

Thinking in Diagrams: Workbook

A textbook about diagrammatic thinking, with a diagram lab in it, covering the systems and feedback family of diagrams.

Online, with a lab for each exercise: thinking-in-diagrams.aryehnielsen.com

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Chapter 1

What Is a Diagram For?

DF 01 Greta's morning drawing

A paragraph drawn

Reasoning ●○○○○ 1 of 5 Polish ●○○○○ 1 of 5

Greta draws for twenty minutes before work each morning and keeps a log. After three months she wrote in it: "I time one sketch every morning, and it now takes me five minutes, down from nine. My times fell fastest in the weeks I drew longest, and not at all in the fortnight I was ill and barely drew. Beside each sketch I mark from one to five how much I enjoyed the session, and the mornings I sketched fastest are the ones I marked highest. On those mornings I keep going past twenty minutes, and the log shows it. I started an online course in January, and I think its lessons have made me faster too, but I've kept no count of the lessons beside my times."

The brief

- ☐ Draw four variables.
- ☐ Draw an effect wherever Greta writes that one quantity changes another.
- ☐ Code the one effect with the weakest support as a hypothesis, so it is drawn dashed.
- ☐ Each name is a quantity that can rise or fall: minutes drawn each morning, not draws every morning.
- ☐ The effects close a circle.

Your palette



Draw here

A large grid of dots for drawing the diagram.

DF 02 Esther's grandchildren's visits

Two readings of one calendar

Reasoning ●●○○○ 2 of 5 Polish ●○○○○ 1 of 5

Esther marks each visit from her grandchildren on her kitchen calendar. “Until my son's family moved two hours' drive away, they came every month. Since the move they've come four times a year, and the calendar shows the drop from the first month after it. Last spring the eldest took a Saturday job at a bakery, and I think that keeps them all away now, though I haven't compared the calendar with her shifts. And I think the less often the children come, the less they want to come, and the less they want to, the less often they come. I haven't asked them.” Her son agrees that the drive cut the visits, and says it alone explains them.

The brief

- ☐ Draw four variables.
- ☐ Draw an effect wherever Esther or her son says one quantity changes another.
- ☐ Code the three effects with the weakest support as hypotheses, so they are drawn dashed.
- ☐ Each name is a quantity that can rise or fall: visits a year, not the grandchildren visit.
- ☐ Esther and her son disagree only about dashed effects.

Your palette



Draw here

A large grid of dots for drawing the diagram.

DF 03 Hedgehogs in Britain's countryside

Sorting a report's evidence

Reasoning ●●○○○ 2 of 5 Polish ●●○○○ 2 of 5

A county wildlife trust's newsletter sums up the report The State of Britain's Hedgehogs 2022 for its members. "Surveys show rural hedgehogs down by between a third and three-quarters in twenty years. Fewer are found dead on roads too, perhaps three-quarters fewer since 1990, though traffic has grown: with fewer hedgehogs about, fewer are killed. Whether road deaths are behind the decline, the report's authors call unclear. Badgers eat hedgehogs and compete with them for earthworms and beetle larvae, and the authors call it likely that badgers reduce hedgehog numbers where there are many of them. Studies show that wide, grassy field margins hold more earthworms and ground beetles; whether hedgehogs are fewer where their prey is scarcer is among the questions the authors list as still being studied. Researchers found that on arable land hedgehogs seek out village gardens to feed and are densest there, and a small hole at the foot of a fence opens one garden to the next."

The brief

- ☐ Draw at least five variables.
- ☐ Draw an effect wherever the report's authors find or suspect that one quantity changes another.
- ☐ Code at least two effects as hypotheses, so they are drawn dashed.
- ☐ Each name is a quantity that can rise or fall: hedgehogs killed on roads each year, not roadkill.
- ☐ An effect is solid where you judge its support strong enough; when the authors call an effect likely, that is testimony, weaker than a count.

Your palette



Draw here

A large grid of dots for drawing a diagram.

DF 04 Objects in orbit

A circle closed by a model

Reasoning ●●●○○ 3 of 5 Polish ●●○○○ 2 of 5

Notes from ESA's Space Environment Report 2026 and NASA's Orbital Debris Quarterly News. Launches add satellites to orbit, and 2025 had the most launches yet counted. Satellites leave orbit at the end of their life, brought down or left to fall: 1,200 intact satellites and rocket stages re-entered the atmosphere in 2025. On 10 February 2009 the working satellite Iridium 33 and the disused Cosmos 2251 collided at more than 11 km a second; both broke apart, and by the end of March 823 of their larger fragments had been catalogued. More fragments come from satellites and rocket stages that break apart without a collision, which ESA counts as the largest source of fragments today. Accidental collisions are few: Iridium 33 and Cosmos 2251 was the fourth known, and the first between two intact spacecraft. That more satellites and fragments in orbit bring more collisions, enough to set off a cascade of them over the coming centuries, comes from models: Donald Kessler and Burton Cour-Palais's in 1978, and ESA's now.

The brief

- ☐ Draw at least five variables, with satellites in orbit and fragments in orbit apart.
- ☐ Draw an effect wherever one quantity in the notes changes another.
- ☐ Code the two effects that come from models, not counts, as hypotheses, so they are drawn dashed.
- ☐ Each name is a quantity that can rise or fall: collisions each year, not a collision.
- ☐ The two dashed effects, from satellites and fragments in orbit to collisions, come from models, not counts, and close the circles.

Your palette



Draw here

Grid for drawing the diagram.

CS 01 Kelsham Primary School: the head teacher's letter

Counts and beliefs in one letter

Reasoning ●●○○○ 2 of 5 Polish ●●○○○ 2 of 5

In October 2026 Ruth Okafor, head teacher of Kelsham Primary School, wrote to parents. “We have 88 pupils on roll this October, against 126 in October 2020. This September 9 children started with us and 16 left, Year 6 among them. The county council's records show each September's starters falling with the births in our villages four years before. Each October's count sets our funding, £4,800 a pupil: when the roll fell to 108 in 2023, it paid for four teachers, not five, and Years 3 and 4 became one class. With 88 pupils in four classes, our classes are small. Some of you tell us that mixed-age classes are why families have moved to Brayford Primary School, and others that small classes are why you stay. Nobody has counted either.”

The brief

- ☐ Draw at least six variables, with the children starting each September and the pupils leaving each year apart.
- ☐ Draw an effect wherever Ruth Okafor writes that one quantity changes another.
- ☐ Code the two effects with the weakest support, the reasons parents give, as hypotheses, so they are drawn dashed.
- ☐ Each name is a quantity that can rise or fall: pupils leaving each year, not families move.
- ☐ An effect is solid where you judge a count by the school or the county council supports it.

Your palette



Draw here

A large grid of dots for drawing the diagram.

Chapter 2

Drawing the Boundary

SC 01 A first term away from home

One boundary and the parties outside it

Reasoning ●○○○○ 1 of 5 Polish ●○○○○ 1 of 5

Maya starts a geology degree at a university three hundred miles from home. The university gives lectures, sets essays and returns them with grades. Her parents send her an allowance each month. She works two evening shifts a week at a café, which pays her wages, and borrows books from the city library. Draw her studies as the system, with the parties they exchange with outside it. Leave out her housemates and the friends she makes in lectures.

The brief

- ☐ Draw one boundary around Maya's studies.
- ☐ Place four to six external entities outside it.
- ☐ Draw at least four exchanges.
- ☐ Each external entity is a party that gives or receives something, not a feeling or a task.

Your palette



Draw here

A large grid of dots for drawing the system boundary and external entities.

SC 02 Earth

One boundary, at the largest scale

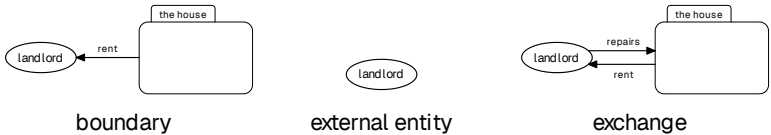
Reasoning ●○○○○ 1 of 5 Polish ●●○○○ 2 of 5

Sunlight reaches Earth from the Sun. Earth reflects part of that sunlight back out to space and radiates heat to space. A trickle of meteoric dust falls in from space, and light gases such as hydrogen escape from the top of the atmosphere. Draw Earth as the system, with what crosses between it and the parties outside it.

The brief

- ☐ Draw one boundary: Earth.
- ☐ Place two external entities outside it.
- ☐ Draw at least four exchanges.
- ☐ Show at least one external entity that both gives to Earth and receives from it.
- ☐ The names show which crossings are energy and which are matter.

Your palette



Draw here

A large grid of dots for drawing the system boundary.

SC 03 A shared house

Named exchanges in both directions

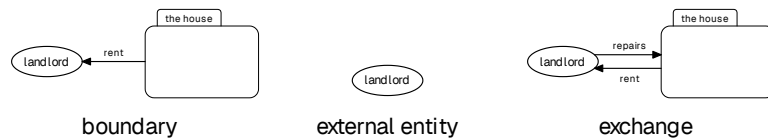
Reasoning ●●○○○ 2 of 5 Polish ●●○○○ 2 of 5

Five students share a rented terraced house for their second year. They pay the landlord rent each month and send him a fault report when something breaks, and he sends a plumber or an electrician to make the repair. An energy supplier provides gas and electricity, and the students pay it by monthly direct debit. The council collects council tax, empties the bins each Tuesday and issues a parking permit for the one car they share. The neighbours take in the students' parcels, and the students feed the neighbours' cat when the neighbours are away. Draw the household as the system, with the parties it exchanges with outside it.

The brief

- ☐ Draw one boundary around the household.
- ☐ Place at least four external entities outside it.
- ☐ Show at least three external entities that both give to the household and receive from it.
- ☐ Each exchange names one thing: rent and repairs is two exchanges.

Your palette



Draw here

SC 04 A national blood service

Named exchanges in both directions, across a nation

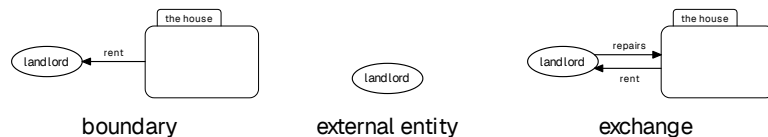
Reasoning ●●○○○ 2 of 5 Polish ●●●○○ 3 of 5

A national blood service collects blood from volunteer donors at sessions across the country. It tests every donation and writes to any donor whose blood shows an infection. It separates the blood into red cells and platelets and delivers both to hospitals, which order what they need each day and pay for each unit. The health ministry funds the service and receives its annual report. The regulator licenses the service and receives a report of every serious incident, such as a transfusion given to the wrong patient. Research laboratories receive donations unfit for transfusion as research samples and send back their study results. Draw the service as the system, with the parties it exchanges with outside it.

The brief

- ☐ Draw one boundary around the blood service.
- ☐ Place at least five external entities outside it.
- ☐ Show at least four external entities that both give to the service and receive from it.
- ☐ Draw at least eight exchanges.
- ☐ Donors sit outside the boundary: the service exchanges with them and doesn't run them.

Your palette



Draw here

SC 05 A community garden

Nested boundaries and owners

Reasoning ●●●○○ 3 of 5 Polish ●●●○○ 3 of 5

Linden Street garden is a community garden on a former car park, divided into growing beds, compost bays and a tool shed. The water supplier pipes water to the growing beds, and the vegetables grown there go to the food bank each Saturday. A café on the corner brings its food scraps to the compost bays, and the parks department delivers fallen leaves there each autumn and collects finished compost for its flower beds. Neighbours bring their grass cuttings to the compost bays and borrow tools from the tool shed. Draw the garden as the system, divided into its parts, with each exchange reaching the part that handles it.

The brief

- ☐ Draw at least two nested boundaries inside the garden, one for each part.
- ☐ Place at least five external entities outside the garden.
- ☐ Draw each exchange to the part that handles it.
- ☐ Each part is named for what it does, not for who works in it.

Your palette



Draw here

A large grid of dots for drawing the system diagram.

CS 02 Kelsham Primary School and the parties it deals with

Exchanges both ways, and a party that only receives

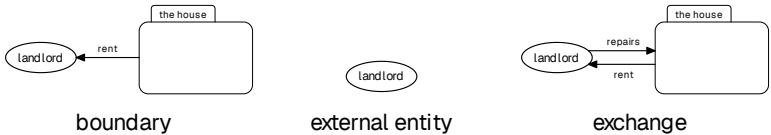
Reasoning ●●○○○ 2 of 5 Polish ●●○○○ 2 of 5

Before the governors meet the county council, Tom Hale asks them to list what Kelsham Primary School exchanges with each party it deals with. Families send their children as pupils and tell the school what they think of it, and the school sends them a report on each child every term. The county council pays the school its funding and receives the count each October, and David Brennan, its officer for school places, sends a forecast of starters. Dale Coaches sends the school bus timetable, and the school sends it the list of children on the bus. When a child moves to Brayford Primary School, the school sends the child's records there. Larkfield Homes, the builder of the 60 homes at Mill Lane, sends the dates its first homes will be lived in, and the school sends leaflets for its buyers. Draw the school as the system, with the parties it exchanges with outside it.

The brief

- ☐ Draw one boundary around the school.
- ☐ Place at least five external entities outside it.
- ☐ Show at least four external entities that both give to the school and receive from it.
- ☐ Each exchange names one thing: funding and the forecast of starters are two exchanges.
- ☐ Leave off what passes between two parties outside the school, such as the county council's payments to Dale Coaches.

Your palette



Draw here

A large grid of dots for drawing the diagram.

Chapter 3

Surfacing Influences

IM 01 Cycling to work through the winter

A central outcome and its direct influences

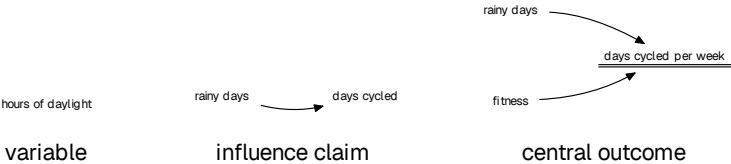
Reasoning ●○○○○ 1 of 5 Polish ●○○○○ 1 of 5

Tomás rides nine kilometres to work and takes the bus on the days he doesn't. From October he counts the days he rides each week. The hours of daylight fall through the autumn, and the rainy days per week rise. The council is putting street lights along his route, so the length of lit route grows month by month. His office has two showers, and on busy mornings fewer are free when he arrives. His fitness, built up over the summer, makes the ride quicker. The bus fare went up in September. Nobody has measured how much any of these moves the days he rides.

The brief

- ☐ Draw at least four direct influences on days cycled per week.
- ☐ Draw no indirect influences: each influence claim ends at days cycled per week.
- ☐ Each variable is a quantity that can rise or fall: hours of daylight, not the dark.

Your palette



Draw here

A large grid of dots for drawing an influence map.

IM 02 World food prices

Influences that reach the central outcome through another variable

Reasoning ●○○○○ 1 of 5 Polish ●●○○○ 2 of 5

The FAO food price index tracks what the world pays for cereals, vegetable oils, dairy, meat and sugar. The size of the world's grain harvest sets how much is on sale, and the area in drought across growing regions cuts the harvest. Farmers spread less fertilizer when its cost climbs, and the grain harvest falls with it. Fertilizer is made and shipped with fossil fuels, so its cost follows the oil price, which also sets what it costs to move and process food. A dear barrel makes ethanol and biodiesel pay, and biofuel demand takes maize and vegetable oil off the food market. When a harvest fails, some governments ban grain exports, and the more grain under export bans, the fewer cargoes importers can bid for. The area in drought and fertilizer cost act on the index only through the grain harvest; the oil price acts on it straight and through fertilizer cost and biofuel demand.

The brief

- ☐ Draw at least four direct influences on the world food price index.
- ☐ Draw at least three indirect influences.
- ☐ Each indirect influence reaches the index through the variable it acts on.

Your palette



Draw here

A large grid of dots for drawing an influence map.

IM 03 An amateur football team's season

Clusters, each labeled for what its variables share

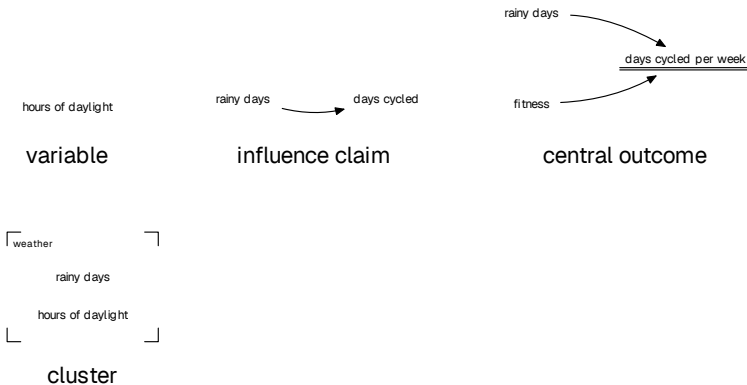
Reasoning ●●○○○ 2 of 5 Polish ●●○○○ 2 of 5

The Rovers, an amateur team, play on Sunday mornings in a county league, and their season is counted in league points. The squad size was twenty-two in September; players leaving for work or university cut it through the winter. Training attendance on Wednesday nights runs from eight to eighteen, and the players who come keep their match fitness. The players injured each week, mostly with pulled hamstrings, are fewer when match fitness is high. The coach spends half of each session on how the back four hold their line, and the training time on tactics shows in clean sheets. Team morale shows in how hard the players run in the last twenty minutes of a match, and players with low morale leave. The players at post-match socials in the clubhouse keep the team's morale up. Nobody at the club has measured how much any of these moves the points.

The brief

- ☐ Draw at least three clusters.
- ☐ Put every variable but league points in a cluster.
- ☐ Draw at least three direct influences on league points.
- ☐ Each cluster's label names what its variables share.

Your palette



Draw here

A large grid of dots for drawing.

IM 04 Algal blooms in a lake**Your palette**

hours of daylight rainy days → days cycled rainy days → days cycled rainy days → days cycled

variable

polarity

influence claim

bus fare →
rainy days →
fitness →

days cycled

·
**

weight

rainy days →

days cycled per week

fitness →

central outcome

weather

rainy days

hours of daylight

cluster

IM 04 Algal blooms in a lake

Weight, and upgrading only the influences that were measured

Reasoning ●●○○○ 2 of 5 Polish ●●●○○ 3 of 5

Lake Esk supplies drinking water to three towns, and most Augusts its surface turns green with algae. The lake authority counts the weeks of algal bloom each summer. Over ten years it has measured three things that rise and fall with them: phosphorus in farm runoff, sewage overflows per year from the towns' treatment works, and summer water temperature. Farm runoff carries about two-thirds of the phosphorus that reaches the lake, and sewage overflows most of the rest; the three warmest summers had the longest blooms. Fertilizer spread on the fields around the lake feeds the runoff, and heavy rainstorms, a few each summer, wash it into the streams. Anglers blame the shrinking area of reed beds along the shore, and boat operators blame the number of summer visitors. The authority has measured neither.

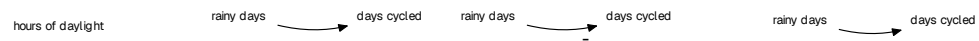
The brief

- ☐ Give each direct influence on weeks of algal bloom each summer a weight.
- ☐ Upgrade exactly three influences, giving each a + or -.
- ☐ Leave at least two influences without a + or -.
- ☐ Each causal claim is one the authority measured; every other claim stays an influence claim.

Your palette

On the page before this sheet.

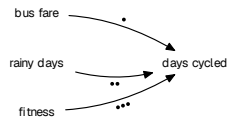
Draw here

IM 05 An open-source project's contributors**Your palette**

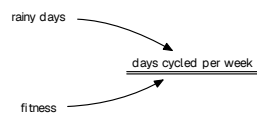
variable

polarity

influence claim



weight



central outcome



cluster

IM 05 An open-source project's contributors

Upgrades that close a path of causal claims, read as a causal loop diagram

Reasoning ●●●○○ 3 of 5 Polish ●●●○○ 3 of 5

Ledger is an open-source library that reads spreadsheet files, and its maintainers count its active contributors each month. Six years of the project's records show three things. Releases made while more contributors are active carry more fixes. More fixes per release bring more users, as the package registry counts them. More users bring more active contributors, since most first contributions come from someone who hit a bug in their own work. The three run in a circle: active contributors, fixes per release, users, and back to active contributors. The maintainers believe newcomers stay when their first change is reviewed within a week, when the documentation pages explain how the code is laid out, and when issues are labeled for newcomers. Donations, about four thousand dollars a year, pay a maintainer for a few hours each week, most of them spent on review. None of these has been measured.

The brief

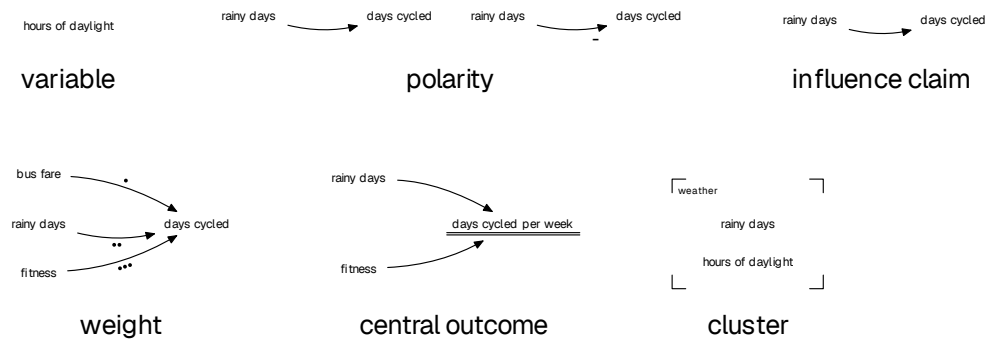
- ☐ Upgrade the influences the project's records show until they close a path of causal claims.
- ☐ Keep at least two influence claims.
- ☐ Draw at least two clusters.
- ☐ Every causal claim is one the project's records show.

Your palette

On the page before this sheet.

Draw here

Diagram drawing area with a grid of dots.

CS 03 Kelsham Primary School: what decides where a child starts**Your palette**

On the page before this sheet.

Draw here

Chapter 4

Loops That Amplify, Loops That Correct

CL 01 A riverbank cleanup that grows by word of mouth

One reinforcing loop

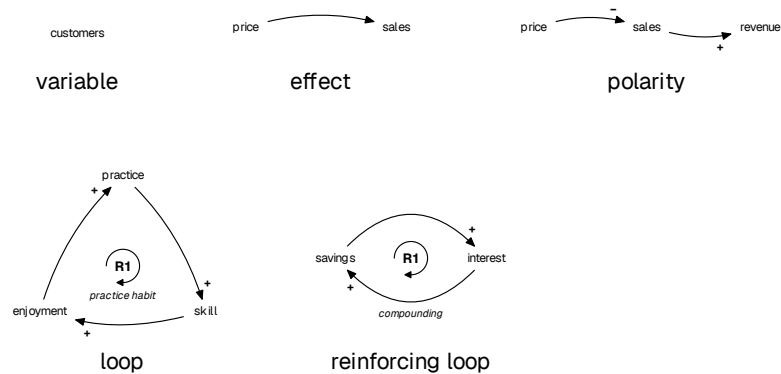
Reasoning ●○○○○ 1 of 5 Polish ●○○○○ 1 of 5

Neighbors meet one Saturday a month to clear litter from a city riverbank. Each cleared stretch shows from the footpath, and people who walk there talk about it. Some of them come to the next cleanup, and some of those keep coming. Show the smallest complete feedback explanation. Leave out the weather and the litter the river carries in.

