1 to 5, so the maximum is $(3 + 2 + 2 + 1) \times 5 = 40$.

Idea	Strength (×3)	Fitting (×2)	Cost (×2)	Appearance (×1)	Total
Clamp hook	$5 \to 15$	$3 \to 6$	$4 \to 8$	$3 \to 3$	32
Adhesive hook	$2 \to 6$	$5 \to 10$	$5 \to 10$	$3 \to 3$	29
Fold-down hook	$4 \to 12$	$2 \to 4$	$2 \to 4$	$5 \to 5$	25

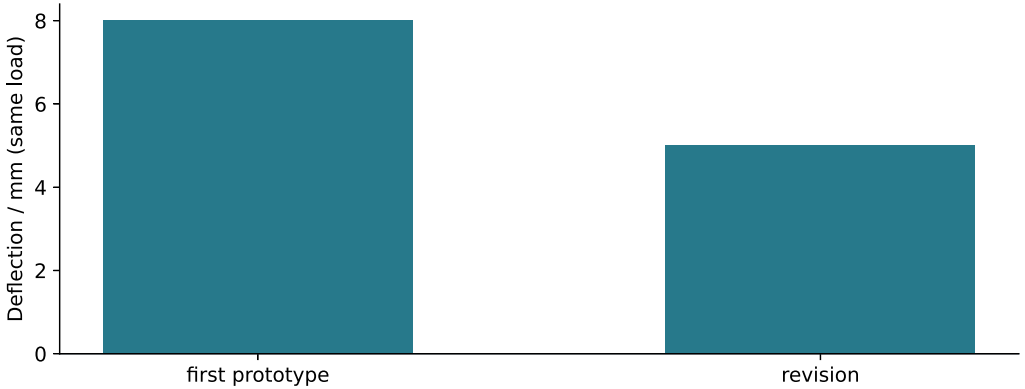
The clamp hook wins with 32 out of 40 (80 %). Without weights the adhesive hook would score 15 against the clamp hook's 15, a tie, which shows why the weights matter: strength is the most important need. Scores are still judgements, so justify each one with evidence, and ask users or your teacher to check them.

Developing the idea with models

Development turns a chosen idea into a design that can be made. Use models of increasing **fidelity**:

1. A card model to check size and how it sits on the desk.
2. A rough 3D print to check that it clamps desks of 18 to 25 mm.
3. A CAD model to fix exact dimensions and prepare for manufacture.
4. Prototypes for strength and user testing.

State what each model tests and what it leaves out. Mei's card model tested fit only; it could not test strength, and she said so.

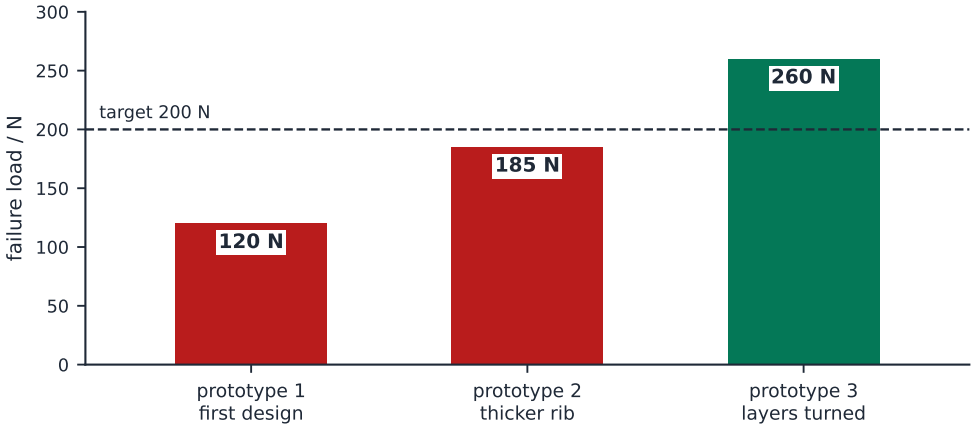


Deflection falls from 8 mm to 5 mm under the same load: a 3 mm, 37.5 % reduction

When one revision is compared with another, the test must be the same: same load, same desk thickness, same measurement. Mei's second hook bent 5 mm instead of 8 mm under the same 100 N load, a 37.5 % reduction. That is evidence that the deeper arm is stiffer.

One change at a time

A fair comparison changes one **variable** 变量 at a time and keeps the others the same. If a new prototype changes both the material and the shape, and it performs better, you cannot tell which change helped. Record every change and its result in a development log, with photographs, so the evidence for each decision is clear.



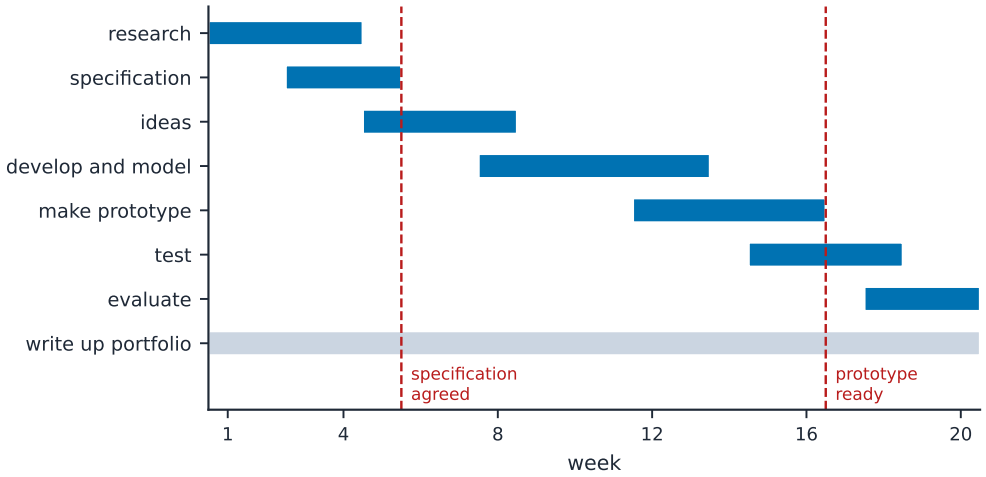
Each prototype changed one thing

Mei's first printed hook snapped at 120 N, along a print layer. Prototype 2 changed only the rib thickness: 185 N, better but still below the 200 N target. Prototype 3 kept the thicker rib and changed only the print orientation, so the layers ran along the hook instead of across the load: 260 N, a pass. The results show that both rib thickness and print orientation affected failure load. The first fracture along a layer points to interlayer bonding as a weakness, which is a real insight into 3D-printed parts (unit 2).

Making and testing

Planning

A plan shows what you will do, when, and with what. A **Gantt chart** 甘特图 shows tasks as bars against time, so you can see overlaps and deadlines.



A project plan with two milestones

A **production plan** 生产计划 for the final prototype lists the stages in order, the materials and components, the tools and machines, the quality checks at each stage and the time needed. A good plan lets someone else make the product, and lets you notice early if you are falling behind.

Working safely

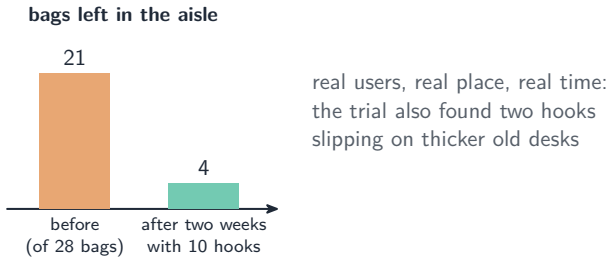
Before using any tool or machine, write a **risk assessment** 风险评估: list each hazard, who could be harmed, how likely and how serious it is, and the control measures. For Mei: hot nozzle and print bed (do not touch while printing; let parts cool); sharp edges after printing (file and check); load tests (weights hung low over a padded floor, eye protection, stand to the side). Use machines only after training and with your teacher's permission.

Testing against the specification

Test the final prototype against **every** success criterion, using the test method you planned:

Criterion	Result	Met?
Holds 200 N for 1 minute	Held 200 N; 3 mm bend, fully recovered	Yes
Fits 18 to 25 mm desks	Fitted 18 and 21 mm; loose on 25 mm	Partly
Fitted in under 30 s	Mean 12 s, slowest 26 s (10 students)	Yes
Projection ≤40 mm; no sharp edges	34 mm; edge check not recorded	Partly verified
Under ¥10 per hook at 500	¥6.80 for printing time and material only	Full cost unverified
Single material, marked	PLA, marked with its code	Yes

Also run **user trials**: real users use the product in the real place. Mei left 10 hooks in her classroom for two weeks: bags in the aisle fell from 21 to 4, and students reported two hooks slipping on old, thicker desks. Present results clearly with tables and graphs, and include photographs of the tests.