The brief

- ☐ Use exactly four variables.
- ☐ Close one loop.
- ☐ Mark every effect + or -.
- ☐ Label the loop R1.
- ☐ Give the loop a short name.

Your palette



Draw here

CL 02 Hunger and eating

One balancing loop

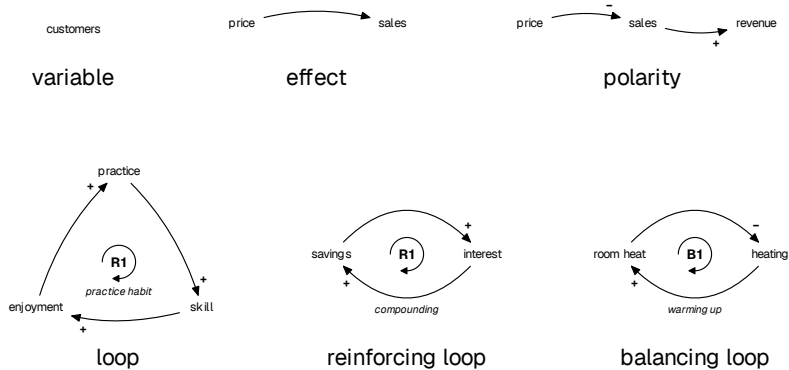
Reasoning ●○○○○ 1 of 5 Polish ●●○○○ 2 of 5

When hunger rises, a person eats. Food eaten fills the stomach, and as fullness grows, hunger falls. Once hunger is low, eating stops until it returns hours later. Show this correction as feedback, not as a sequence of meals. One effect reverses direction, and the loop's kind follows from it.

The brief

- ☐ Use three or four variables.
- ☐ Find the single – effect.
- ☐ Label the loop B1.
- ☐ Name its target-seeking behavior.

Your palette



Draw here

A large grid of dots for drawing the causal loop diagram.

CL 03 A housing shortage and the building boom that overshoots it

Balancing loop with delay

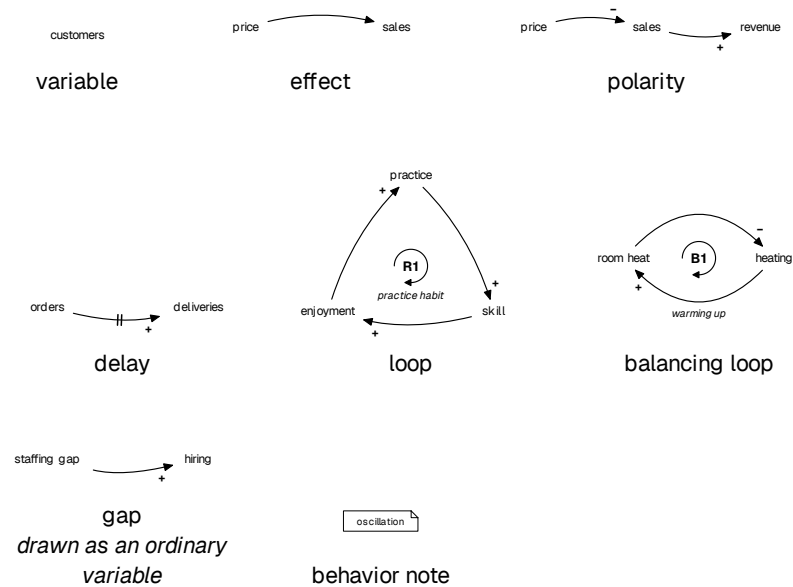
Reasoning ●●○○○ 2 of 5 Polish ●●○○○ 2 of 5

A growing city has fewer homes than its households need, and rents climb. High rents lead developers to start new buildings, which take two to three years to finish. Starts continue while rents stay high, so the homes arrive together and overshoot the need. Draw the intended correction, with the delay on an effect, not in a new variable.

The brief

- ☐ Show the homes needed, the shortage, building starts, and the housing stock.
- ☐ Put a delay on building starts → housing stock.
- ☐ Use one behavior note.
- ☐ Name the likely behavior in it: oscillation.

Your palette



Draw here

CL 04 A friendship group that grows until gatherings feel crowded

Coupled R and B loops

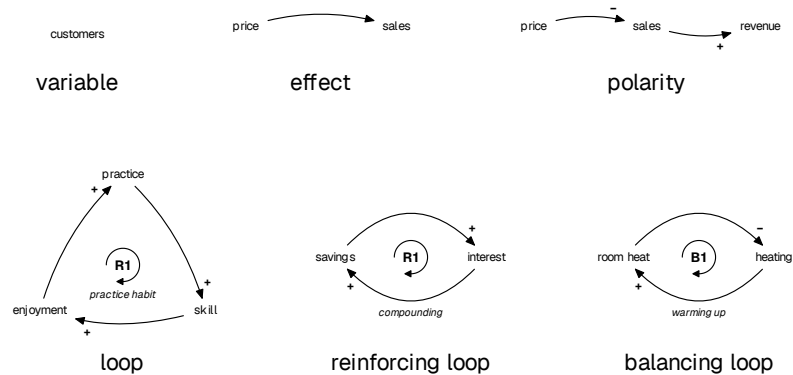
Reasoning ●●○○○ 2 of 5 Polish ●●●○○ 3 of 5

A group of friends meets every Friday evening, and members invite friends of their own; some of those stay. As the group grows, the gatherings get crowded, conversations split up, and members enjoy them less and invite fewer people. Build one reinforcing loop of growth and one balancing loop of crowding around the group's size, which they share.

The brief

- ☐ Create one R loop.
- ☐ Create one B loop.
- ☐ Share at least one variable between them.
- ☐ Place the variables so that no two effects cross.

Your palette



Draw here

CL 05 Borrowing to get to the end of the month

Short-term gain, long-term erosion

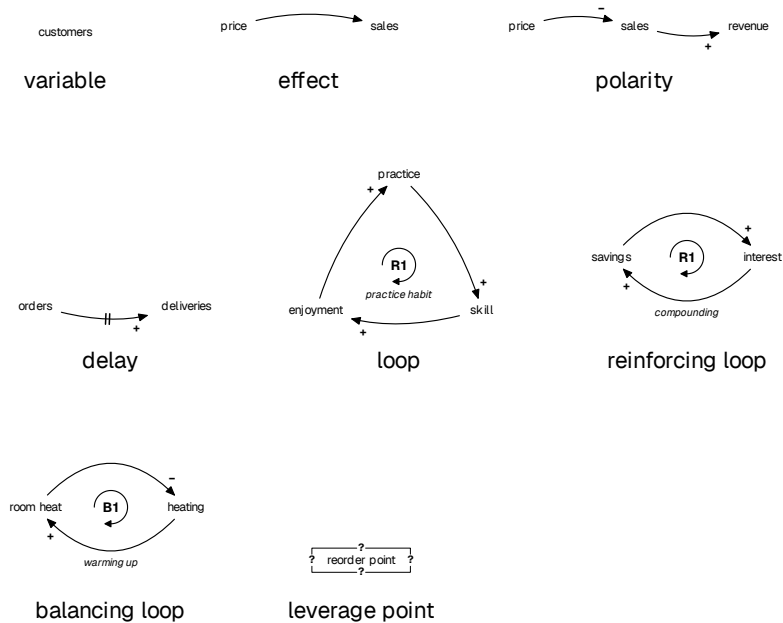
Reasoning ●●●○○ 3 of 5 Polish ●●●○○ 3 of 5

A household's bills outrun its income, and it covers the month's gap with a credit card. The cash closes the gap at once. Weeks later, repayments with interest start taking money from every month, and the gap reopens wider.

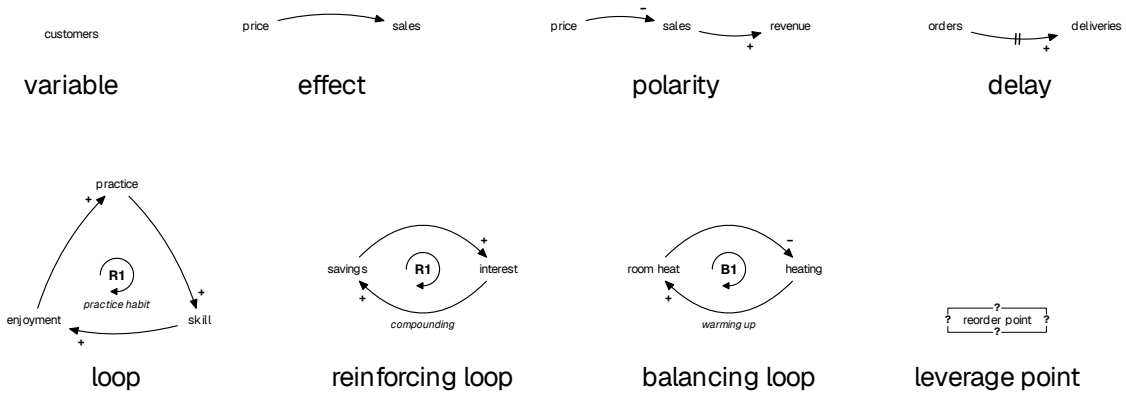
The brief

- ☐ Separate fast relief from slow consequence.
- ☐ Mark at least one delayed effect.
- ☐ Make the variable you would monitor first a leverage point.

Your palette



Draw here

CS 04 Kelsham Primary School: funding that follows its pupils**Your palette**

CS 04 Kelsham Primary School: funding that follows its pupils

Coupled loops, a delay and a leverage point

Reasoning ●●●○○ 3 of 5 Polish ●●●○○ 3 of 5

Kelsham Primary School is paid £4,800 a year for each pupil, set from the count each October and paid through the school year after it. In October 2020 it had 126 pupils in five classes. By October 2023 it had 108, the governors could pay for four teachers, and Years 3 and 4 became one class. Ruth Okafor, the head teacher, hears from some parents that mixed-age classes are why they chose Brayford Primary School, six miles away, where classes hold up to 30. Others stay because Kelsham's classes are smaller: 88 pupils in four classes in October 2026. Tom Hale, who chairs the governors, asks where the school could act. Draw both stories as loops through the pupils on roll, and mark the variable you would change first as a leverage point.

The brief

- ☐ Close one reinforcing loop through the school's funding and its teachers.
- ☐ Close one balancing loop through class size.
- ☐ Let the two loops share at least one variable.
- ☐ Mark the delay the October count makes.
- ☐ Make the variable you would change first a leverage point.
- ☐ Name each loop by what it does.

Your palette

On the page before this sheet.

Draw here

Diagram drawing area with a grid of dots.

Chapter 5

Delays, External Drivers, and Competing Loops

CL 06 A food bank in a downturn

Multiple loops and a boundary

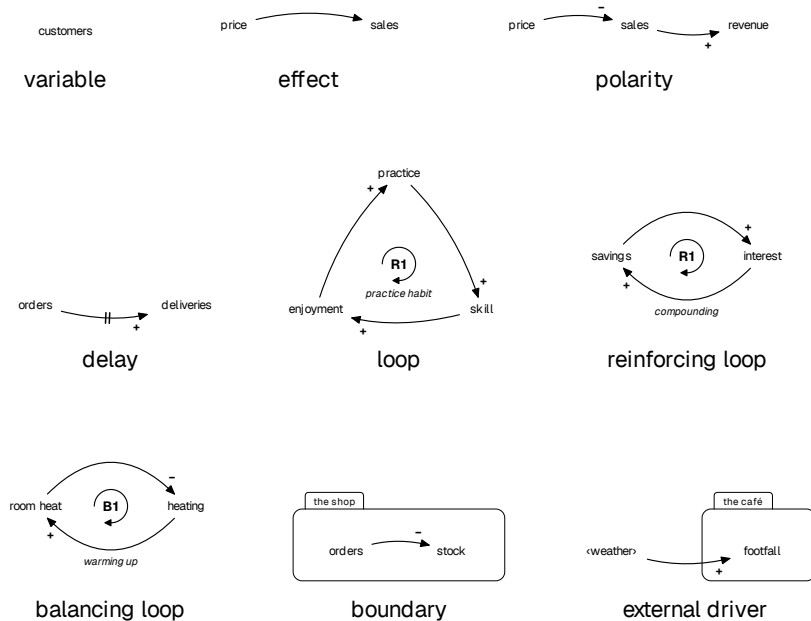
Reasoning ●●●○○ 3 of 5 Polish ●●●●○ 4 of 5

Layoffs at local employers reach a volunteer food bank months later, as families' savings run out. The food bank recruits volunteers, but the regulars give up shifts to train them, so more need goes unmet until trained volunteers take shifts weeks later. Keep layoffs outside the food bank's boundary.

The brief

- ☐ Draw the food bank's boundary and name it.
- ☐ Include one external driver.
- ☐ Show two delays.
- ☐ Close two loops and name each one.

Your palette



Draw here

CL 07 Antibiotics and the resistance they breed

Policy resistance

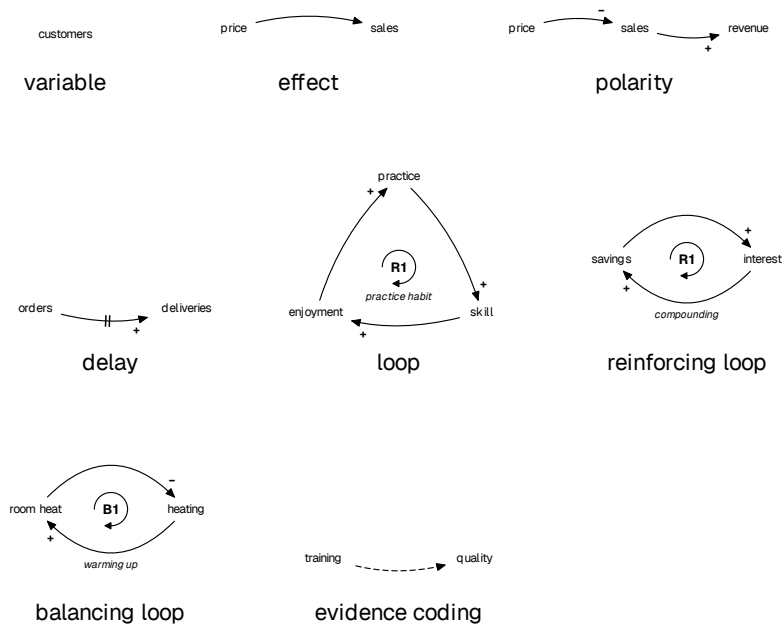
Reasoning ●●●●○ 4 of 5 Polish ●●●●○ 4 of 5

Doctors prescribe antibiotics to cure infections, and cures bring infections down. Over years, heavy use breeds resistant bacteria: treatments fail, infections spread, and prescribing rises. Drug makers might answer the failures with new antibiotics a decade later, but new antibiotics earn little, so that effect is uncertain.

The brief

- ☐ Draw at least three loops.
- ☐ Make the loops interact by sharing variables.
- ☐ Code at least one uncertain effect as a hypothesis.
- ☐ Code an effect as a hypothesis only where you are unsure of it.
- ☐ Keep the evidence legend small and inside the canvas.

Your palette



Draw here

In the lab, with the brief's structure checked as you draw: thinking-in-diagrams.aryehnielsen.com/feedback/delays-drivers-and-competing-loops/#exercise-causal-loop-07

CL 08 A parent who finishes the homework

Shifting the burden archetype

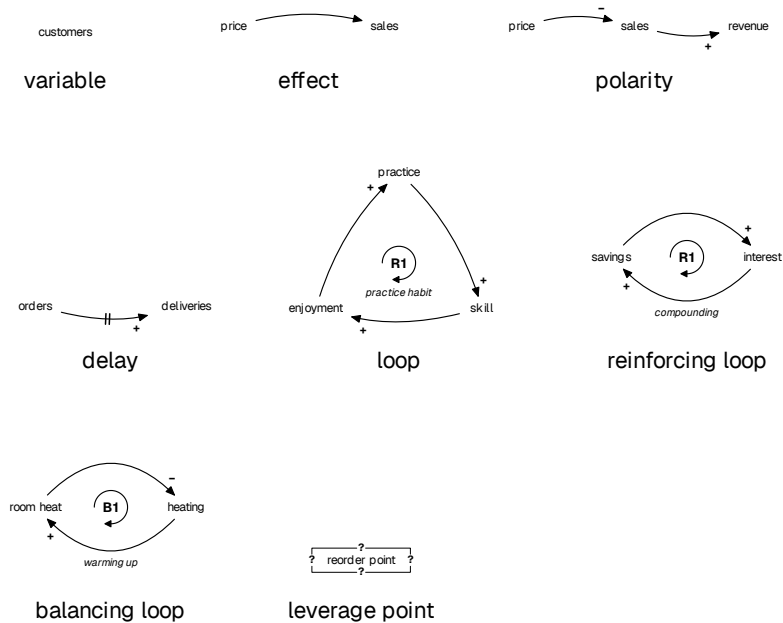
Reasoning ●●●●○ 4 of 5 Polish ●●●●○ 4 of 5

A child stuck on homework turns to a parent, who on rushed evenings finishes it. Tonight's homework gets done, but the child comes to rely on the help and tries less, and the skill that would let the child finish alone builds only over weeks.

The brief

- ☐ Use the shifting-the-burden structure.
- ☐ Close two balancing loops: the quick relief and the slower fundamental response.
- ☐ Close a reinforcing loop through which the relief builds dependence.
- ☐ Show the relief crowding out the fundamental response with a – effect.
- ☐ Name every loop by behavior, not topic.
- ☐ Create a clear visual hierarchy: main story first, detail second.

Your palette



Draw here

In the lab, with the brief's structure checked as you draw: thinking-in-diagrams.aryehnielsen.com/feedback/delays-drivers-and-competing-loops/#exercise-causal-loop-08

CL 09 An old town and its visitors

Competing viewpoints and nonlinear pressure

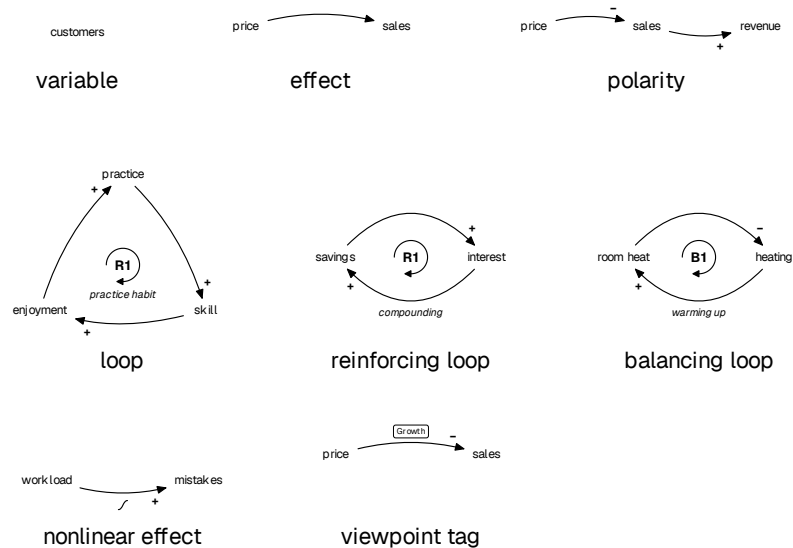
Reasoning ●●●●● 5 of 5 Polish ●●●●● 5 of 5

Visitors to an old town fill holiday lets, and more lets draw more visitors; the council limits lets as crowding grows. Residents leave as lets replace homes and as crowding rises: slowly, then fast once summer visitors outnumber them. Local shops close, and more residents leave. Tag what residents, shopkeepers and the council each stress.

The brief

- ☐ Include two reinforcing loops: visitor growth and the loss of residents.
- ☐ Include a balancing control loop.
- ☐ Mark one threshold as a nonlinear effect.
- ☐ Tag three viewpoints without using color.

Your palette



Draw here

CL 10 A forest region and its fires

Your palette

customers

variable

price → sales

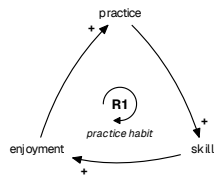
effect

price $\xrightarrow{-}$ sales $\xrightarrow{+}$ revenue

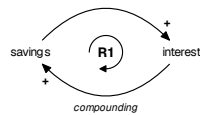
polarity

orders $\xrightarrow{+}$ deliveries

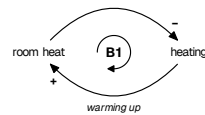
delay



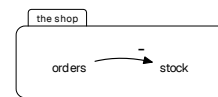
loop



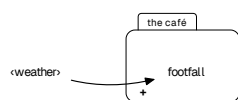
reinforcing loop



balancing loop



boundary



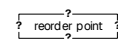
external driver

workload $\xrightarrow{\sim}$ mistakes

nonlinear effect

training $\xrightarrow{---}$ quality

evidence coding



leverage point

oscillation

behavior note

price $\xrightarrow{\text{Growth}}$ sales

viewpoint tag

CL 10 A forest region and its fires

Publication-ready multi-loop model

Reasoning ●●●●● 5 of 5 Polish ●●●●● 5 of 5

Small fires once thinned a dry forest's undergrowth. Crews now put out small and severe fires alike, so dry fuel builds for decades and the fires that escape burn hotter. Drought years make severe fires likelier. Whether severe fires lead agencies to fund prescribed burns, which thin the fuel, is uncertain.

The brief

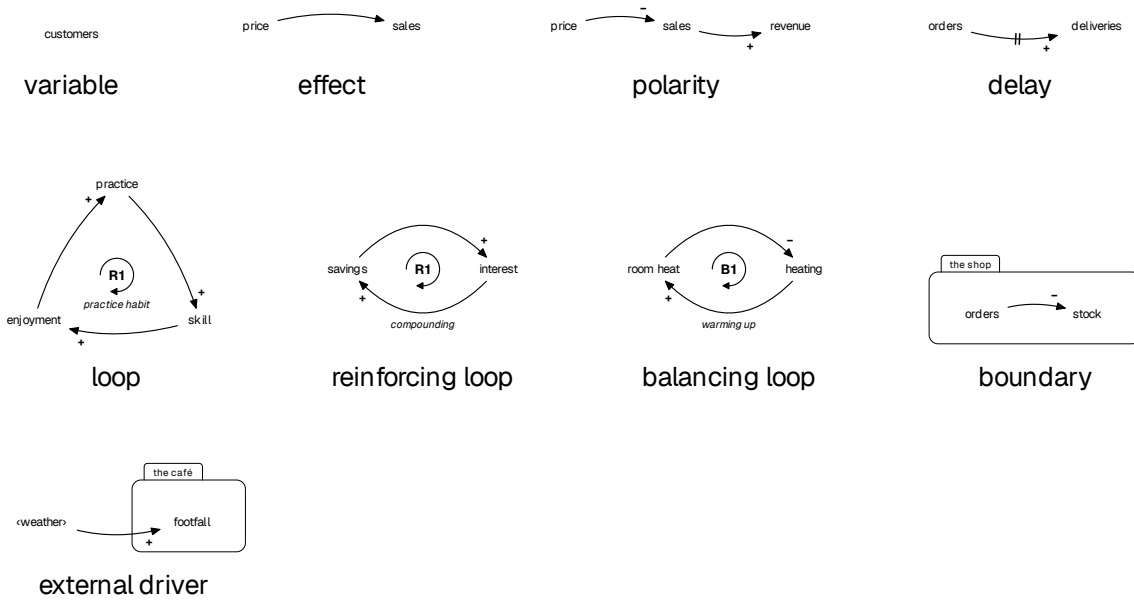
- ☐ Synthesize four or more named loops.
- ☐ Add drought years as an external driver, outside a named boundary.
- ☐ Use evidence coding, declared in the legend.
- ☐ Polish spacing, label placement, and reading order.