The user trial: 21 bags fell to 4

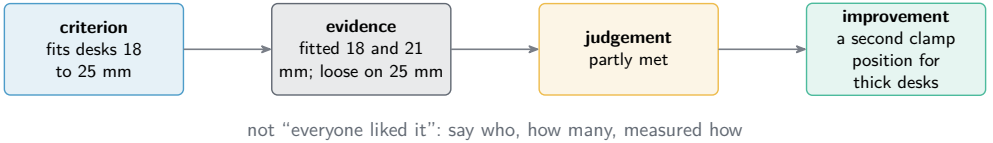
Evaluating and presenting

Evaluating honestly

An **evaluation** 评价 judges the solution against the specification, using the test evidence. It should be honest: a criterion that was only partly met is not a failure of the project, as long as you explain why and how to fix it.

- Go through each criterion and state whether it was met, with the evidence.
- Explain the strengths and limitations of the solution, and of the tests (sample size, conditions, time).
- Suggest **improvements**, each linked to evidence: "Add a second clamp position for 25 mm desks, because the hook slipped on the 25 mm test block and on two older desks."
- Consider the wider impact: sustainability, cost at larger scale, and who else could benefit.

Avoid weak evaluation such as "my product was successful and everyone liked it". Say who, how many, measured how.



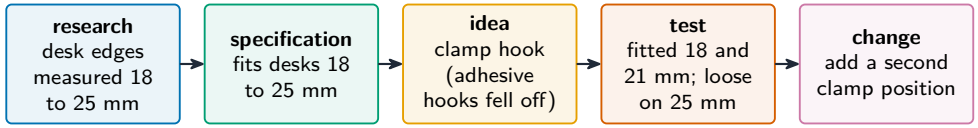
Criterion, evidence, judgement, improvement

How the project could go further

Think about what would change if the product were made for sale: injection moulding instead of 3D printing at large numbers (unit 2 break-even), testing on many more desks, and checking safety standards. Mei calculated that a ¥15 000 mould with a ¥0.90 cost per hook would be cheaper than printing at ¥6.80 from 2543 hooks, since $15\,000 \div (6.80 - 0.90) \approx 2542.37$. This comparison excludes any extra setup, labour and reject costs.

Presenting the portfolio

- Be **concise**: show the most important evidence and decisions, not everything you did.
- Use **annotated** photographs, sketches, tables and graphs instead of long paragraphs.
- Make every decision traceable: research → specification → idea → test → change.
- Reference every source you used, and acknowledge help from others and any AI tools, following your school's academic integrity policy. **Academic integrity** 学术诚信 means the work you submit as your own is your own.



each step names the evidence for the next: the examiner can follow the thread

Research, specification, idea, test, change: one thread the examiner can follow

Practice

1. Explain why "reduce plastic waste" is a poor design problem for a school project, and suggest a better one.
2. Distinguish between primary and secondary research, with an example of each for a project to design a phone stand.
3. Explain why product analysis should say what each existing product teaches you, not just describe it.
4. Write a design brief for a product that helps students carry wet umbrellas into classrooms.
5. Rewrite these specification points as measurable success criteria with test methods: "strong", "easy to use", "cheap".
6. A shelf must hold books of up to 12 kg. Using g = 9.8 N/kg and a factor of safety of 2, state a strength criterion.
7. Explain which percentile Mei should use for the hook's maximum projection, and which for the height of a shelf that students must reach.
8. Describe two techniques for generating ideas.
9. Three ideas are scored: idea X strength 4, cost 3, appearance 5; idea Y strength 5, cost 2, appearance 3; idea Z strength 3, cost 5, appearance 4. Weights: strength 3, cost 2, appearance 1. Find each weighted total and the maximum possible score, and choose an idea.
10. Explain why a weighted decision matrix is better than simply adding scores.
11. Explain why Mei's card model was useful even though it could not test strength.
12. A prototype changes both the material and the wall thickness, and is stronger. Explain what is wrong with this test and how to improve it.
13. Using the load-test graph, explain what Mei learned from prototypes 2 and 3.
14. Outline what a production plan should contain.
15. Write three lines of a risk assessment for using a laser cutter.
16. Mei's hook loosened on 25 mm desks. Write an improvement that is linked to evidence.
17. Evaluate the statement: "My project was successful because everyone liked it."
18. A mould costs ¥15 000 and each moulded hook costs ¥0.90; printing costs ¥6.80 per hook. Find the break-even number of hooks.