Your palette

On the page before this sheet.

Draw here

Grid area for drawing the causal loop diagram.

CS 05 Kelsham Primary School: births, new homes and two loops**Your palette**

CS 05 Kelsham Primary School: births, new homes and two loops

External drivers, a delay of four years and competing loops

Reasoning ●●●○○ 3 of 5 Polish ●●●○○ 3 of 5

David Brennan forecasts Kelsham Primary School's starters from the births in its villages four years before. Births fell from 22 in 2016 to 11 in 2025, so the starters go on falling until 2029, whatever the school does. The first of the 60 homes at Mill Lane will be lived in from 2027, and he forecasts 0.25 children of primary school age for each, 15 children in all, joining in any year group. Inside the school, its funding still follows its pupils a school year behind each October count, and parents still weigh mixed-age classes against small ones. Draw the loops through the roll inside the school's boundary, with births and the new homes outside it.

The brief

- ☐ Draw the school's boundary and name it.
- ☐ Keep births in the villages and the homes at Mill Lane outside it as external drivers.
- ☐ Mark the four years from births to starters, and the October count, as delays.
- ☐ Close one reinforcing loop through the school's funding.
- ☐ Close one balancing loop through class size.
- ☐ Let the two loops share variables, so they compete.
- ☐ Name each loop by what it does.

Your palette

On the page before this sheet.

Draw here

Diagram drawing area with a grid of dots.

Chapter 6

What Accumulates

SF 01 Words a language learner knows

One stock and one inflow

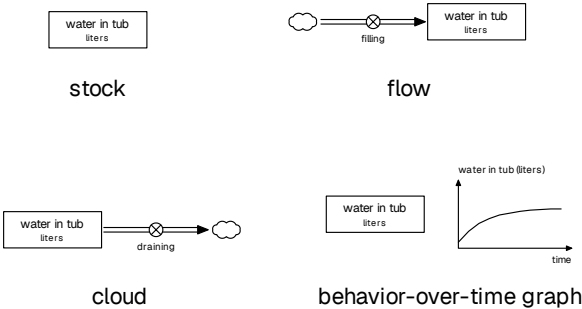
Reasoning ●○○○○ 1 of 5 Polish ●○○○○ 1 of 5

Lena is learning Portuguese from a box of flashcards. She knows about 300 words today and learns about forty new ones a week, a few each evening. Leave forgetting out: draw only the words she knows and the words she learns. Count what she knows in words, and time in weeks.

The brief

- ☐ Draw one stock: the words Lena knows.
- ☐ Fill it with one inflow.
- ☐ Draw one cloud, where the new words come from.
- ☐ Add a behavior-over-time graph of the stock, rising steadily.
- ☐ The stock is counted at an instant, in words; the flow per week, in words per week.

Your palette



Draw here

A large grid of dots for drawing.

SF 02 Firewood at a scout camp

Inflow and outflow

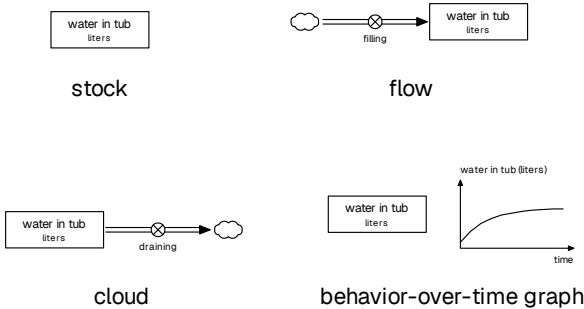
Reasoning ●○○○○ 1 of 5 Polish ●●○○○ 2 of 5

A scout patrol camps in a field for the weekend. Through Saturday afternoon the scouts gather fallen branches into a woodpile by the fire, about thirty kilograms an hour. After dark they gather about five kilograms an hour, and the campfire burns about twelve kilograms an hour. Count the wood in kilograms, and time in hours.

The brief

- ☐ Draw one inflow: the wood the scouts gather.
- ☐ Draw one outflow: the wood the fire burns.
- ☐ Put a cloud at each end, where the wood comes from and where it goes.
- ☐ Add a behavior-over-time graph of the stock, falling steadily.
- ☐ The graph covers the evening, after gathering slows.

Your palette

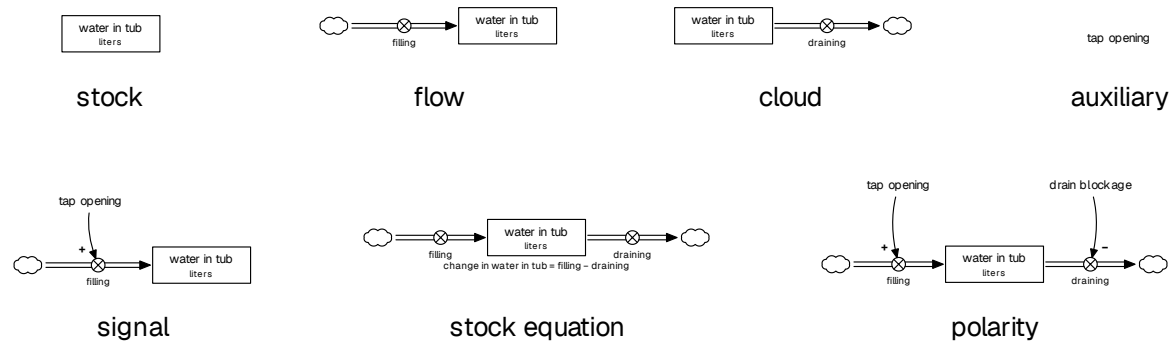


Draw here

A large grid of dots for drawing.

SF 03 Goats on a family smallholding

Your palette



SF 03 Goats on a family smallholding

Net flow and equations

Reasoning ●●○○○ 2 of 5 Polish ●●○○○ 2 of 5

The Mensah family keeps goats on a smallholding: twenty at the start of the year. Each spring the herd has about one kid for every goat in it, so a bigger herd has more kids. Each year the family buys about two goats at market and sells about fifteen. Count the herd in goats, and time in years.

The brief

- ☐ Draw two inflows: kids born, and goats bought.
- ☐ Draw one outflow: goats sold.
- ☐ Add an auxiliary for the kids each goat has in a year.
- ☐ Draw a path of signals from the herd to kids born.
- ☐ Show the herd's stock equation.
- ☐ Kids born reads two signals: one from the herd, one from kids per goat per year.

Your palette

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Draw here

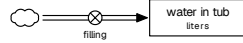
Diagram drawing area with a grid of dots.

SF 04 Diesel for an island's power station

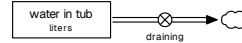
Your palette



stock



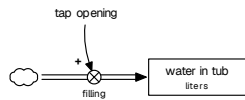
flow



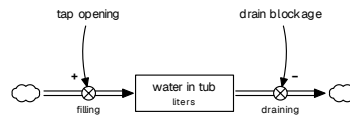
cloud

tap opening

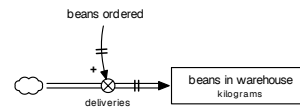
auxiliary



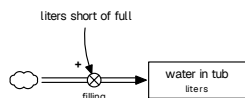
signal



polarity

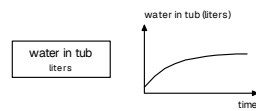


delay



gap

*drawn as an ordinary
variable*



behavior-over-time
graph

SF 05 Bottles in a deposit-return scheme

Connected stocks and conservation

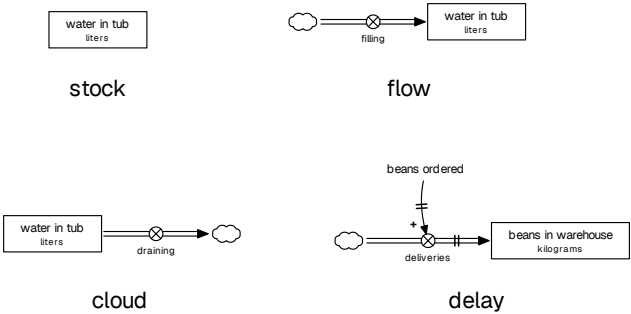
Reasoning ●●●○○ 3 of 5 Polish ●●●○○ 3 of 5

A country runs a deposit-return scheme for drink bottles. Bottlers deliver bottles to shops, where a bottle waits about two weeks on a shelf. A shopper keeps a bottle about five weeks before taking it back to a return machine; about one bottle in ten is thrown away instead. The machines are emptied twice a week, and the bottles collected for recycling. Count every stock in bottles, and time in weeks.

The brief

- ☐ Draw three stocks, one for each place a bottle waits: on shop shelves, with shoppers, in return machines.
- ☐ Join the stocks with transfers, so a bottle leaving one stage arrives in the next.
- ☐ Mark one material delay.
- ☐ The three stocks sit in a row in the order bottles pass through, and the delay is on the flow out of the stage where bottles wait longest.

Your palette



Draw here

A large grid of dots for drawing the diagram.

CS 06 Kelsham Primary School: the roll, filled and drained

One stock, its two flows and the years of the roll

Reasoning ●●○○○ 2 of 5 Polish ●●○○○ 2 of 5

Ruth Okafor counts the pupils on roll each October: 126 in October 2020, 95 in October 2025 and 88 in October 2026. Children start in Reception each September, and pupils leave, Year 6 for secondary school and others for other schools. In the year to October 2026, 9 children started and 16 pupils left; in the year to October 2020, 19 started and 20 left. In every year between, fewer started than left. Count the roll in pupils, and time in years.

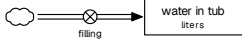
The brief

- ☐ Draw one stock: the pupils on roll, counted in pupils.
- ☐ Fill it with one inflow: the children starting each September.
- ☐ Drain it with one outflow: the pupils leaving.
- ☐ Show the roll's stock equation.
- ☐ Add a behavior-over-time graph of the roll, falling steadily.
- ☐ The stock equation balances for the year to October 2026: 95 pupils, plus 9 starters, less 16 leavers, is 88.

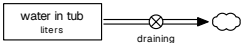
Your palette



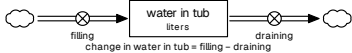
stock



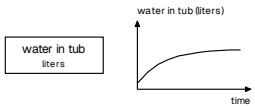
flow



cloud



stock equation



behavior-over-time graph

Draw here

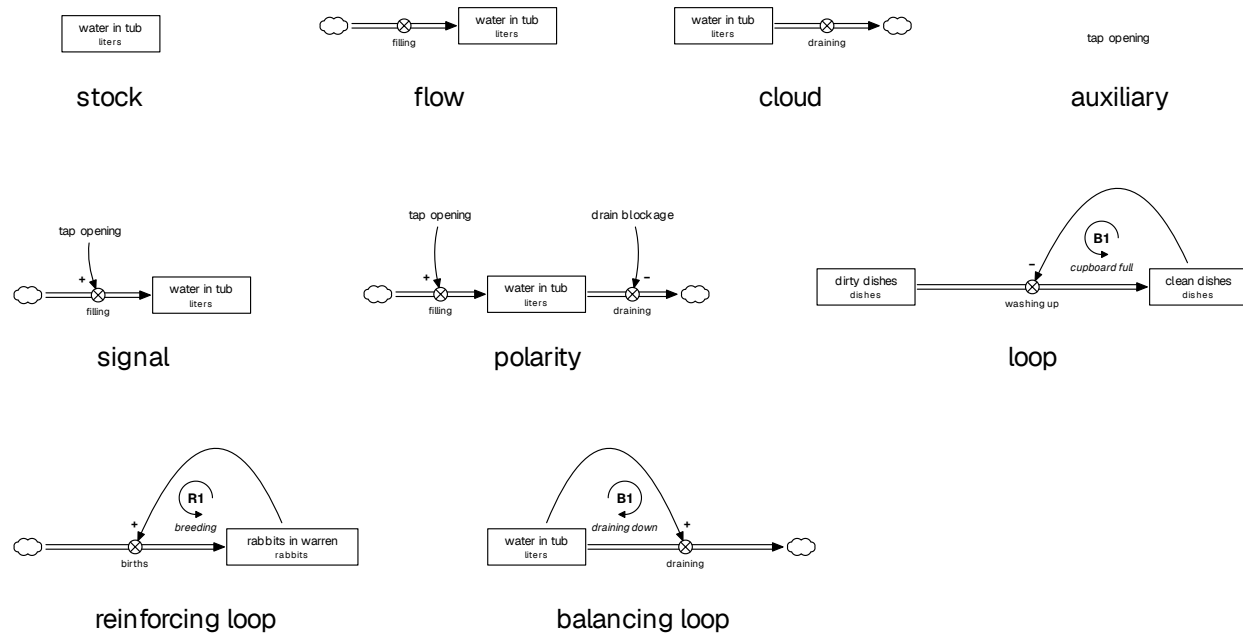
Grid area for drawing diagrams.

Chapter 7

Stocks Inside Feedback

SF 06 Players of an online game

Your palette



SF 06 Players of an online game

Stocks embedded in feedback

Reasoning ●●●○○ 3 of 5 Polish ●●●●○ 4 of 5

Players around the world join an online puzzle game only by invitation: each day about one player in fifty invites a friend, who joins. Matches run on a fixed number of servers, so the more players there are, the longer each waits for a match, and the longer the wait, the more players quit each day. Count the stock in players, and time in days.

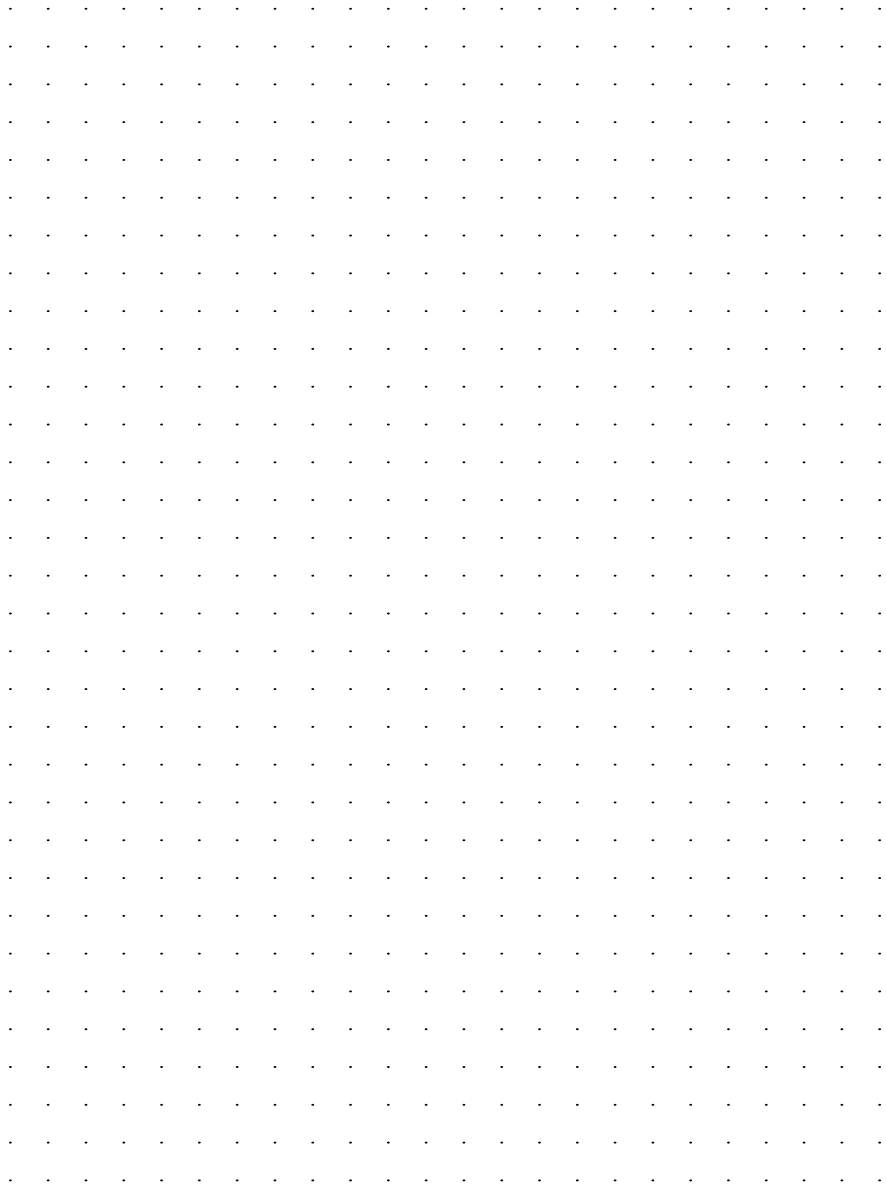
The brief

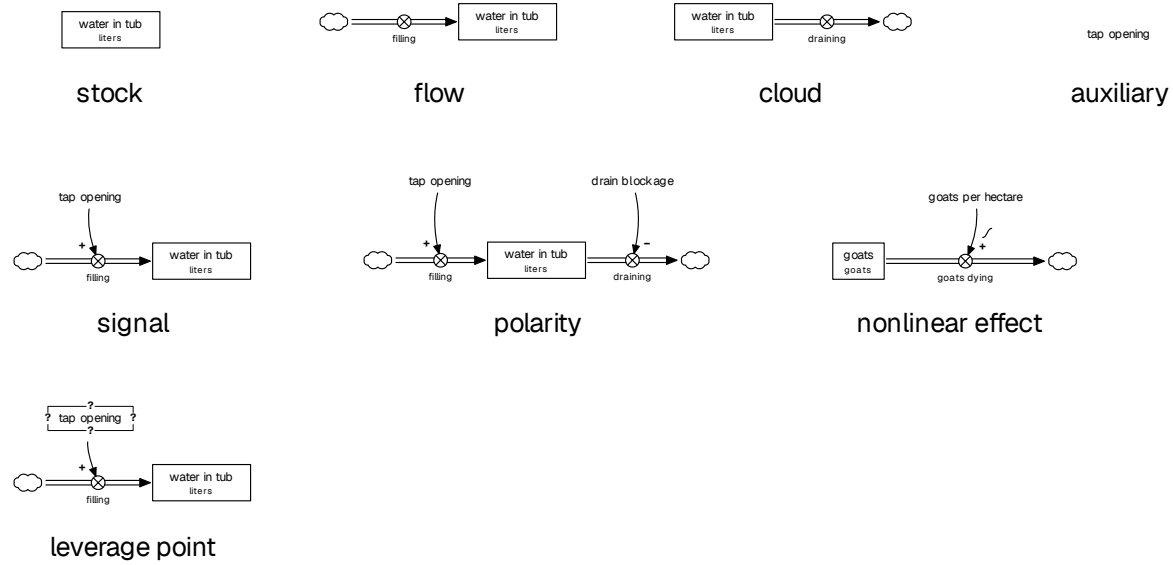
- ☐ Draw two flows: players joining, and players quitting.
- ☐ Declare one reinforcing loop.
- ☐ Declare one balancing loop.
- ☐ Run each loop through a flow, so that it passes through the stock.
- ☐ Each loop is named for what goes around it, such as word of mouth or queue frustration.

Your palette

On the page before this sheet.

Draw here



SF 07 Dogs at a rescue shelter**Your palette**

SF 07 Dogs at a rescue shelter

Capacity and nonlinear rates

Reasoning ●●●●○ 4 of 5 Polish ●●●●○ 4 of 5

A town's dog rescue shelter has 40 places. Owners and the council refer about eight dogs a week to its waiting list, and owners withdraw about one a week after finding a home elsewhere. Staff take dogs in from the list, but intake slows sharply as the places fill: about six dogs a week while 30 are in care, almost none at 38. Crowding lengthens stays: a dog waits about four weeks for adoption while the shelter is half full, seven while it is full. The manager proposes recruiting foster homes, each adding a place. Count both stocks in dogs, and time in weeks.

The brief

- ☐ Draw two stocks: dogs on the waiting list, and dogs in care.
- ☐ Join them with intake, a transfer.
- ☐ Mark the signal by which filling places slow intake as nonlinear.
- ☐ Mark what foster homes would add to as the one leverage point.
- ☐ The nonlinear signal reaches intake through occupancy.

Your palette

On the page before this sheet.

Draw here

Diagram drawing area with a grid of dots.

SF 08 Seedlings raised on a windowsill

Aging chain

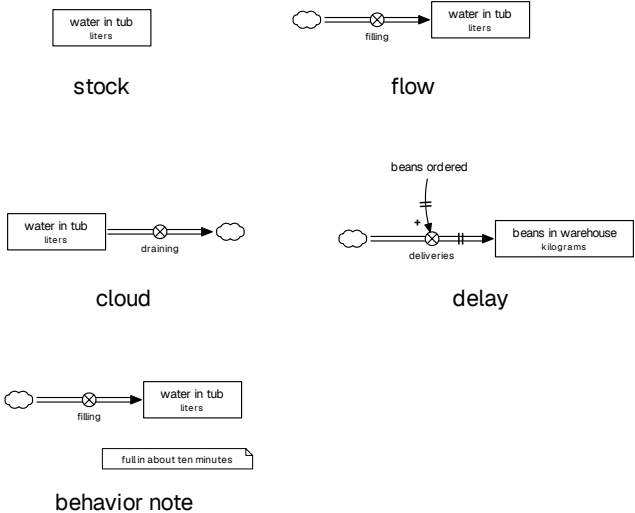
Reasoning ●●●●○ 4 of 5 Polish ●●●●○ 4 of 5

Amira raises tomatoes and peppers from seed on her kitchen windowsill. Each spring she sows about 60 seeds in trays; about one in five fails to sprout, and the rest come up within two weeks. Seedlings grow on the sill for about five weeks, and a few die of damping off. Before going into the garden, each seedling spends exactly ten days in a cold frame, hardening off, and cold nights kill a few there. The cold frame holds 24, so seedlings wait on the sill until it has room. Count every stage in seedlings, a seed counted from the day it is sown, and time in days.

The brief

- ☐ Draw a stock for each stage: sown in trays, seedlings on the sill, in the cold frame, planted out.
- ☐ Chain the stages with transfers, so a seedling leaving one arrives in the next.
- ☐ Mark the ten days in the cold frame as a material delay.
- ☐ Add a behavior note.
- ☐ Where seedlings pile up, and why, is in the note.

Your palette



Draw here

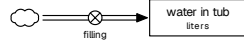
A large grid of dots for drawing.

SF 09 A city's bike-share fleet

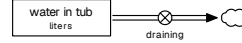
Your palette



stock



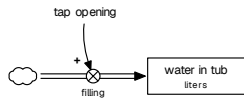
flow



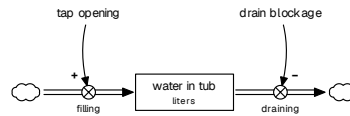
cloud

tap opening

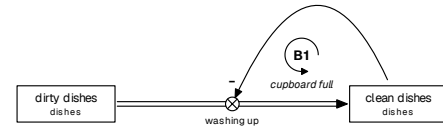
auxiliary



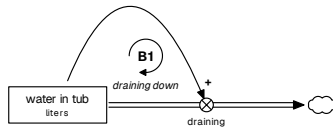
signal



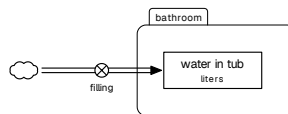
polarity



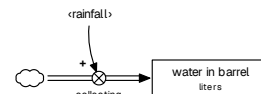
loop



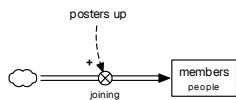
balancing loop



boundary



external driver



evidence coding

Multiple stocks, a boundary and evidence

A city's bike-share scheme has docks on a hilltop and by the river. Riders seldom pedal uphill, so rides between the two run downhill and bikes collect at the riverside docks; on rainy days about a third fewer bikes are ridden. Vans collect bikes from the riverside docks and bring them to the scheme's workshop, where mechanics check and repair them; the vans then deliver them to the hilltop docks. Bikes beyond repair are scrapped. Staff record rides, collections and deliveries each day. They believe the vans deliver more bikes the lower the hilltop docks run, but nobody has checked. Rain, and scrapped bikes once they leave, lie outside the scheme. Count every stock in bikes, and time in days.

- ☐ Draw a stock for each place bikes wait: the hilltop docks, the riverside docks, the workshop.
- ☐ Join the stocks with transfers, so no bike appears or vanishes between them.
- ☐ Declare a balancing loop through the vans' deliveries.
- ☐ Draw the scheme's boundary, with rain outside it as an external driver.
- ☐ Code the signal you judge less supported as a hypothesis.
- ☐ Rain's signal rests on ride counts and is solid; the vans' response, a belief, is the hypothesis, and the legend shows the coding.

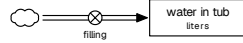
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SF 10 Teachers in a country's schools

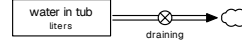
Your palette



stock



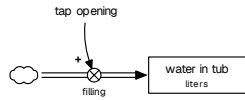
flow



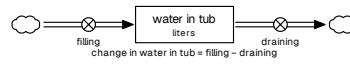
cloud

tap opening

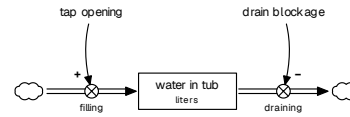
auxiliary



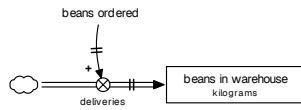
signal



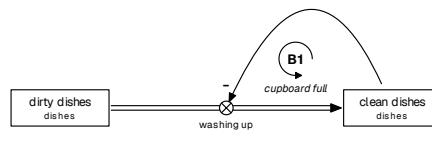
stock equation



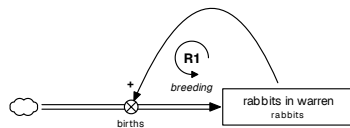
polarity



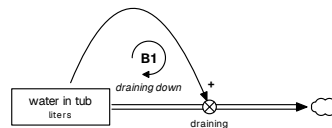
delay



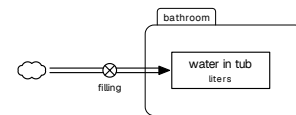
loop



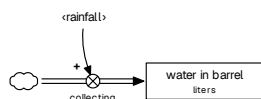
reinforcing loop



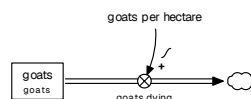
balancing loop



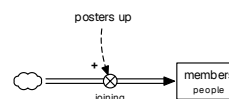
boundary



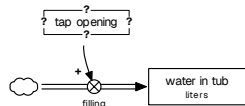
external driver



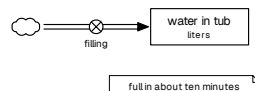
nonlinear effect



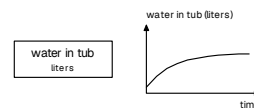
evidence coding



leverage point



behavior note

behavior-over-time
graph

SF 10 Teachers in a country's schools

A complete model

Reasoning ●●●●● 5 of 5 Polish ●●●●● 5 of 5

Student teachers take a one-year course; about one in ten drops out. Newly qualified teachers count as experienced after three years, and about one in eight leaves each year before then; about one experienced teacher in fourteen leaves each year. Pupil numbers are rising, and the fewer experienced teachers there are, the heavier each one's workload. In exit surveys, teachers name workload as their main reason for leaving, and resignations rise a year or two after workload does. Head teachers believe that mentoring by experienced teachers keeps new teachers from leaving, but nobody has measured it. The education ministry proposes funding more training places; whether they would fill is untested. Pupil numbers lie outside the schools. Count every stage in teachers, student teachers included, and time in years.

The brief

- ☐ Draw a stock for each stage: student teachers, newly qualified teachers, experienced teachers.
- ☐ Join the stages with transfers.
- ☐ Declare two or more loops.
- ☐ Run every loop through a stock.
- ☐ Code each signal you judge less supported as a hypothesis.
- ☐ Mark what the ministry proposes to change as the one leverage point.
- ☐ Mark the year or two between heavier workload and more resignations as a signal delay.
- ☐ The leverage point's signal is a hypothesis, as mentoring's is; the legend shows the coding, and every other signal is solid.

Your palette

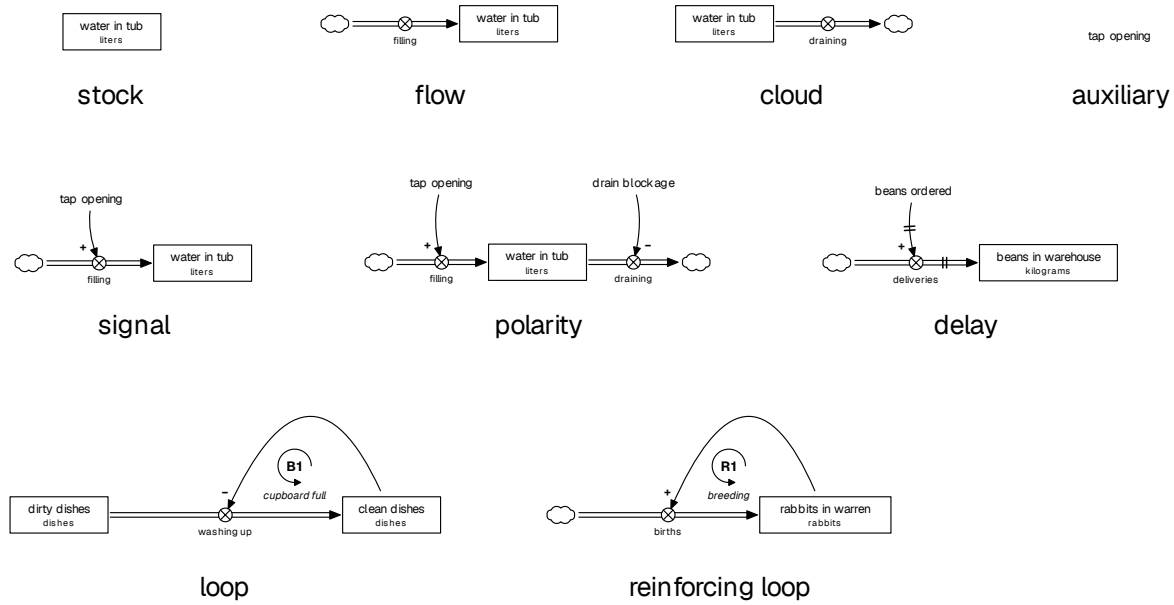
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Draw here

Diagram drawing area with a grid of dots.

CS 07 Kelsham Primary School: four classes in a chain

Your palette



CS 07 Kelsham Primary School: four classes in a chain

A chain of stocks, and a loop through the flow that fills it

Reasoning ●●●●○ 4 of 5 Polish ●●●●○ 4 of 5

Since 2023 Kelsham Primary School has taught four classes: Reception, Years 1 and 2, Years 3 and 4, and Years 5 and 6. Children start in Reception each September; each September after that every pupil moves up a year, those finishing Reception, Year 2 and Year 4 into the next class, and Year 6 leaves for secondary school. Each October's count of every pupil sets the school's funding for the school year after it, at £4,800 a pupil. With less funding, Years 3 and 4 were taught as one class, and Priya Shah and other parents weigh mixed-age classes when they choose a school for a child about to start. Leave out pupils who move school during a school year. Count every class in pupils, and time in years.

The brief

- ☐ Draw a stock for each class: Reception, Years 1 and 2, Years 3 and 4, Years 5 and 6.
- ☐ Join the classes with transfers, as pupils move up each September.
- ☐ Close one reinforcing loop from the classes through the school's funding to the flow of children starting.
- ☐ Run the loop through a stock.
- ☐ Mark the school year between the October count and the funding it sets as a signal delay.
- ☐ The October count reads every class, not only Reception: the funding follows every pupil on roll.

Your palette

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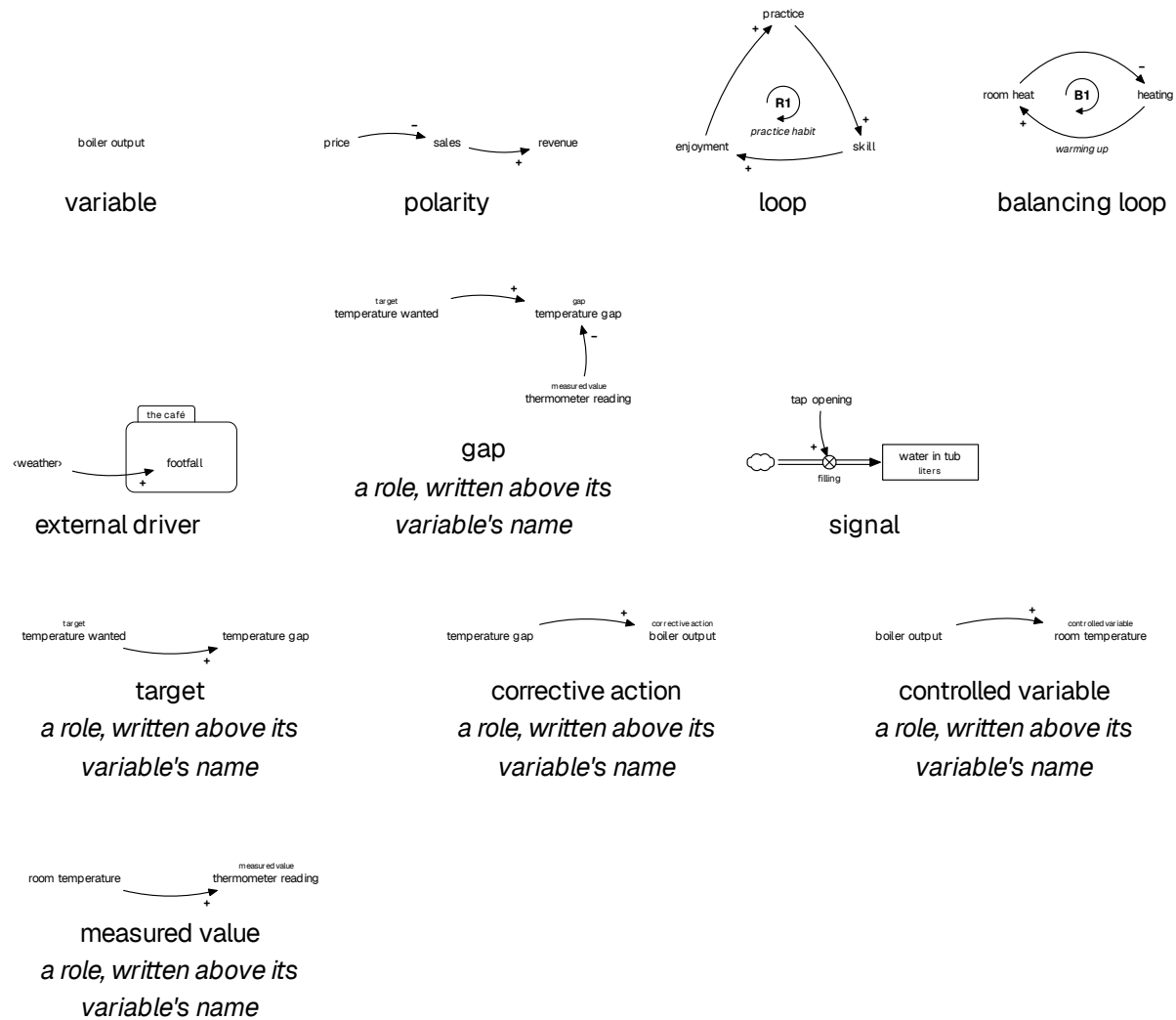
Draw here

Chapter 8

Sense, Compare, Correct

FC 01 Fresh air in a choir's rehearsal room

Your palette



FC 01 Fresh air in a choir's rehearsal room

One balancing loop that holds a target

Reasoning ●○○○○ 1 of 5 Polish ●○○○○ 1 of 5

Forty singers rehearse for two hours in a room with its windows shut, and every breath adds carbon dioxide to the air. A meter on the wall shows the carbon dioxide in the air, in parts per million. The caretaker has set the ventilation fan to hold the air near 1,000 parts per million: the further the meter's reading rises above that, the faster the fan runs, and the faster it runs, the more carbon dioxide it carries out of the room.

The brief

- ☐ Draw one control loop of five variables, each with its part: the target, the gap, the fan's speed as the corrective action, the carbon dioxide in the air as the controlled variable, and the meter's reading as the measured value.
- ☐ Declare the control loop balancing.
- ☐ Draw the singers' breathing as an external driver acting on the carbon dioxide in the air.
- ☐ The fan's speed and the carbon dioxide in the air are two variables.

Your palette

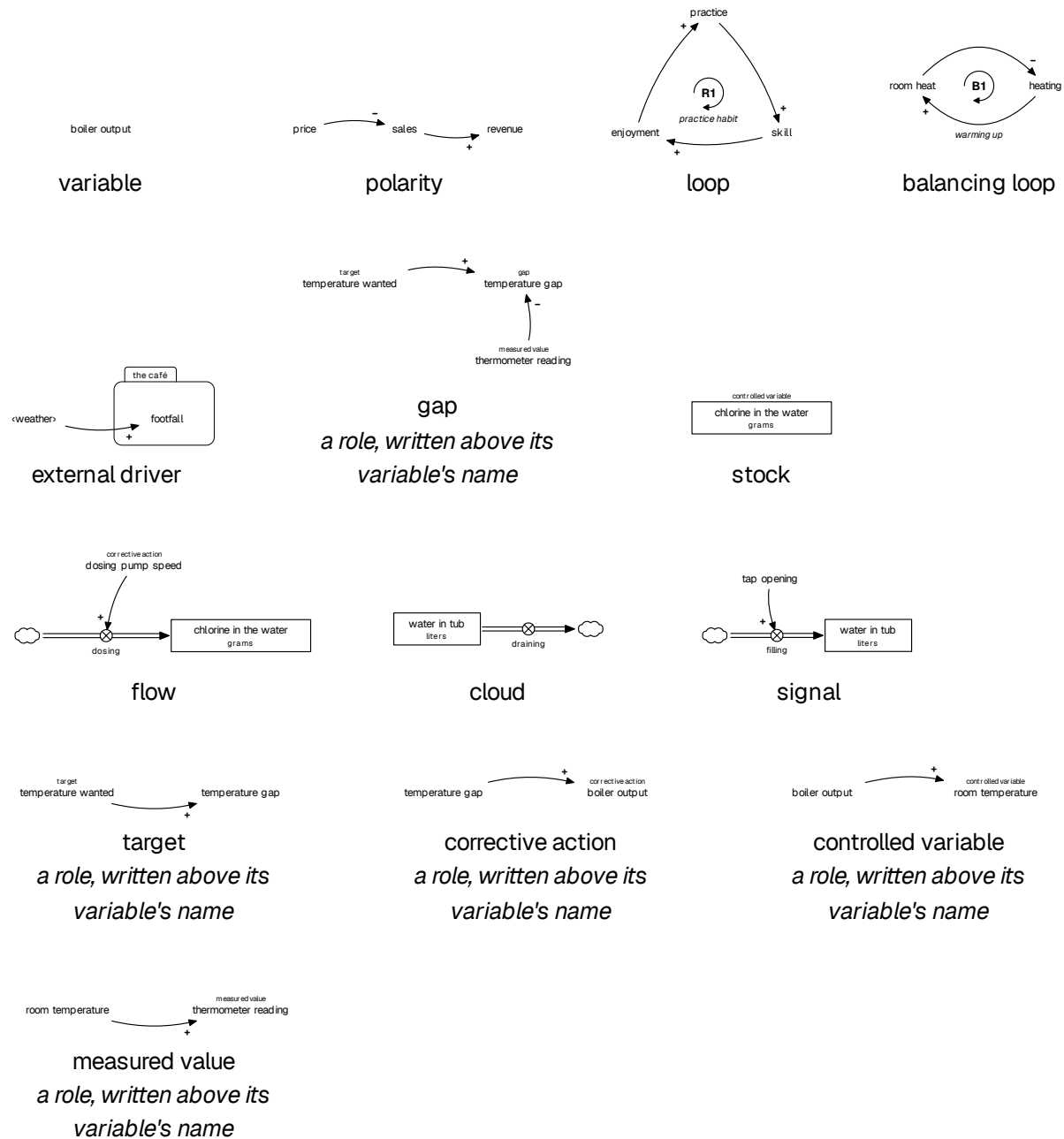
On the page before this sheet.

Draw here

Grid area for drawing the control loop.

FC 02 Chlorine in a town's outdoor swimming pool

Your palette



FC 02 Chlorine in a town's outdoor swimming pool

A target, a corrective action, and what uses it up

Reasoning ●○○○○ 1 of 5 Polish ●●○○○ 2 of 5

A town's outdoor swimming pool holds about 500 cubic meters of water, and the staff keep about 750 grams of chlorine in the water. A dosing pump adds chlorine from a tank: the faster it runs, the faster chlorine goes in. Sunshine and swimmers use chlorine up, faster on hot, crowded afternoons. Every two hours the staff test the water and set the pump's speed by how far the result falls short of 750 grams. Count the chlorine in grams, and time in hours.

The brief

- ☐ Draw the chlorine in the water as one stock, the controlled variable.
- ☐ Draw sunshine and swimmers as an external driver acting on the flow that uses chlorine up.
- ☐ Close one control loop through the flow that adds chlorine: the gap, the pump's speed, the chlorine in the water and the test result.
- ☐ The target and the test result name the same quantity, in grams.

Your palette

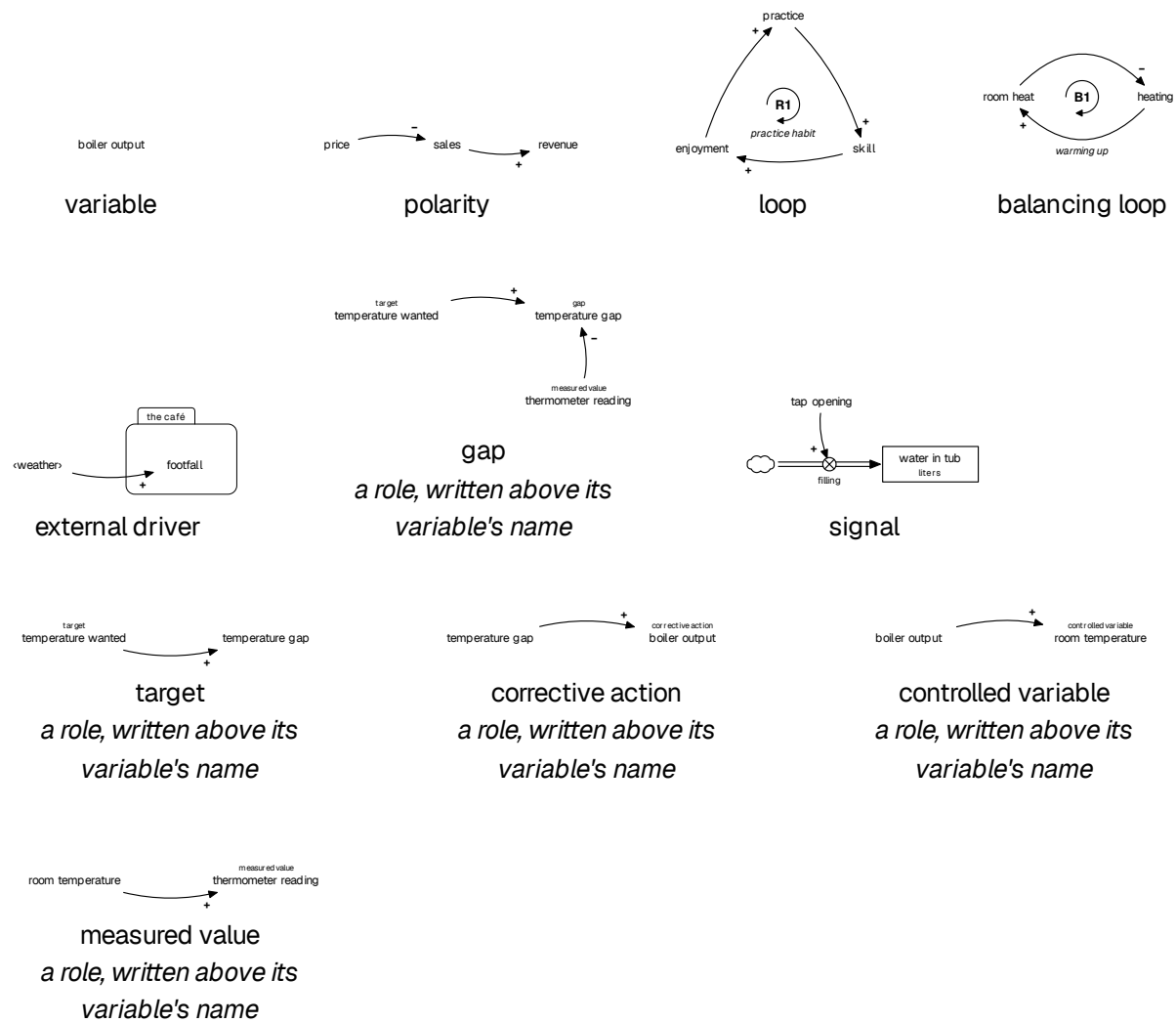
On the page before this sheet.

Draw here

Grid area for drawing the diagram.