Answers.

1. It is too big and vague: there is no clear user, context or measurable test, and it cannot be solved in a school project. Better: "Design a way for students in my school canteen to return reusable cups so that fewer single-use cups are used", which has real users, a place and measurable outcomes (cups returned per day).
2. Primary research is data you collect yourself, such as measuring the phone sizes and viewing angles of 20 classmates. Secondary research uses others' data, such as published anthropometric data on eye height or a review comparing existing stands.
3. Describing products adds nothing to the design. The value is in what each product teaches: what works, what fails and why, which then becomes a specification point or a design decision (for example, adhesive hooks peeled, so use a mechanical clamp).
4. For example: "Design a low-cost holder that lets secondary students store a wet folding umbrella beside their desk during lessons, so that water does not drip on the floor or bags, and the umbrella can be collected quickly at the end of the lesson."
5. Strong: "holds 50 N for 1 minute without breaking or permanent bending; test by hanging weights". Easy to use: "8 of 10 first-time users assemble it in under 1 minute without instructions; test by timing users". Cheap: "material and making cost under ¥20 per unit at 100 units; test by cost calculation".
6. $12 \times 9.8 \approx 118$ N; with a factor of safety of 2, the shelf must hold about 235 N (for example, 240 N for 1 minute) without breaking or permanent bending.
7. The projection must leave knee clearance, so it is set for large users, the 95th percentile. A shelf students must reach is a reach dimension, so it is set for small users, the 5th percentile.
8. Any two: brainstorming (many ideas quickly without judging); SCAMPER (changing an existing product by substituting, combining, adapting and so on); a morphological chart (listing ways of achieving each function and combining them); biomimicry (borrowing solutions from nature); sketching with annotation.
9. X: $12 + 6 + 5 = 23$. Y: $15 + 4 + 3 = 22$. Z: $9 + 10 + 4 = 23$. Maximum = $(3 + 2 + 1) \times 5 = 30$. X and Z tie at 23; choose by the most important criterion, strength, so X, or test both with users before deciding.
10. Not all criteria matter equally. Weights make more important criteria count more, but a high total can still hide a failed safety requirement. Reject ideas that fail mandatory requirements before ranking the remaining ideas. Weights also make the reasons for the choice visible.

11. It tested size, fit and how the hook sat on the desk quickly and cheaply, before time and material were spent on prints. Each model only has to answer its own question, as long as its limits are stated.
12. Two variables changed, so the improvement cannot be attributed to either. Make two prototypes: one changes only the material, the other only the wall thickness, keeping everything else (load, test method, desk) the same.
13. Prototype 2 showed that a thicker rib helped a little (185 N) but was not enough. Prototype 3, which changed only the print orientation, held 260 N. Both changes improved failure load; the first fracture along a layer supports investigating inter-layer bonding.
14. The stages in order, materials and components with sizes, tools and machines, quality checks at each stage, safety notes and the time for each stage.
15. For example: hazard, fire from the laser; control, never leave it running, keep the lid closed, extraction on, fire blanket nearby. Hazard, toxic fumes from some plastics; control, cut only approved materials such as acrylic, never PVC. Hazard, eye damage; control, use only with the lid closed and after training.
16. "Add a second clamp position or a thicker rubber pad so the hook grips 25 mm edges, because it slipped on the 25 mm test block and on two older desks in the user trial; then retest on 18, 21 and 25 mm blocks."
17. The statement is weak. "Everyone" is vague and "liked it" is not a criterion. A good evaluation states each specification point, the measured result (for example, held 200 N; fitted in 12 s on average by 10 students; bags in the aisle fell from 21 to 4), the limitations of the tests, and evidence-based improvements.
18. 15 000 + 0.90n = 6.80n, so 5.90n = 15 000 and n $\approx$ 2542.37 hooks. Moulding is cheaper from 2543 whole hooks under these cost assumptions.

Exam tips

- Choose a problem with real users you can reach and outcomes you can measure.
- Make every research activity lead to a specification point or a decision.
- Write each criterion with a number, a unit and a test method before you build.
- Use the 95th percentile for clearance and the 5th for reach.
- Show how you chose: a weighted matrix with justified scores.
- Change one variable per prototype, and record why.
- Evaluate against every criterion with evidence, and link each improvement to a test result.