FC 03 A kayaker crossing a river

Your palette



FC 03 A kayaker crossing a river

An external driver acting on the controlled variable

Reasoning ●●○○○ 2 of 5 Polish ●●○○○ 2 of 5

A kayaker is learning to cross a river. She aims the bow at a tree on the far bank, and the current pushes the bow downstream, away from the tree. She sees how far the bow has swung off the tree and takes extra strokes on the downstream side, which turn the bow back upstream, until it points at the tree again. Halfway across she picks a new tree. Count a heading as an angle: the further upstream the bow points, the larger the angle.

The brief

- ☐ Draw the current's push as an external driver acting on the boat's heading.
- ☐ Close one control loop: the gap, her extra strokes, the boat's heading and the heading as she sees it.
- ☐ Draw one target: the heading to the tree she aims at.
- ☐ The new tree halfway across is her choice: no signal ends at the target.

Your palette

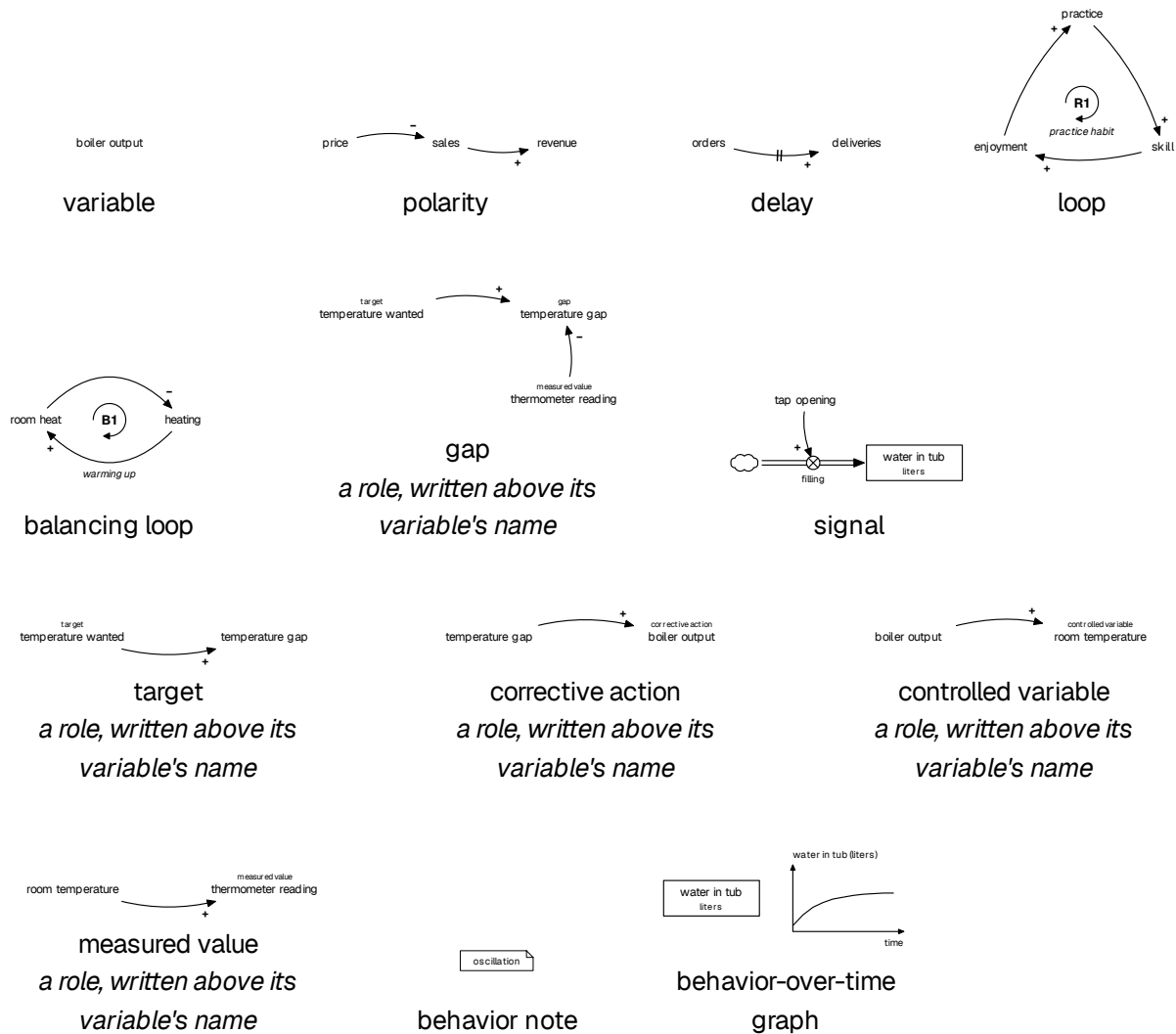
On the page before this sheet.

Draw here

Grid area for drawing.

FC 04 A shower whose hot water arrives late

Your palette



FC 04 A shower whose hot water arrives late

A corrective action that arrives late

Reasoning ●●○○○ 2 of 5 Polish ●●●○○ 3 of 5

Sofia wants her morning shower at about 38 °C. After a turn of the tap, the water at the shower head changes about five seconds later, once the hot water reaches it. She feels the water, and while it feels too cold she keeps turning the tap toward hot. By the time the hot water arrives she has turned the tap too far, so the water runs too hot; she turns the tap back, and the water swings too hot and too cold before it settles near 38 °C.

The brief

- ☐ Mark the seconds between a turn of the tap and the water at the shower head as a delay on the forward path.
- ☐ Close one control loop: the gap, the tap, the water temperature at the head and how hot the water feels.
- ☐ Add a behavior-over-time graph of the water temperature at the head, overshooting and swinging, with a line at the temperature she wants.
- ☐ The delay sits between the tap and the water at the head, not between the water and her skin.

Your palette

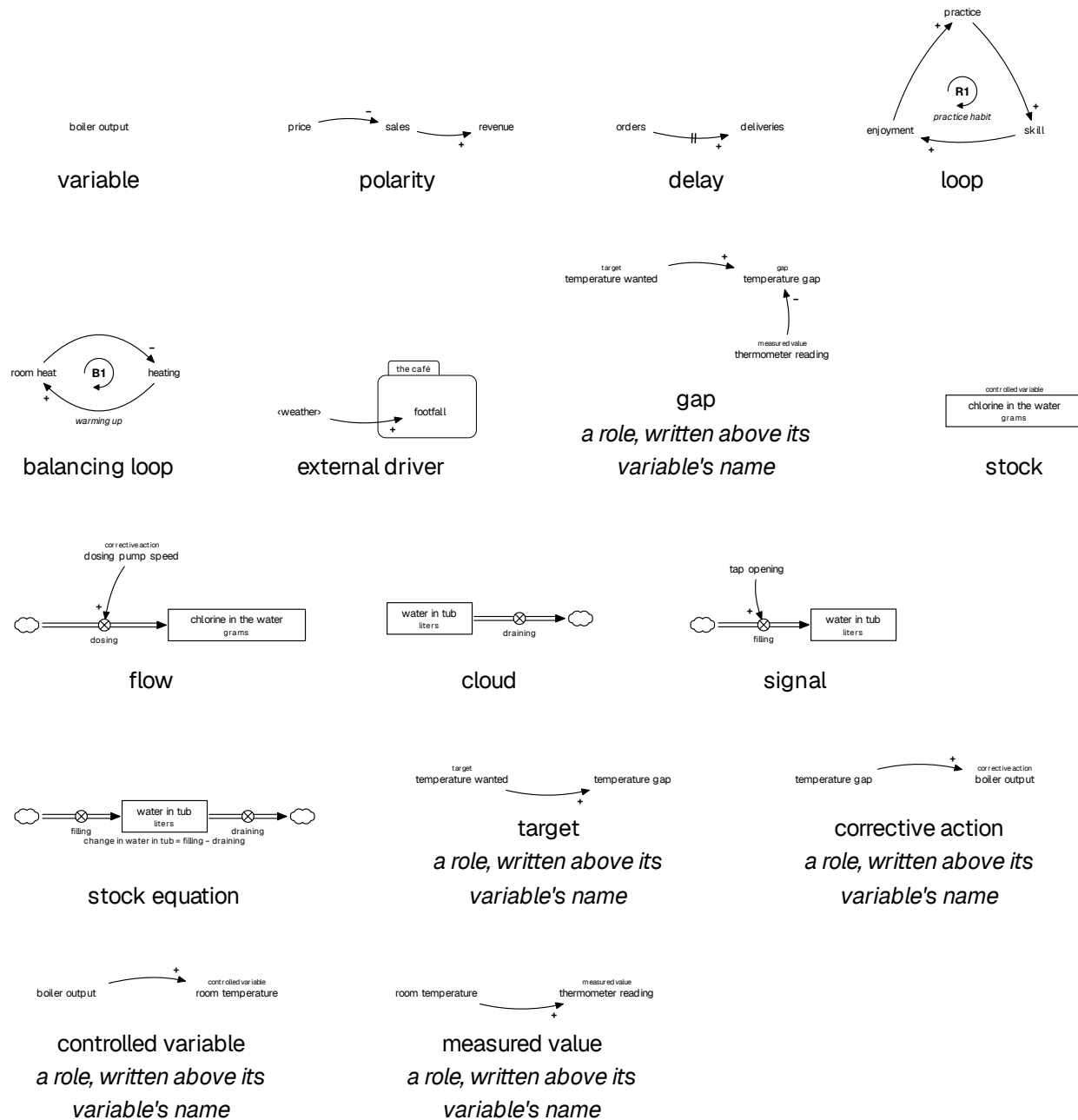
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Draw here

Grid area for drawing.

FC 05 Elephants in a national park

Your palette



FC 05 Elephants in a national park

Control with accumulation

Reasoning ●●●○○ 3 of 5 Polish ●●●○○ 3 of 5

A national park's managers aim to hold its elephants near 2,000. In this park about 150 calves are born each year and about 60 elephants die, more in a year of drought. Every two years a survey plane counts the herd. From the latest count the managers approve moving elephants to other parks: the further the count is above 2,000, the more moves they approve. Moves approved this year happen the next year, when the elephants are caught and taken away by truck. Count the herd in elephants, and time in years.

The brief

- ☐ Draw the elephants in the park as one stock, the controlled variable, counted in elephants.
- ☐ Mark the year between moves approved and elephants moved as a delay on the forward path.
- ☐ Close one control loop through the flow of elephants moved: the gap, moves approved, the elephants in the park and the aerial count.
- ☐ Moves approved are a variable, and elephants moved the flow: the year lies between them.

Your palette

On the page before this sheet.

Draw here

Grid area for drawing.

CS 08 Kelsham Primary School: the governors and the reserve

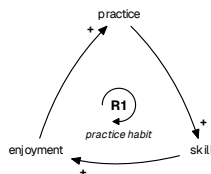
Your palette

boiler output

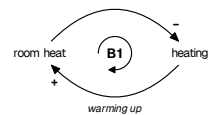
variable



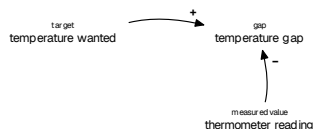
polarity



loop

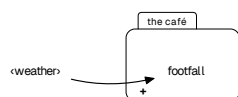


balancing loop

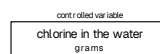


gap

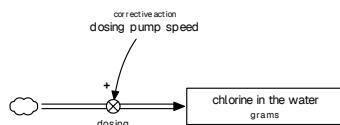
a role, written above its
variable's name



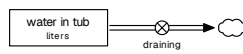
external driver



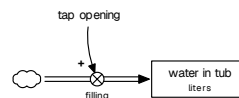
stock



flow



cloud



signal



target

a role, written above its
variable's name



corrective action

a role, written above its
variable's name



controlled variable

a role, written above its
variable's name



measured value

a role, written above its
variable's name

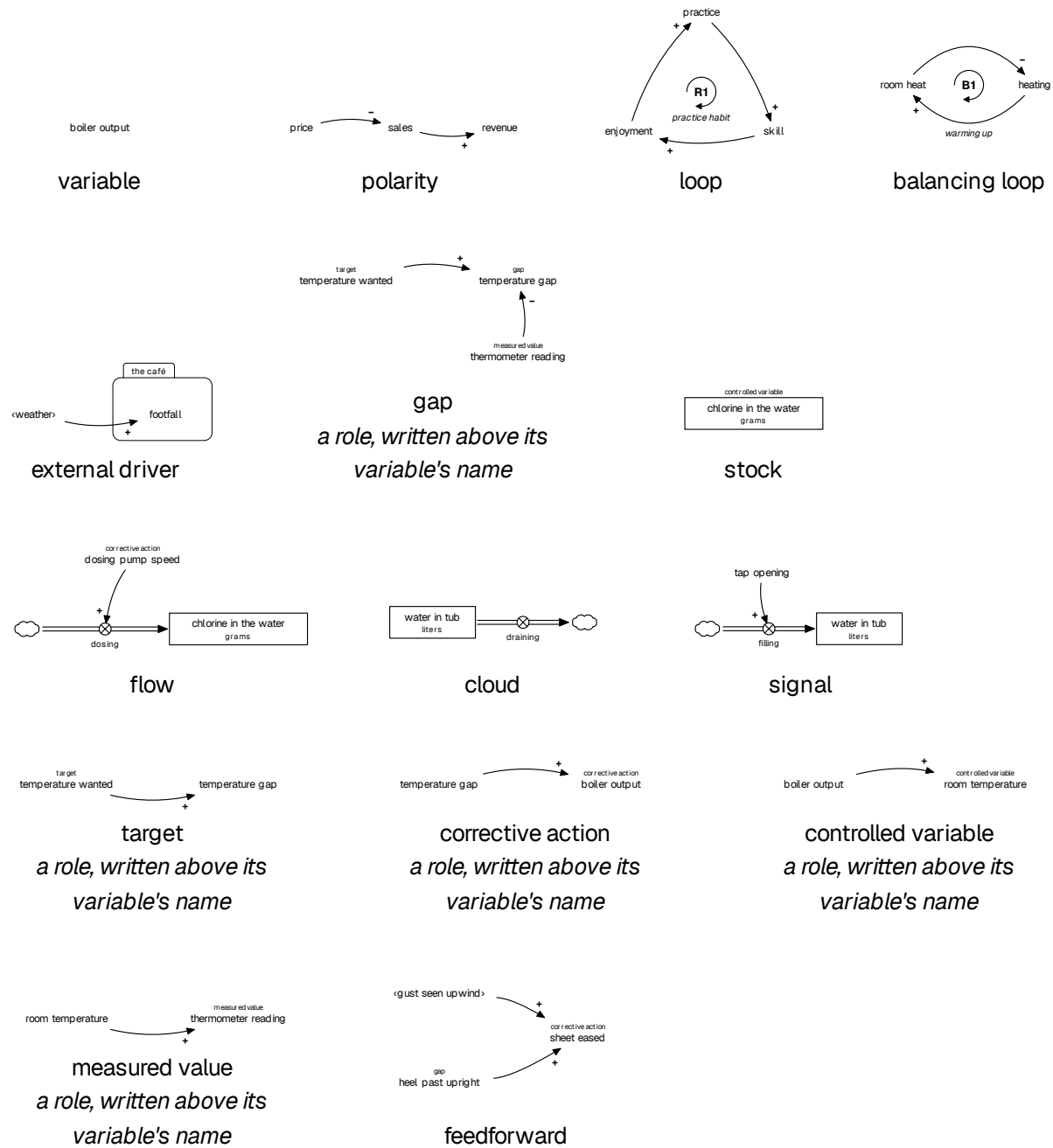
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Chapter 9

Anticipation, Limits, and Nested Control

FC 06 Entry gates at a concert as trains arrive

Your palette



FC 06 Entry gates at a concert as trains arrive

Feedforward, then correction

Reasoning ●●●○○ 3 of 5 Polish ●●●●○ 4 of 5

Fans reach a stadium concert by train and queue at the entry gates. The stewards aim for a wait of about ten minutes, which at the gates' pace is a queue of about 600 people. Every few minutes a steward counts the queue, and the further the count runs above 600, the more gates the stewards open. A full train brings about 1,000 fans to the gates within a few minutes of arriving. The station's arrivals board shows each train due, and when it shows a full train the stewards open more gates before its fans reach the queue. Count the queue in people, and time in minutes.

The brief

- ☐ Read the trains due on the arrivals board into gates open, by a path that passes no gap.
- ☐ Draw trains arriving as an external driver acting on the flow of people joining the queue.
- ☐ Close one control loop through the flow of people passing through the gates: the gap, gates open, the people queuing and the stewards' count.
- ☐ The feedforward path and the gap's signal both end at gates open.

Your palette

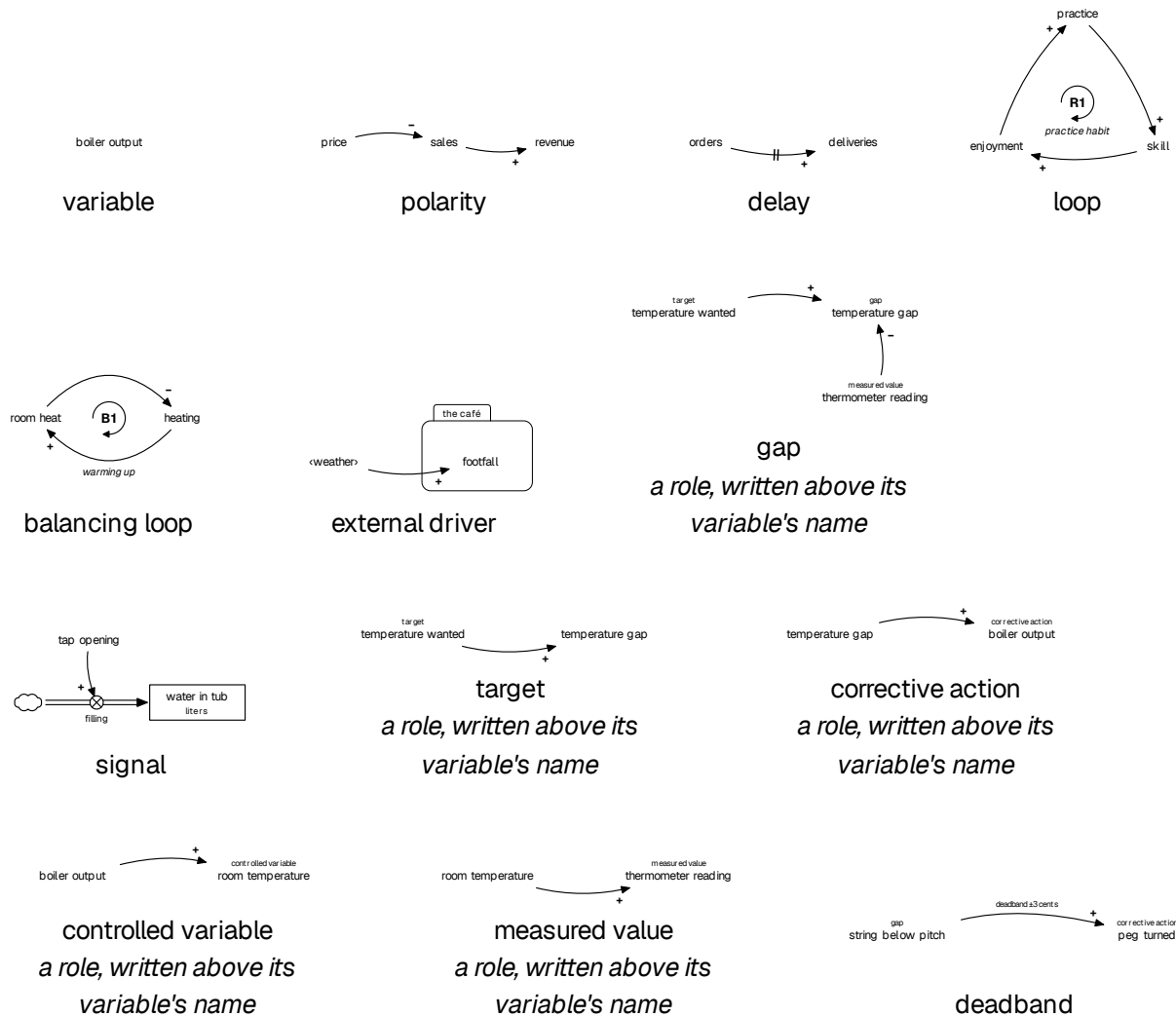
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Draw here

Diagram drawing area with a grid of dots.

FC 07 Tuning a guitar with a clip-on tuner

Your palette



FC 07 Tuning a guitar with a clip-on tuner

A noisy reading, a wait, and a band left alone

Reasoning ●●●●○ 4 of 5 Polish ●●●●○ 4 of 5

Amara tunes her guitar's high E string to about 330 Hz with a clip-on tuner, which shows how many cents the string sits sharp or flat of E. Right after she plucks, the reading wobbles by several cents as the note rings and fades, so she waits about two seconds for it to settle before she reads it. When the settled reading is more than 3 cents flat she turns the peg to tighten the string, further the flatter it reads; when it is more than 3 cents sharp she turns the peg back; within 3 cents she leaves the peg alone. The strings are new, and as they stretch the string goes flat between tunings.

The brief

- ☐ Mark the wait while the tuner's reading settles as a delay on the return path.
- ☐ Write her 3 cents either way as a deadband on the signal from the gap to the peg.
- ☐ Draw the pluck's wobble as an external driver acting on the tuner's reading.
- ☐ Leaving the peg alone inside 3 cents is the deadband, not a second variable.

Your palette

On the page before this sheet.

Draw here

Diagram drawing area with a grid of dots.

FC 08 A home reef aquarium

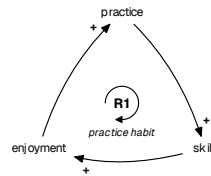
Your palette

boiler output

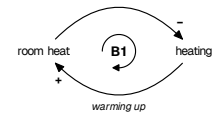
variable



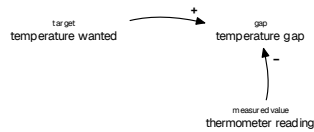
polarity



loop

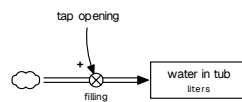


balancing loop



gap

*a role, written above its
variable's name*



signal



target

*a role, written above its
variable's name*



corrective action

*a role, written above its
variable's name*



controlled variable

*a role, written above its
variable's name*



measured value

*a role, written above its
variable's name*

oscillation

behavior note

Three targets, one shared corrective action

Keiko keeps a reef aquarium at home and holds three quantities near targets: the water at 25 °C, its salinity at 35 parts per thousand, and its alkalinity at 8 dKH. A thermometer in the tank reads the temperature, and the heater's output rises the cooler it reads. Once a week she reads the salinity with a refractometer and tests the alkalinity with a kit, then changes part of the water for new salt water mixed at 34 parts per thousand and 11 dKH: the higher the salinity reads, or the lower the alkalinity, the more water she changes that week. The new water comes from a bucket a few degrees cooler than the tank. The harder the heater runs, the faster the water evaporates, leaving its salt behind.

- ☐ Close three control loops, for temperature, salinity and alkalinity, each with its target, reading and gap.
- ☐ Make the water changed per week the corrective action of both the salinity loop and the alkalinity loop.
- ☐ Draw the heater's signal to salinity and the water changes' signal to the water temperature as cross-effects.
- ☐ A behavior note names the tradeoff between the loops.

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FC 09 A mail service's spam filter

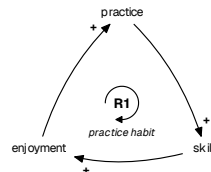
Your palette

boiler output

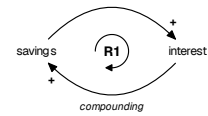
variable



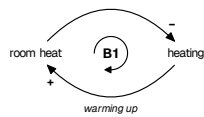
polarity



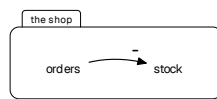
loop



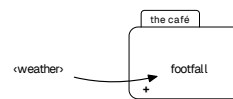
reinforcing loop



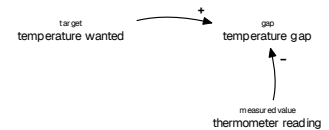
balancing loop



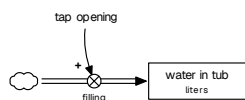
boundary



external driver



gap

a role, written above its
variable's name

signal



target

a role, written above its
variable's name

corrective action

a role, written above its
variable's name

controlled variable

a role, written above its
variable's name

measured value

a role, written above its
variable's name

override

a role, written above its
variable's name

evidence coding

FC 09 A mail service's spam filter

Two loops on one corrective action, and a person's release

Reasoning ●●●●● 5 of 5 Polish ●●●●● 5 of 5

A mail service filters spam for hundreds of millions of users. It aims to let no more than 1 message in 1,000 reaching inboxes be spam, and to lose no more than 1 real message in 10,000 to spam folders. Users report the spam that gets through, and complain when real mail goes missing; the service's engineers read both each day and set how strict the filter is, stricter as reports rise and less strict as complaints rise. New spam campaigns start around the world every day, whatever the filter does. The engineers believe that each time the filter is made stricter, spammers change their tactics and get more spam through, but nobody has measured it. A user who finds a real message in the spam folder can mark it not spam, which releases it and makes the filter less strict for messages like it. Draw the model's boundary around spam filtering at the service, its users and the spammers' tactics.

The brief

- ☐ Draw a named boundary, with new spam campaigns worldwide outside it as an external driver.
- ☐ Close two control loops through filter strictness: one on spam reaching inboxes, read from users' reports, and one on real mail lost to spam folders, read from complaints.
- ☐ Declare the reinforcing loop through spammers' new tactics, inside the boundary.
- ☐ Draw users' releases of messages marked not spam as an override whose signal ends at filter strictness.
- ☐ The override is named as a quantity, mail released as not spam, which someone can count and read later.

Your palette

On the page before this sheet.

Draw here

Diagram drawing area with a grid of dots.

FC 10 Cooling a data center through a heatwave

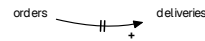
Your palette

boiler output

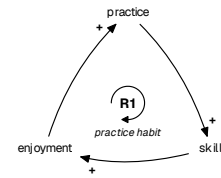
variable



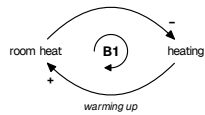
polarity



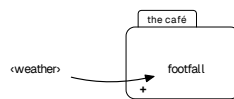
delay



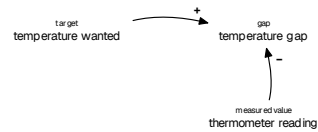
loop



balancing loop



external driver



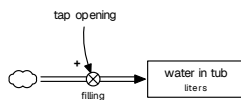
gap
a role, written above its
variable's name



evidence coding

oscillation

behavior note



signal



target
a role, written above its
variable's name



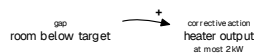
corrective action
a role, written above its
variable's name



controlled variable
a role, written above its
variable's name



measured value
a role, written above its
variable's name



saturation



override
a role, written above its
variable's name

Nested loops, a limit, and a person taking over

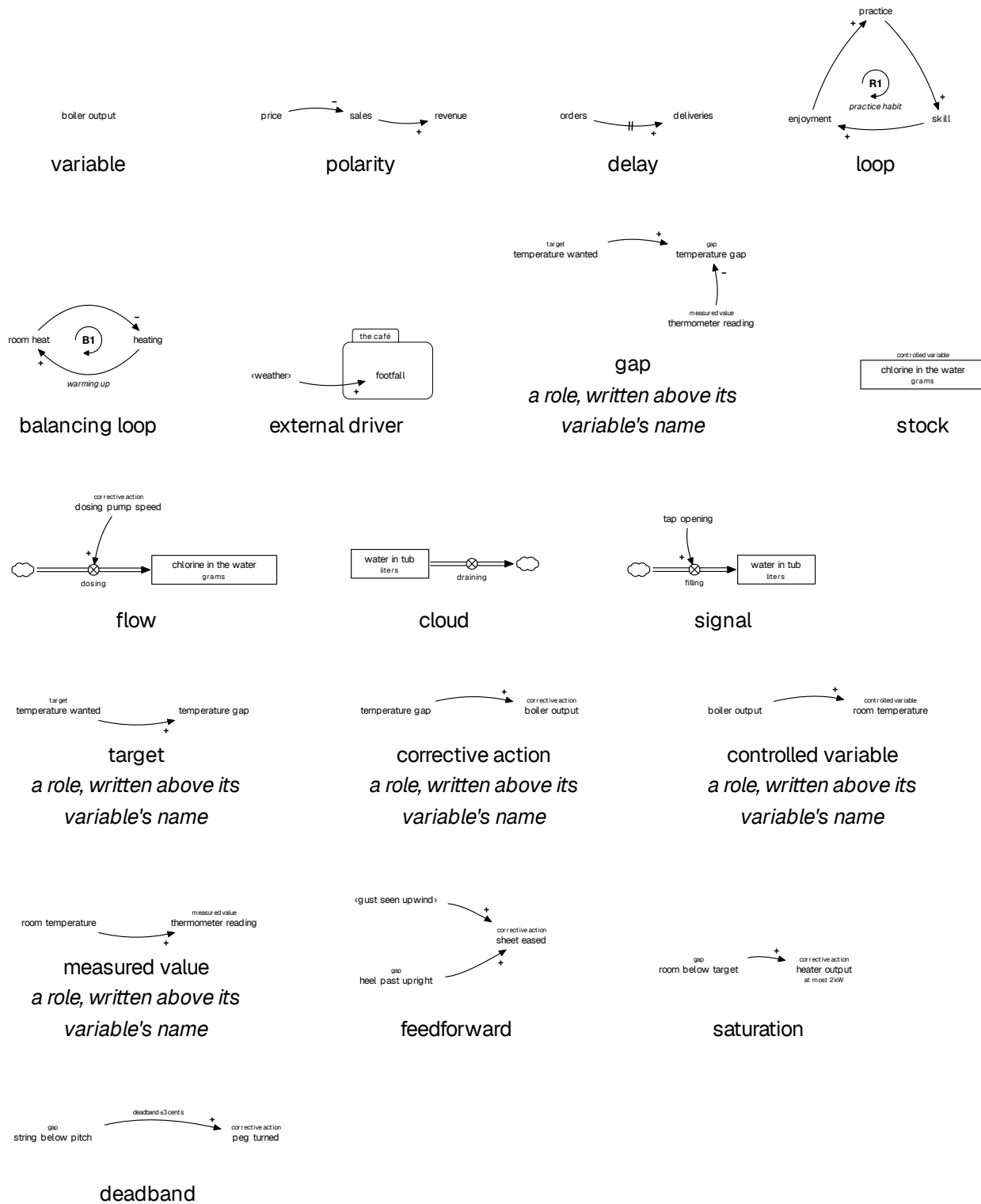
A data center's cooling units blow cold air into its server rooms. A thermometer in that supply air reads its temperature every few seconds, and the units raise their cooling output the further it reads above the supply-air target. Engineers set that target: each hour they read the temperature at the servers' air inlets, which they hold near 27 °C, and lower the supply-air target the warmer the inlets read. The cooling output can rise no higher than the chillers' full output. In a heatwave the supply air warms, and once the chillers are at full output it keeps warming however low the target is set. The engineers can then set the cooling output themselves, in place of the units' rule, or shut down some servers, which they believe lowers the inlet temperature, though nobody knows by how much.

- ☐ Nest the fast loop on the supply air inside the slow loop on the server inlet temperature, whose corrective action is the supply-air target.
- ☐ Write the chillers' full output as the limit on cooling output.
- ☐ Draw the heatwave as an external driver acting on a controlled variable.
- ☐ Draw the engineers' own cooling setting as an override whose signal ends at cooling output.
- ☐ Code the signal for how much shutting down servers lowers the inlet temperature as a hypothesis.
- ☐ Recovery shows only in a later hourly inlet reading: the slow loop closes on that reading, not on the supply air.

On the page before this sheet.

CS 09 Kelsham Primary School: a floor on staffing and the council's loop

Your palette



Chapter 10

Structures That Recur

AR 01 Watering a lawn a little every evening

Your palette

customers

variable

price → sales

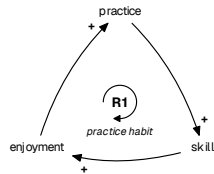
effect

price $\xrightarrow{-}$ sales $\xrightarrow{+}$ revenue

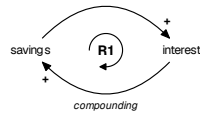
polarity

orders $\xrightarrow{+}$ deliveries

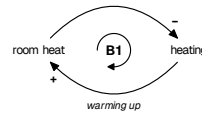
delay



loop



reinforcing loop



balancing loop

oscillation

behavior note

Archetype: fixes that fail

archetype

pests $\xrightarrow{+}$ symptomatic solution spraying

symptomatic solution
a role, written above its
variable's name

spraying $\xrightarrow{+}$ side effect predators lost

side effect
a role, written above its
variable's name

AR 01 Watering a lawn a little every evening

A relief that brings the problem back

Reasoning ●○○○○ 1 of 5 Polish ●○○○○ 1 of 5

Every summer evening, Rosa waters her lawn for ten minutes wherever it has turned brown, and by morning the grass is green again: the browner the lawn, the more she waters. Ten minutes wets only the top few centimeters of soil, so over the following weeks the grass keeps its roots there, where the soil dries first: the more evening watering, the faster the grass dries in heat. The faster the grass dries, the browner the lawn in each hot spell.

The brief

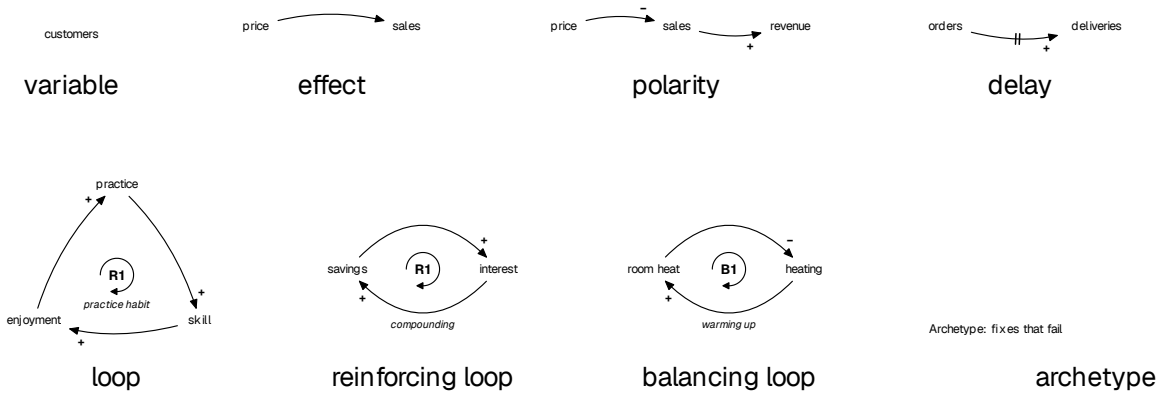
- ☐ Draw the morning's relief as one balancing loop through the brown lawn and the evening watering.
- ☐ Draw the drying grass's return to the brown lawn as one reinforcing loop.
- ☐ Mark one delay: the weeks before the watering makes the grass dry faster.
- ☐ The two loops match fixes that fail, with its delay on the side effect's chain.
- ☐ Write the symptomatic solution above the evening watering.
- ☐ Write the side effect above how fast the grass dries.
- ☐ Add a behavior note.
- ☐ The note names the relief each morning and the browning that comes back faster.
- ☐ The brown lawn is drawn once, as the variable the watering relieves and the drying grass makes worse.

Your palette

On the page before this sheet.

Draw here

Diagram drawing area with a grid of dots.

AR 02 Electric cars and public chargers**Your palette**

AR 02 Electric cars and public chargers

Growth held back by what it uses

Reasoning ●○○○○ 1 of 5 Polish ●●○○○ 2 of 5

In a country of five million people, electric cars are cheap to run, and their owners tell friends, family and colleagues so: the more electric cars on the road, the more owners' recommendations, and the more recommendations, the more electric cars people buy. Owners without a driveway charge at public chargers, so the more electric cars on the road, the longer the queues at public chargers, and the more public chargers, the shorter the queues. Word of hour-long waits takes months to reach people choosing their next car; then the longer the queues, the fewer electric cars join the road.

The brief

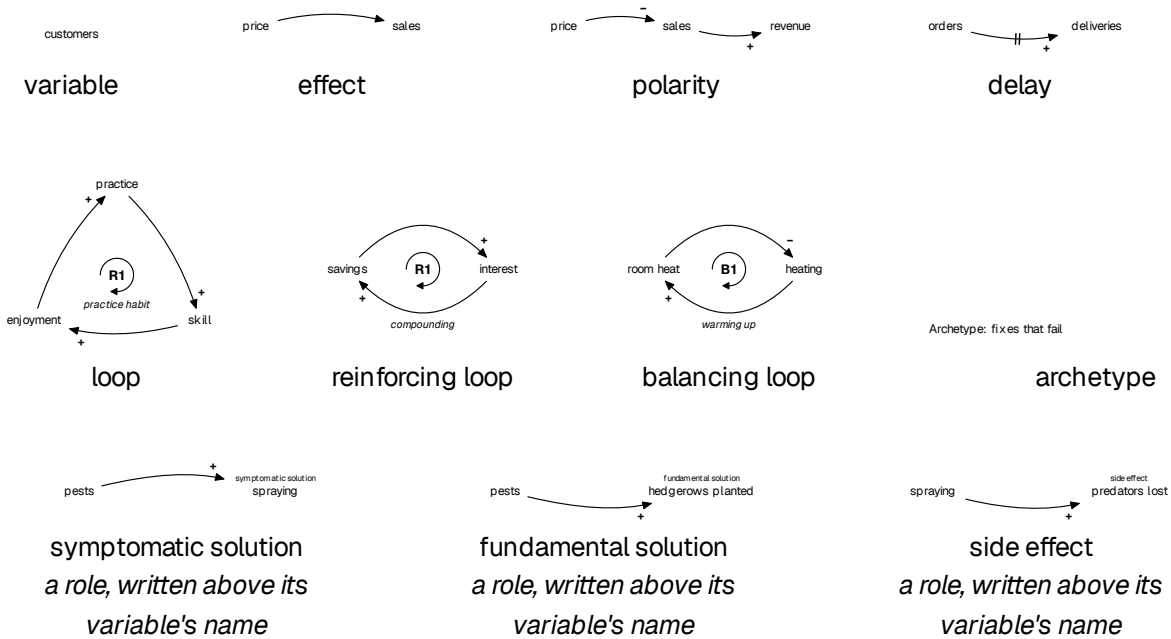
- ☐ Draw the recommendations as one reinforcing loop through the electric cars on the road.
- ☐ Draw the queues holding back new electric cars as one balancing loop.
- ☐ The two loops match limits to growth: a reinforcing loop and a balancing loop sharing one variable.
- ☐ Mark the months before word of the queues reaches buyers as a delay inside the balancing loop.
- ☐ The number of public chargers is the constraint: a variable outside both loops, with an effect into the balancing loop.

Your palette

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Draw here

Diagram drawing area with a grid of dots.

AR 03 A climbing club that hires guides for its trips**Your palette**

A quick relief that holds back a slower one

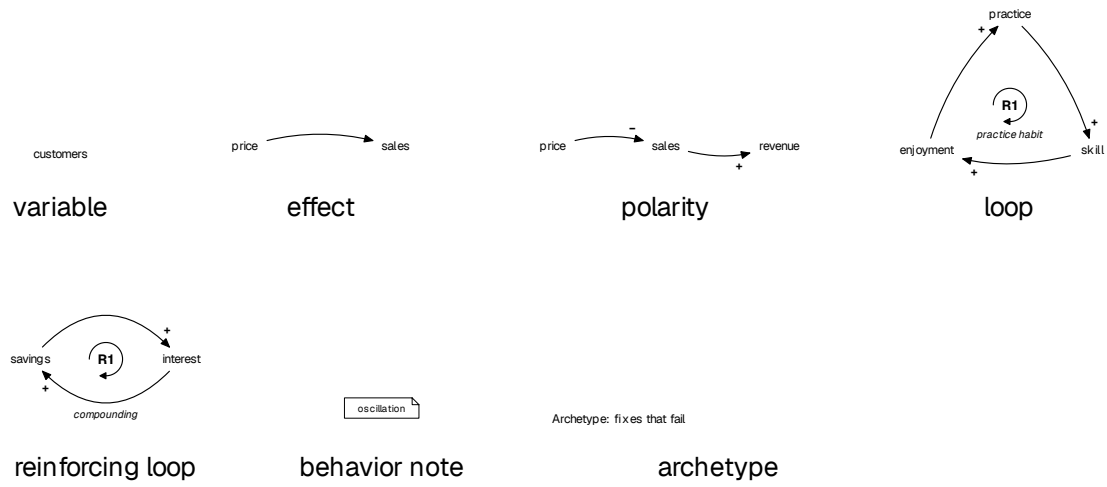
A climbing club of sixty members runs two trips a month, and each trip needs one qualified leader for every six climbers. When a trip is short of a leader, the club hires a mountain guide for the weekend and the trip goes ahead: the more trips short of a leader, the more hired guides, and the more hired guides, the fewer trips short of a leader. Members can qualify to lead trips themselves through courses and logged climbs that take a full season: the more trips short of a leader, the more members training to lead, and a season later, the more members training, the fewer trips short of a leader. Each guided trip shows the members that a guide will be hired: the more hired guides, the more the club relies on them, and the more it relies on them, the fewer members train to lead.

- ☐ Draw two balancing loops through the trips short of a leader: one through the hired guides, one through the members training to lead.
- ☐ Draw the reliance on hired guides closing one reinforcing loop.
- ☐ The loops match shifting the burden, with its delay on the training's loop.
- ☐ Write the symptomatic solution above the hired guides.
- ☐ Write the fundamental solution above the members training to lead.
- ☐ Write the side effect above the reliance on hired guides.
- ☐ The side effect is the reliance the hired guides build up, not a second shortage of leaders.

On the page before this sheet.

AR 04 Two parks and one maintenance budget

Your palette



AR 04 Two parks and one maintenance budget

A small lead that a split widens

Reasoning ●●○○○ 2 of 5 Polish ●●●○○ 3 of 5

A town of thirty thousand people has two parks, one by the river and one on the hill, and one maintenance budget for both. Each spring the council splits the budget by the two parks' visitor counts from the year before, and the larger a park's share, the better it is mowed, cleaned and repaired that year. The more visitors to the riverside park, the larger the share of the budget to the riverside park, and the larger that share, the more visitors to the riverside park. The more visitors to the hilltop park, the smaller the riverside park's share, and the larger the riverside park's share, the fewer visitors to the hilltop park. In the first year, the riverside park had a few hundred more visitors than the hilltop park.

The brief

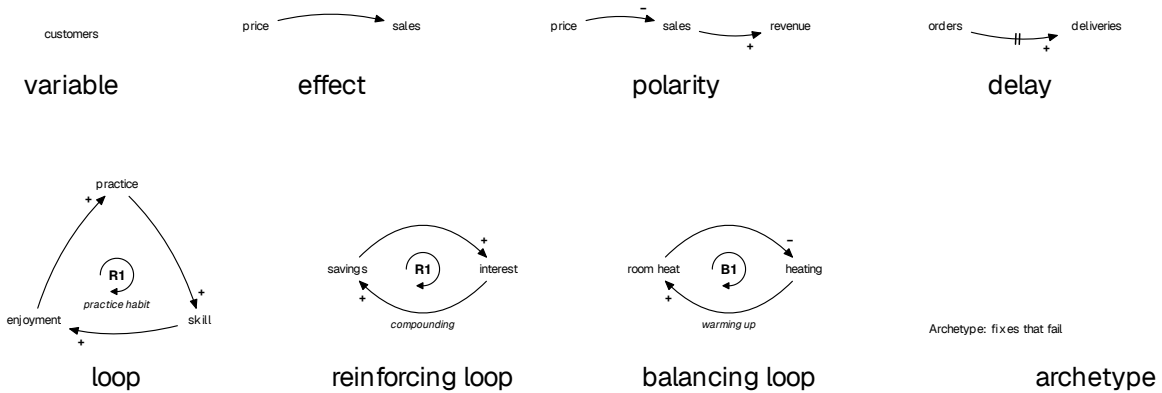
- ☐ Draw the share of the budget to the riverside park as one variable, with two reinforcing loops through it: one through each park's visitors.
- ☐ The two loops match success to the successful: two reinforcing loops sharing one variable.
- ☐ Add a behavior note on the gap between the two parks' visitors.
- ☐ The two loops are drawn as mirror images, one on each side of the share.
- ☐ In the note: the first year's gap is small, and the split widens it every year after.

Your palette

On the page before this sheet.

Draw here

Diagram drawing area with a grid of dots.

AR 05 Three countries' fleets on one fishing ground**Your palette**

AR 05 Three countries' fleets on one fishing ground

Gains kept by each, losses shared by all

Reasoning ●●●○○ 3 of 5 Polish ●●●○○ 3 of 5

Three countries, called here the northern, western and eastern, send fishing fleets to one fishing ground in international waters. Each fleet's owners spend what they earn on more boats: the more northern boats, the more northern earnings, and the more northern earnings, the more northern boats, and the same holds for the western and eastern fleets. Every boat adds to the total catch, and the larger the total catch, the fewer fish are left to breed. The young fish that go unborn would have been caught years later, so only then does the catch per boat fall: the larger the total catch, the smaller the catch per boat, after a delay of years. The larger the catch per boat, the more each fleet earns; and the smaller the catch per boat, the more boats each fleet sends to make up its catch.

The brief

- ☐ Draw each fleet's boats and earnings as a reinforcing loop, and its boats, the total catch and the catch per boat as another: two for each of the three fleets.
- ☐ Draw each fleet's boats returning to its earnings through the total catch and the catch per boat as a balancing loop, one for each fleet.
- ☐ The loops match tragedy of the commons, with its delay on the total catch's effect on the catch per boat.
- ☐ The total catch is one variable, which all three fleets' boats add to, not one for each fleet.
- ☐ No effect crosses another where moving a variable would avoid it.

Your palette

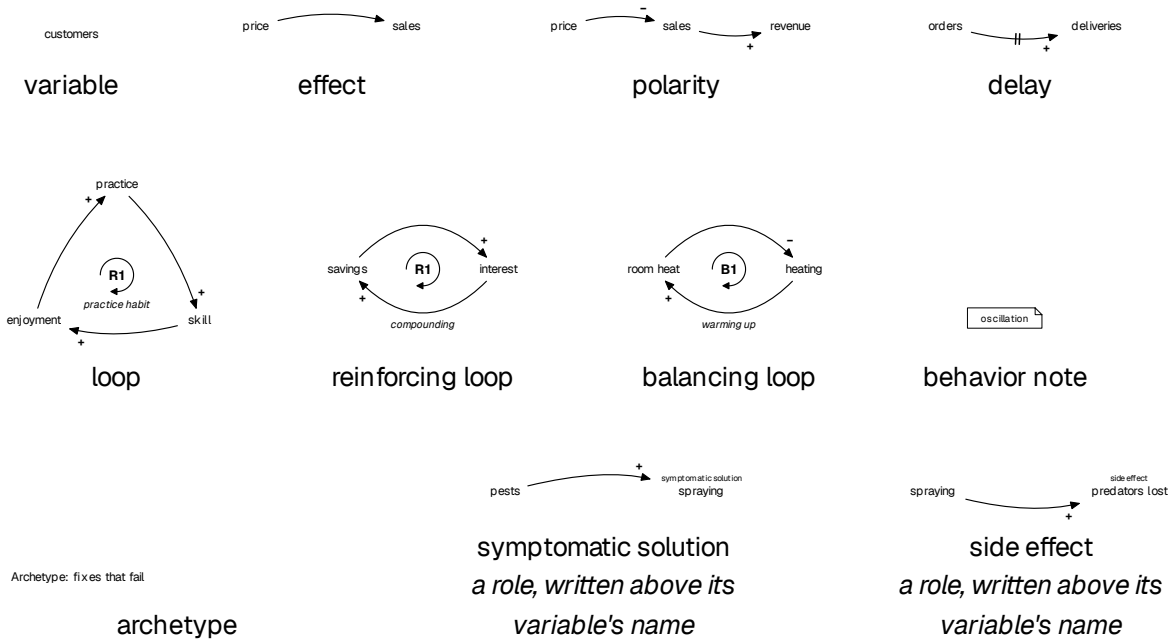
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Diagram drawing area with a grid of dots.

CS 10 Kelsham Primary School: merging classes to balance the budget

Your palette



CS 10 Kelsham Primary School: merging classes to balance the budget

A saving that brings the spending back

Reasoning ●●●○○ 3 of 5 Polish ●●●○○ 3 of 5

Kelsham Primary School is paid £4,800 for each pupil, set from the October count before each school year, so its funding falls a year after its roll does: the fewer pupils on roll, the less school funding, a year later, and the less school funding, the more spending above funding. When the school spends more than its funding, the governors merge classes. In 2023, with 108 pupils, they taught Years 3 and 4 as one class and paid four teachers instead of five, saving £52,000 a year at once: the more spending above funding, the more mixed-age classes, and the more mixed-age classes, the less spending above funding. Some parents, Priya Shah among them, would rather each year were taught as a class of its own, as at Brayford Primary School: the more mixed-age classes, the more parents choosing the town school, and the more parents choosing the town school, the fewer pupils on roll. In October 2026 the roll is 88, and Tom Hale, who chairs the governors, proposes teaching Reception with Years 1 and 2.

The brief

- ☐ Draw the saving as one balancing loop through spending above funding and mixed-age classes.
- ☐ Draw the families' leaving as one reinforcing loop back to spending above funding.
- ☐ Mark one delay: the October count, which sets the funding a year after pupils leave.
- ☐ The two loops match fixes that fail, with its delay on the side effect's chain.
- ☐ Write the symptomatic solution above its variable.
- ☐ Write the side effect above its variable.
- ☐ Declare the archetype the loops match, in one line.
- ☐ Add a behavior note.
- ☐ The note names the saving each merger brings at once and the spending that comes back as the roll falls.

Your palette

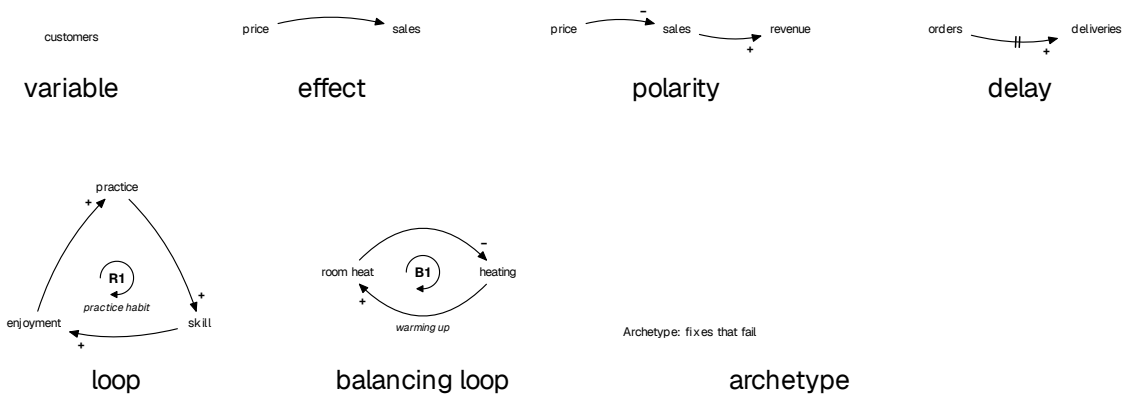
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Diagram drawing area with a grid of dots.

Chapter 11

Diagnosing Tangled Situations

AR 06 An arms race between two neighboring countries**Your palette**

AR 06 An arms race between two neighboring countries

Each side's safety read against the other's

Reasoning ●●●○○ 3 of 5 Polish ●●●●○ 4 of 5

Two neighboring countries, called here North and South, each judge their safety by how their armed forces compare with the other's. North buys arms until its forces are well ahead of South's: the more arms North buys, the larger North's lead in forces, and the larger that lead, the fewer arms North buys. South buys arms while North is ahead: the more arms South buys, the smaller North's lead, and the larger North's lead, the more arms South buys. Each country pays for its arms from the budget that also pays for its schools and hospitals: the more arms either country buys, the less the two countries spend on schools and hospitals.

The brief

- ☐ Draw each country's arms purchases closing a balancing loop through one variable that compares the two countries' forces.
- ☐ The two loops match escalation.
- ☐ Draw the spending on schools and hospitals, reached from both countries' purchases.
- ☐ One variable compares the two countries' forces, and both loops pass through it.
- ☐ The spending on schools and hospitals returns to neither loop.
- ☐ The declared archetype is escalation, not eroding goals, though the same loops match both.

Your palette

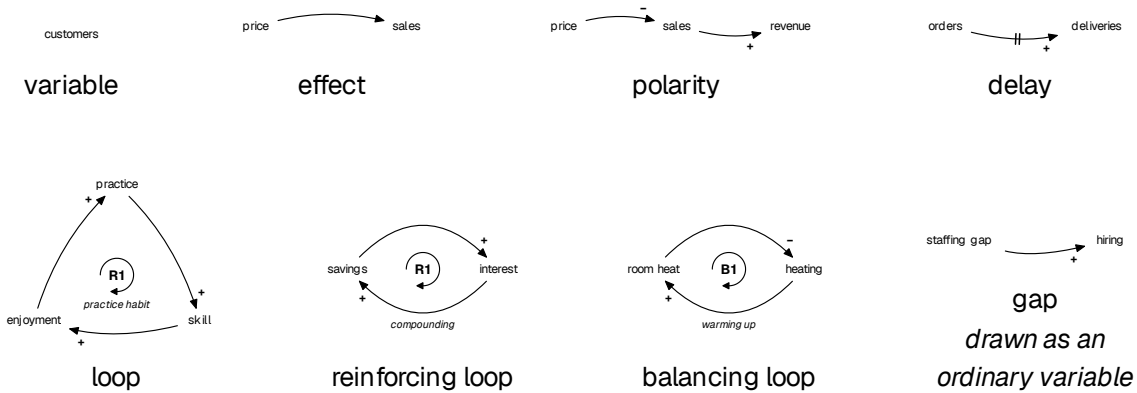
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Diagram drawing area with a grid of dots.

AR 07 A country's railways

Your palette



Archetype: fixes that fail

archetype

AR 07 A country's railways

Growth held back by trains never ordered

Reasoning ●●●●○ 4 of 5 Polish ●●●●○ 4 of 5

A country's railway operator draws passengers with punctual trains and cheap fares: the more passengers, the more fare offers it can pay for, and the more fare offers, the more passengers. Crowded trains wait longer at every station: the more passengers, the lower the punctuality, and the higher the punctuality, the more passengers. The operator reads its need for more trains from how far punctuality falls short of its punctuality target, once a year's figures are in: the lower the punctuality, the greater the need for more trains, after a delay, and the higher the target, the greater the need. A new train takes four years to build: the greater the need, the more trains in service, after a delay, and the more trains in service, the higher the punctuality. When the need is large, the operator lowers its target rather than order trains: the greater the need for more trains, the lower the punctuality target.

The brief

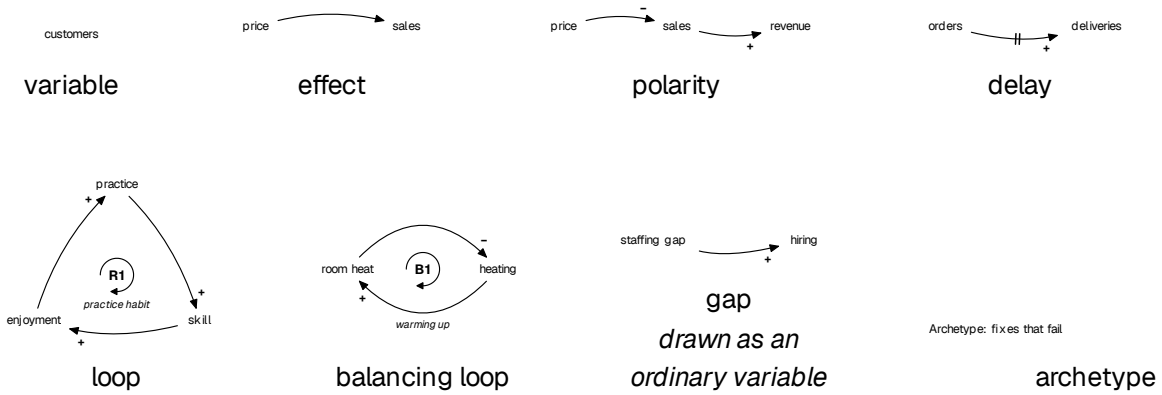
- ☐ Draw the passengers and the fare offers closing a reinforcing loop.
- ☐ Draw a balancing loop through the passengers and the punctuality, and one through the need for more trains and the trains in service.
- ☐ The loops match growth and underinvestment, with its delay where new trains arrive.
- ☐ Draw a delay where the operator reads its need for more trains, and one where new trains arrive.
- ☐ The punctuality target acts on the need for more trains, and the greater the need, the lower the target.

Your palette

On the page before this sheet.

Draw here

Diagram drawing area with a grid of dots.

AR 08 Knee exercises after an operation**Your palette**

AR 08 Knee exercises after an operation

A target that moves toward what was done

Reasoning ●●●●○ 4 of 5 Polish ●●●●○ 4 of 5

After an operation on her knee, Priya sets herself a weekly target of fifteen sessions of the exercises her physiotherapist gave her. Each Sunday she counts the sessions done that week, and the gap is the target minus the sessions done: the higher the target, the larger the gap, and the more sessions done, the smaller the gap. When the gap is large she fits extra sessions into the next week, so the gap raises the sessions done a week later: the larger the gap, the more sessions done, after a delay. On busy weeks at work she falls short, and each time she does, she sets next week's target closer to what she managed: the larger the gap, the lower the weekly target.

The brief

- ☐ Draw two balancing loops through the gap: one through the sessions done, one through the weekly target.
- ☐ The loops match eroding goals, with its delay on the extra sessions.
- ☐ The gap is a variable of its own: the weekly target minus the sessions done.
- ☐ The second loop is named for the lowered target, which closes the gap without a session more.

Your palette

On the page before this sheet.

Draw here

Diagram drawing area with a grid of dots.

AR 09 Two parents sharing care after a separation**Your palette**

customers

variable

price → sales

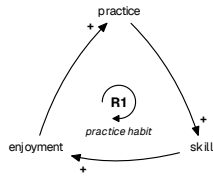
effect

price $\xrightarrow{-}$ sales $\xrightarrow{+}$ revenue

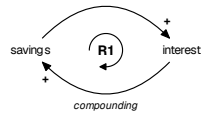
polarity

orders $\xrightarrow{+}$ deliveries

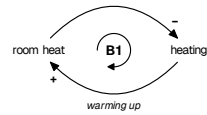
delay



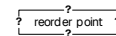
loop



reinforcing loop



balancing loop



leverage point

Archetype: fixes that fail

archetype

AR 09 Two parents sharing care after a separation

Partners whose own fixes hold each other back

Reasoning ●●●●● 5 of 5 Polish ●●●●● 5 of 5

Maya and Tom separated last year and share the care of their two children, a week each. Each helps the other's weeks go well, with lifts to football and the same homework rules in both homes: the better Maya's weeks go, the better Tom's go, and the better Tom's weeks go, the better Maya's go. When a week goes badly, each makes changes alone to ease their own weeks, such as a new bedtime or a swapped weekend: the worse Maya's weeks go, the more changes she makes alone, and the more changes she makes alone, the better her weeks go; the same holds for Tom. Each one's changes reach the other's home a week or two later, with the children: the more changes Maya makes alone, the worse Tom's weeks go, after a delay, and the more changes Tom makes alone, the worse Maya's weeks go, after a delay. Both parents see how settled the children are, which rises the better either parent's weeks go.

The brief

- ☐ The loops match accidental adversaries.
- ☐ Draw a delay on each parent's changes' effect on the other's weeks.
- ☐ Mark one leverage point.
- ☐ The two delays sit where each parent's changes reach the other's weeks, not on the help each gives the other.
- ☐ The leverage point is a measure both parents can see.

Your palette

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Draw here

Diagram drawing area with a grid of dots.

AR 10 A coastal town and its sea walls

Your palette

customers

variable

price → sales

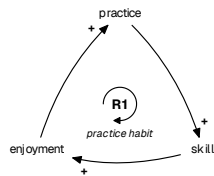
effect

price → sales → revenue
- +

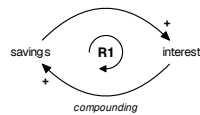
polarity

orders → deliveries
+ +

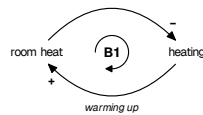
delay



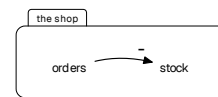
loop



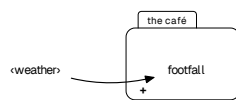
reinforcing loop



balancing loop



boundary



external driver

training → quality

evidence coding

? reorder point ?

leverage point

oscillation

behavior note

Archetype: fixes that fail

archetype

pests → symptomatic solution
spraying

symptomatic solution
a role, written above its
variable's name

pests → fundamental solution
hedgerows planted

fundamental solution
a role, written above its
variable's name

spraying → side effect
predators lost

side effect
a role, written above its
variable's name

AR 10 A coastal town and its sea walls

Two archetypes sharing one variable

Reasoning ●●●●● 5 of 5 Polish ●●●●● 5 of 5

A coastal town of eight thousand people floods when winter storms push the sea over its seafront: the more winter storms, the more flooding of the seafront. Each flood brings calls for sea walls, and a wall stops the sea at once: the more flooding of the seafront, the more sea walls built, and the more sea walls built, the less flooding. The walls stop the waves from carrying sand along the shore, so the beach in front of them thins, and years later the sea reaches the walls with more force: the more sea walls built, the more sand lost from the beach, and the more sand lost, the more flooding, after a delay. Restoring the dunes behind the beach would protect the coast for decades, though new dunes take years to grow: the more flooding, the more dune restoration, and the more dune restoration, the less flooding, after a delay. Behind each new wall, the town allows homes and shops: the more sea walls built, the more building behind the walls. The town's engineers think the new building makes dune restoration costlier, since the land behind the beach is no longer free, but they have no figures yet: the more building behind the walls, the less dune restoration.

The brief

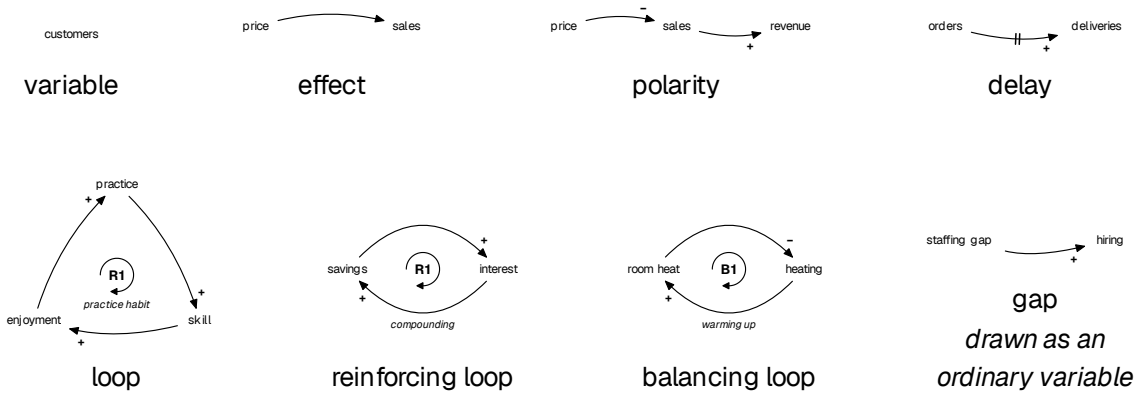
- ☐ Declare each archetype the structure holds, at least two.
- ☐ The declared archetypes are coupled: their matches share a variable.
- ☐ Mark at least two leverage points.
- ☐ Code the effect you judge less supported as a hypothesis, declared in the legend.
- ☐ Draw at least three loops.
- ☐ Beside the diagram, rank the leverage points in a list, each with its reason.
- ☐ The winter storms sit outside a boundary named for the town's coast, and nothing inside acts on them.
- ☐ No variable is drawn twice: the sea walls built are one variable, in both archetypes.

Your palette

On the page before this sheet.

Draw here

Diagram drawing area with a grid of dots.

CS 11 Kelsham Primary School: the town school's pull and its rising class size**Your palette**

Archetype: fixes that fail

archetype

CS 11 Kelsham Primary School: the town school's pull and its rising class size

Two archetypes coupled through one share

Reasoning ●●●●● 5 of 5 Polish ●●●●● 5 of 5

Brayford Primary School teaches each year in classes of its own, and Kelsham's families know it. The larger Brayford's share of the villages' starters, the more Kelsham children at Brayford, and the more Kelsham children at Brayford, the larger the share, as brothers, sisters and friends follow them there. The larger Brayford's share, the fewer pupils on roll at Kelsham; the fewer pupils on roll, the more mixed-age classes at Kelsham; and the more mixed-age classes, the larger Brayford's share. Helen Marsh, Brayford's head teacher, aimed for classes of 26. The more Kelsham children at Brayford, the larger its average class size, and the larger the average class size, the more pupils a class above Brayford's aim. Above its aim, Brayford offers fewer places to children from outside the town the next September: the more pupils a class above the aim, the smaller Brayford's share, a year later. Yet each year its classes run above the aim, Brayford's governors raise it, toward the most they allow, 30: the more pupils a class above the aim, the higher the class size Brayford aims for, and the higher the class size Brayford aims for, the fewer pupils a class above it.

The brief

- ☐ Draw Brayford's share of the villages' starters on two reinforcing loops that match success to the successful.
- ☐ Draw the gap between Brayford's class size and its aim on two balancing loops that match eroding goals, with its delay on the places held back.
- ☐ Declare both archetypes.
- ☐ The declared archetypes are coupled: their matches share a variable.
- ☐ Mark one delay: the September before places held back change the share.
- ☐ Brayford's share of the villages' starters is drawn once, on both archetypes' loops.
- ☐ Beside the diagram, one sentence says what each rise in Brayford's aim does to the pupils on roll at Kelsham.

Your palette

On the page before this sheet.

Draw here

Diagram drawing area with a grid of dots.

Chapter 12

Choosing the Diagram

CD 01 A mountain rescue team

Ines is the new leader of a volunteer mountain rescue team in a valley of hill farms. The police take each emergency call from the hills and pass the team a callout, and after each rescue the team sends the police a rescue report. The team carries casualties down to the hospital in the valley town, and the hospital returns the team's stretchers. For a serious injury or a long carry, the team requests a helicopter from the helicopter service, which airlifts the casualty. Donors give the team money, and the team sends them a yearly account of what it spent. Walkers and farmers phone in reports of washed-out paths and fallen bridges, and the team posts route warnings at the valley's car parks. Ines's question: whom does the team deal with, and what passes each way?

WHICH DIAGRAM?

What does Ines draw, or write, to answer her question?

- a** A system context map
- b** No diagram: a list
- c** A causal loop diagram
- d** An influence map
- e** A stock & flow diagram

Feedback: Answers, chapter 12

CD 01 A mountain rescue team

The parties outside one boundary, and what passes each way

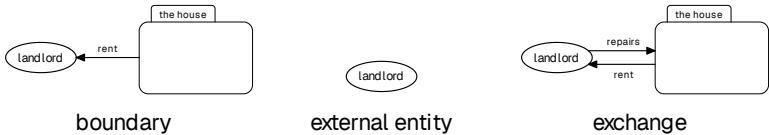
Reasoning ●●○○○ 2 of 5 Polish ●●○○○ 2 of 5

Ines is the new leader of a volunteer mountain rescue team in a valley of hill farms. The police take each emergency call from the hills and pass the team a callout, and after each rescue the team sends the police a rescue report. The team carries casualties down to the hospital in the valley town, and the hospital returns the team's stretchers. For a serious injury or a long carry, the team requests a helicopter from the helicopter service, which airlifts the casualty. Donors give the team money, and the team sends them a yearly account of what it spent. Walkers and farmers phone in reports of washed-out paths and fallen bridges, and the team posts route warnings at the valley's car parks. Ines's question: whom does the team deal with, and what passes each way?

The brief

- ☐ Draw one boundary around the team.
- ☐ Place at least four external entities outside it.
- ☐ Draw at least six exchanges, each naming one thing.
- ☐ Show at least three external entities that both give to the team and receive from it.
- ☐ The helicopter service is a party outside the team, not part of it.

Your palette



Draw here

A large grid of dots for drawing.

CD 02 Moving to another city for a job

Mateus has been offered a job in a city four hours away by train, at a salary a third above what he earns now, leading a team of eight people; he has never led a team. His partner, Ilse, teaches piano to thirty pupils near their flat, and her chances of work in the city depend on its music schools, one of which is hiring. His parents live ten minutes away, and he spends about five hours a week helping them, how many depending on his father's health. Only the salary's pull is plain to him: the higher the salary on offer, the stronger his wish to move. Of the rest, he can't yet say which way each pushes: he would miss the Saturdays with his parents and would also have them to himself; leading eight people might draw him to the job or put him off it; and Ilse hasn't said whether starting again in the city would suit her. Mateus's question: what bears on his wish to move?

WHICH DIAGRAM?

What does Mateus draw, or write, to answer his question?

- a** A causal loop diagram
- b** No diagram: a list
- c** An influence map
- d** A system context map
- e** A stock & flow diagram

Feedback: Answers, chapter 12

CD 02 Moving to another city for a job

What bears on one outcome, most of it in no known direction

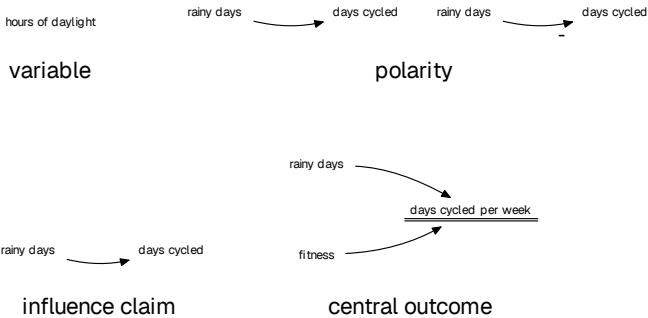
Reasoning ●●○○○ 2 of 5 Polish ●●●○○ 3 of 5

Mateus has been offered a job in a city four hours away by train, at a salary a third above what he earns now, leading a team of eight people; he has never led a team. His partner, Ilse, teaches piano to thirty pupils near their flat, and her chances of work in the city depend on its music schools, one of which is hiring. His parents live ten minutes away, and he spends about five hours a week helping them, how many depending on his father's health. Only the salary's pull is plain to him: the higher the salary on offer, the stronger his wish to move. Of the rest, he can't yet say which way each pushes: he would miss the Saturdays with his parents and would also have them to himself; leading eight people might draw him to the job or put him off it; and Ilse hasn't said whether starting again in the city would suit her. Mateus's question: what bears on his wish to move?

The brief

- ☐ Draw at least four direct influences on Mateus's wish to move.
- ☐ Draw at least one indirect influence.
- ☐ Leave at least three claims without a + or -.
- ☐ Upgrade exactly one claim: the one whose direction Mateus can say.
- ☐ Each variable is a quantity that could be more or less, such as hours a week helping his parents, not a topic such as family.

Your palette



Draw here

A large grid of dots for drawing.

CD 03 Carbon dioxide in the atmosphere

Halima reads that the world's yearly emissions of carbon dioxide may soon stop growing. Burning fossil fuels and clearing land put about 11 billion tonnes of carbon a year into the air, as carbon dioxide. The oceans absorb about 3 billion tonnes of it a year, and forests and other vegetation on land about 2; the rest stays in the air. Suppose emissions hold steady at 11 billion tonnes a year from now on, and the oceans and the vegetation go on absorbing about as much as now. Count the carbon dioxide by the carbon it holds, in billion tonnes, and time in years.

Halima's question: if emissions stop growing and hold steady, does the carbon dioxide in the air stop rising?

WHICH DIAGRAM?

What does Halima draw, or write, to answer her question?

- a** A causal loop diagram
- b** A stock & flow diagram
- c** No diagram: a sentence
- d** An influence map
- e** A feedback control diagram

Feedback: Answers, chapter 12

An amount filled faster than it drains

Halima reads that the world's yearly emissions of carbon dioxide may soon stop growing. Burning fossil fuels and clearing land put about 11 billion tonnes of carbon a year into the air, as carbon dioxide. The oceans absorb about 3 billion tonnes of it a year, and forests and other vegetation on land about 2; the rest stays in the air. Suppose emissions hold steady at 11 billion tonnes a year from now on, and the oceans and the vegetation go on absorbing about as much as now. Count the carbon dioxide by the carbon it holds, in billion tonnes, and time in years. Halima's question: if emissions stop growing and hold steady, does the carbon dioxide in the air stop rising?

- ☐ Draw the carbon dioxide in the air as one stock, counted in billion tonnes of carbon.
- ☐ Draw the emissions as an inflow.
- ☐ Draw at least one outflow: what the oceans and vegetation on land absorb.
- ☐ Add a behavior-over-time graph of the stock while emissions hold steady: its direction is Halima's answer.
- ☐ Emissions held steady still exceed what the oceans and vegetation on land absorb.

stock



122

CD 04 Two siblings and one games console

Noor, eleven, and Felix, nine, share one games console. Each Sunday their father splits the coming week's turns on it between them by their best scores that week in the racing game they both play: the higher Noor's best score, the larger her share of the turns, and the higher Felix's, the smaller her share. The more turns a child gets, the more hours that child plays, and the more hours played, the higher that child's best score. In the first week, Noor scored a few points higher than Felix. Their father's question: is this a story others have seen, and how does it usually run?

WHICH DIAGRAM?

What does their father draw, or write, to answer his question?

- a** A causal loop diagram
- b** An influence map
- c** A system archetype
- d** A stock & flow diagram
- e** No diagram: a sentence

Feedback: Answers, chapter 12

CD 04 Two siblings and one games console

Two loops through one split, and the name of their story

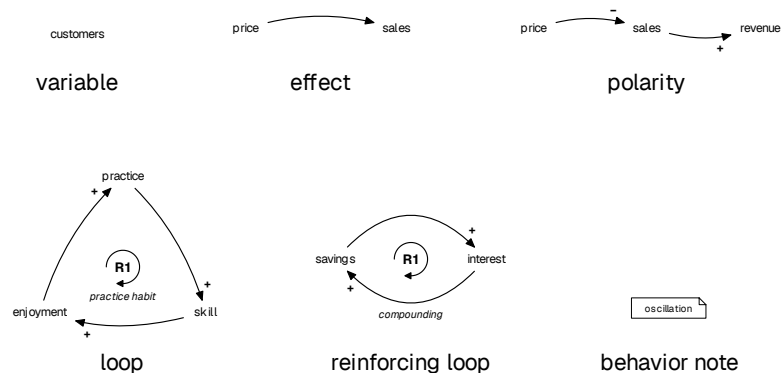
Reasoning ●●●○○ 3 of 5 Polish ●●●○○ 3 of 5

Noor, eleven, and Felix, nine, share one games console. Each Sunday their father splits the coming week's turns on it between them by their best scores that week in the racing game they both play: the higher Noor's best score, the larger her share of the turns, and the higher Felix's, the smaller her share. The more turns a child gets, the more hours that child plays, and the more hours played, the higher that child's best score. In the first week, Noor scored a few points higher than Felix. Their father's question: is this a story others have seen, and how does it usually run?

The brief

- ☐ Draw two reinforcing loops, one through each child's hours on the console.
- ☐ Match the two loops to one of chapter 10's archetypes.
- ☐ Declare that archetype in one line.
- ☐ Add a behavior note on how the split runs, week by week.
- ☐ The father's rule is one variable, Noor's share of the turns, on both loops.
- ☐ In the note: Noor's lead of a few points in the first week, and her share larger every week after.

Your palette



Archetype: fixes that fail

archetype

Draw here

In the lab, with the brief's structure checked as you draw: thinking-in-diagrams.aryehnielsen.com/pattern-and-judgment/choosing-the-diagram/#exercise-choosing-the-diagram-04

CD 05 A canal through a dry summer

Through a dry summer, Ruth keeps the long top stretch of a canal deep enough for boats. Every boat through a lock at either end of the stretch draws thousands of litres of water out of it, and on a busy day dozens of boats pass. Water comes into the stretch from a lake dammed in the hills, along a feeder, and Ruth sets how much she lets in each day; the feeder carries only so much a day. She reads the depth on a gauge board once each morning, and the further it reads below the depth boats need, the more water she lets in that day. Count the water in the stretch as its depth, in centimetres, and time in days. Ruth's question: how do her morning reading and the water she lets in hold the stretch at the depth boats need, and where can that fall short?

WHICH DIAGRAM?

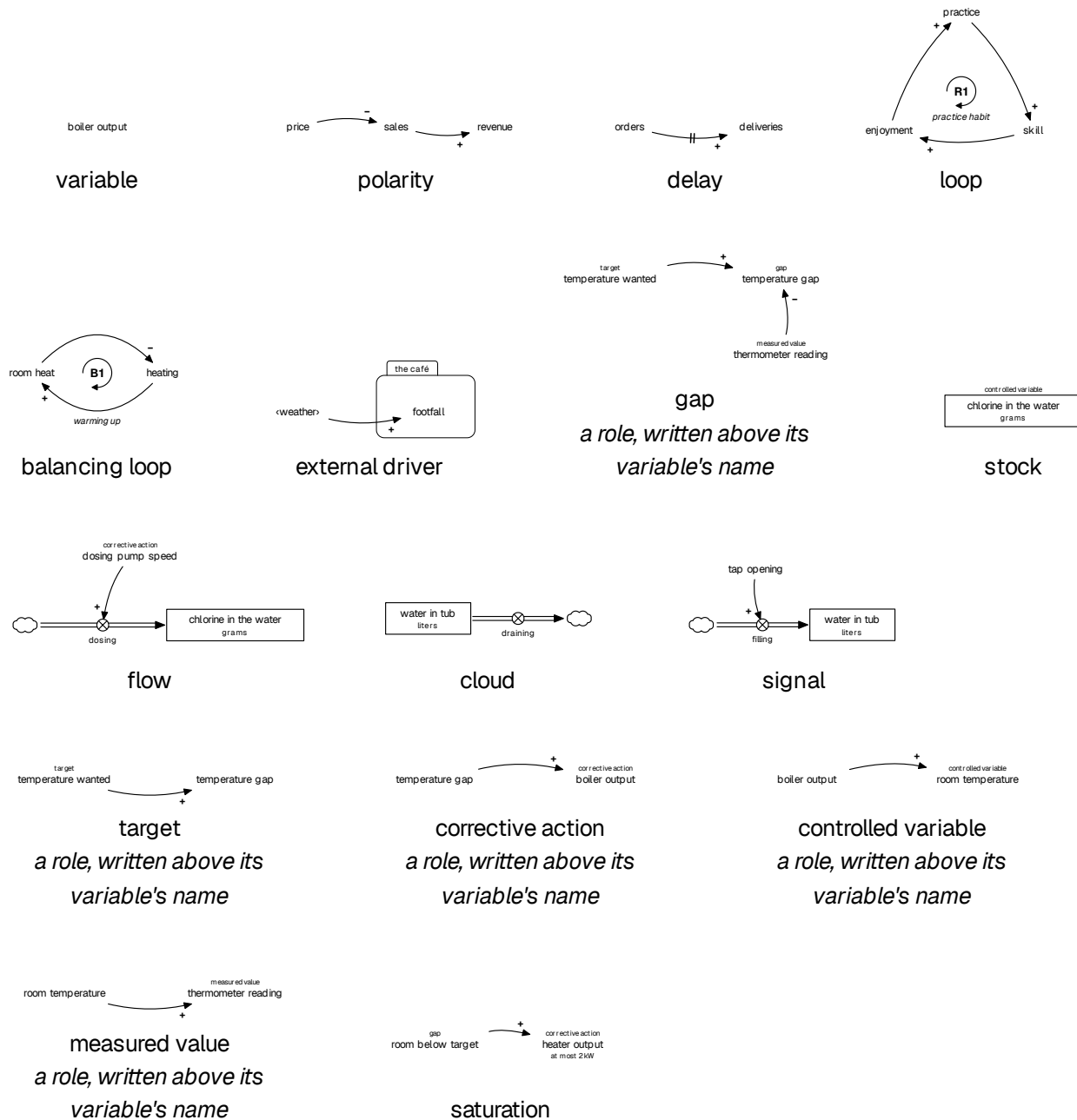
What does Ruth draw, or write, to answer her question?

- a** A stock & flow diagram
- b** A causal loop diagram
- c** A system context map
- d** A feedback control diagram
- e** No diagram: a sentence

Feedback: Answers, chapter 12

CD 05 A canal through a dry summer

Your palette



Reasoning ●●●●○ 4 of 5 Polish ●●●●○ 4 of 5

The brief

- ☐ Draw the water in the stretch as one stock, counted in centimetres of depth.
- ☐ Close one control loop through the water from the hill lake.
- ☐ Write one target: the depth boats need.
- ☐ Draw the boats through the locks as an external driver acting on the water in the stretch.
- ☐ Mark the once-a-morning reading as a delay on the return path.
- ☐ Write what the feeder carries in a day as the limit on the water Ruth lets in.
- ☐ The target depth is Ruth's choice: no signal ends at it.

On the page before this sheet.

CS 12 Kelsham Primary School: the council's question

In October 2026 Kelsham Primary School has 88 pupils, and the county council asks whether to close it. David Brennan, its officer for school places, has the births in the villages to 2025: 12 in 2023, 12 in 2024 and 11 in 2025. Each year's children start school in the September four years later, fewer of them at Kelsham than were born, since some families choose Brayford Primary School: in the year to October 2026, 9 children started and 16 pupils left. Larkfield Homes will finish the 60 homes at Mill Lane from 2027 to 2029, and the county council counts 0.25 children of primary school age for each new home: 15 children in all, joining as the homes are first lived in, and none once the last one is. Tom Hale tells the council the homes will turn the roll around. Count the pupils in pupils, and time in years. David Brennan's question: once the last Mill Lane home is lived in, does the roll go on falling?

WHICH DIAGRAM?**What does David Brennan draw, or write, to answer his question?**

- a** A causal loop diagram
- b** A stock & flow diagram
- c** An influence map
- d** A feedback control diagram
- e** No diagram: a sentence

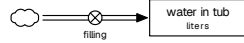
Feedback: Answers, chapter 12

CS 12 Kelsham Primary School: the council's question

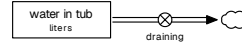
Your palette



stock



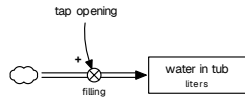
flow



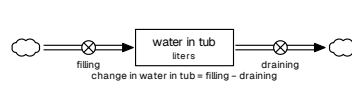
cloud

tap opening

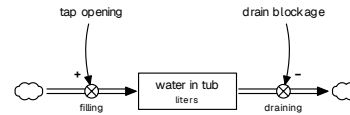
auxiliary



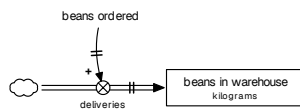
signal



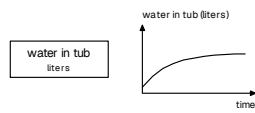
stock equation



polarity



delay

behavior-over-time
graph

CS 12 Kelsham Primary School: the council's question

Choosing the drawing for whether the roll recovers

Reasoning ●●●●○ 4 of 5 Polish ●●●●○ 4 of 5

In October 2026 Kelsham Primary School has 88 pupils, and the county council asks whether to close it. David Brennan, its officer for school places, has the births in the villages to 2025: 12 in 2023, 12 in 2024 and 11 in 2025. Each year's children start school in the September four years later, fewer of them at Kelsham than were born, since some families choose Brayford Primary School: in the year to October 2026, 9 children started and 16 pupils left. Larkfield Homes will finish the 60 homes at Mill Lane from 2027 to 2029, and the county council counts 0.25 children of primary school age for each new home: 15 children in all, joining as the homes are first lived in, and none once the last one is. Tom Hale tells the council the homes will turn the roll around. Count the pupils in pupils, and time in years. David Brennan's question: once the last Mill Lane home is lived in, does the roll go on falling?

The brief

- ☐ Draw the pupils on roll as one stock, counted in pupils.
- ☐ Draw two inflows: the children starting each September, and the children moving into the Mill Lane homes.
- ☐ Draw the pupils leaving as one outflow.
- ☐ Show the stock equation.
- ☐ Draw the births in the villages with a signal to the children starting, delayed by the four years before a child starts.
- ☐ Add a behavior-over-time graph of the roll once the last Mill Lane home is lived in: its direction is David Brennan's answer.
- ☐ The inflow from Mill Lane ends with the last home lived in; the children starting go on each September.

Your palette

On the page before this sheet.

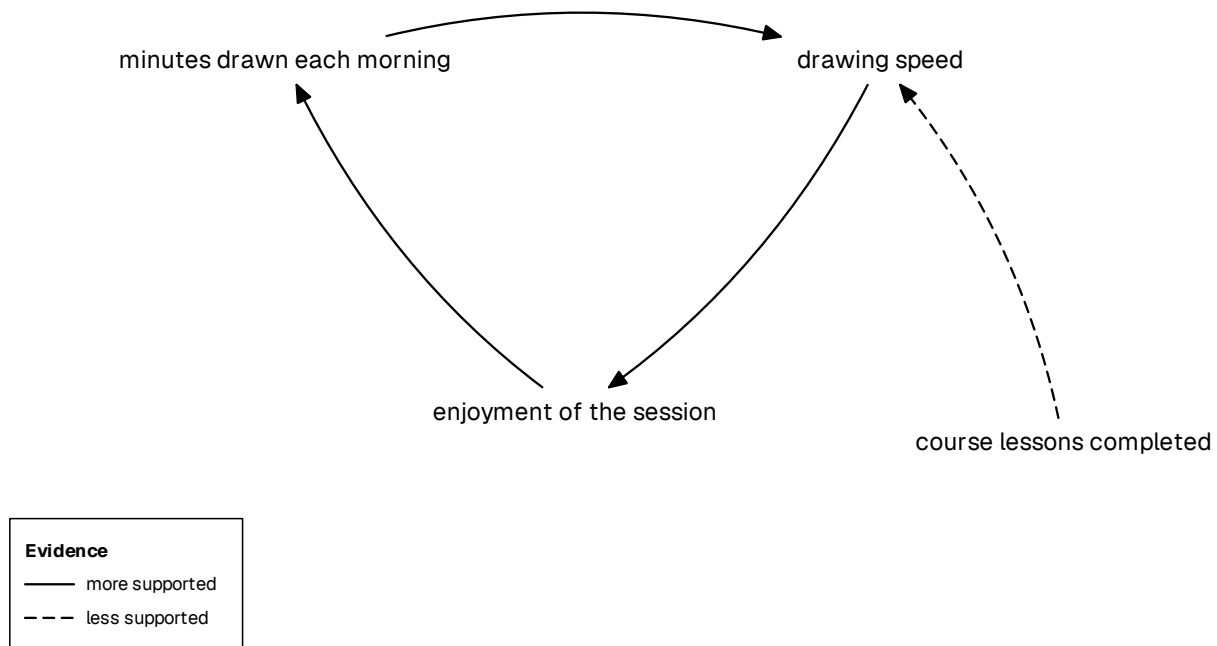
Draw here

Diagram drawing area with a grid of dots.

Answers

Chapter 1 · What Is a Diagram For?

DF 01 Greta's morning drawing



This is one defensible answer, not the only one. Yours can differ and still hold up: the lab's checks show whether it has the brief's structure.

The minutes Greta draws each morning change her drawing speed, her speed changes her enjoyment of the session, and her enjoyment changes the minutes she draws: three effects whose changes she timed, marked or logged side by side, closing a circle, and she draws each solid. The lessons of the online course change her speed too, an effect she believes and hasn't counted alongside her times, so she dashes it, and the legend lists the dashed line as less supported.

Why it works

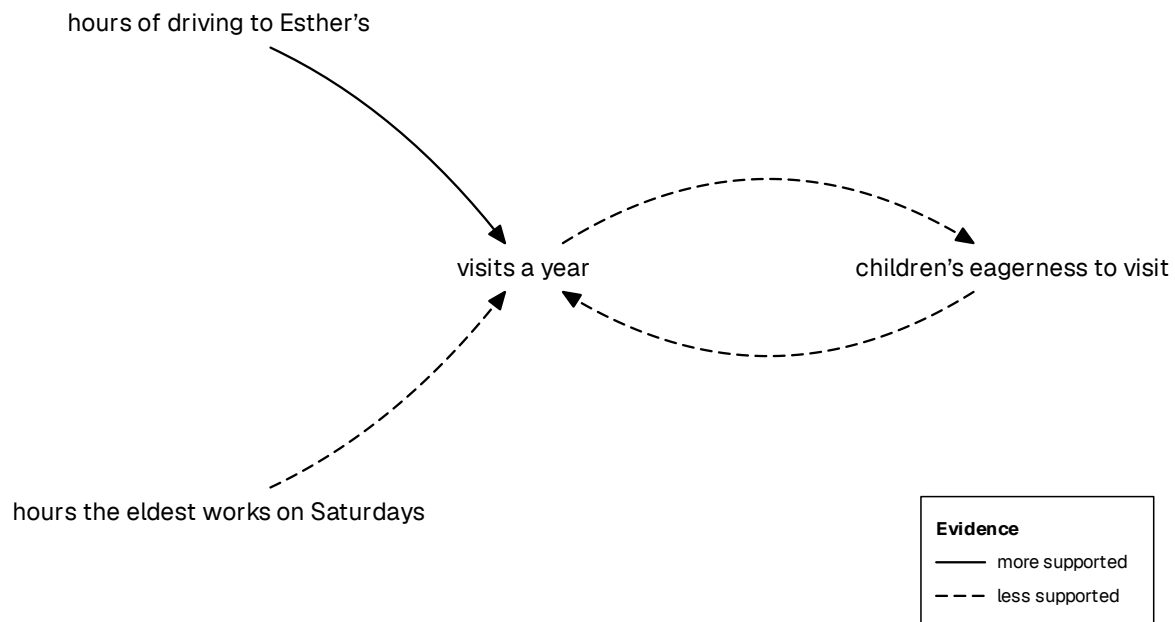
- Four quantities, each able to rise or fall
- Three effects Greta draws solid close a circle, each a change she logged alongside another
- Greta's one belief, course lessons completed → drawing speed, dashed
- Legend on, listing the dashed line as less supported

Step by step

1. Minutes drawn each morning and drawing speed, with an effect between them that Greta draws solid: her log opens with her times beside the weeks she drew longest and the fortnight she barely drew.
2. Enjoyment of the session, with a solid effect into it from drawing speed and another from it to minutes drawn each morning, which closes the circle before anything is dashed: her one-to-five marks and her longer mornings are in the log too, so she draws both solid.
3. Course lessons completed, with a dashed effect on drawing speed, and the legend with it, since this is the one dashed line: Greta has no count of lessons beside her times, so she dashes it.

What another defensible answer might vary

Another answer might close the circle from drawing speed straight back to minutes drawn each morning, since Greta's faster mornings are also her longer ones, and leave enjoyment of the session an effect of speed alone. With a fifth variable, beyond this brief's four, another might add sleep the night before as a second dashed effect on drawing speed. What stays is a circle of solid effects through the minutes she draws, and the course's effect on her speed dashed, with the legend on.

DF 02 Esther's grandchildren's visits

This is one defensible answer, not the only one. Yours can differ and still hold up: the lab's checks show whether it has the brief's structure.

The hours of driving to Esther's changed the visits a year, from twelve to four, from the first month after the move: her calendar counts the change in the visits alongside the move, so she draws the effect solid, and her son agrees with it. She dashes her three beliefs, which no count supports and her son rejects: the hours the eldest works on Saturdays changing the visits, and a circle in which fewer visits lower the children's eagerness to visit and lower eagerness means fewer visits. The legend lists the dashed line as less supported.

Why it works

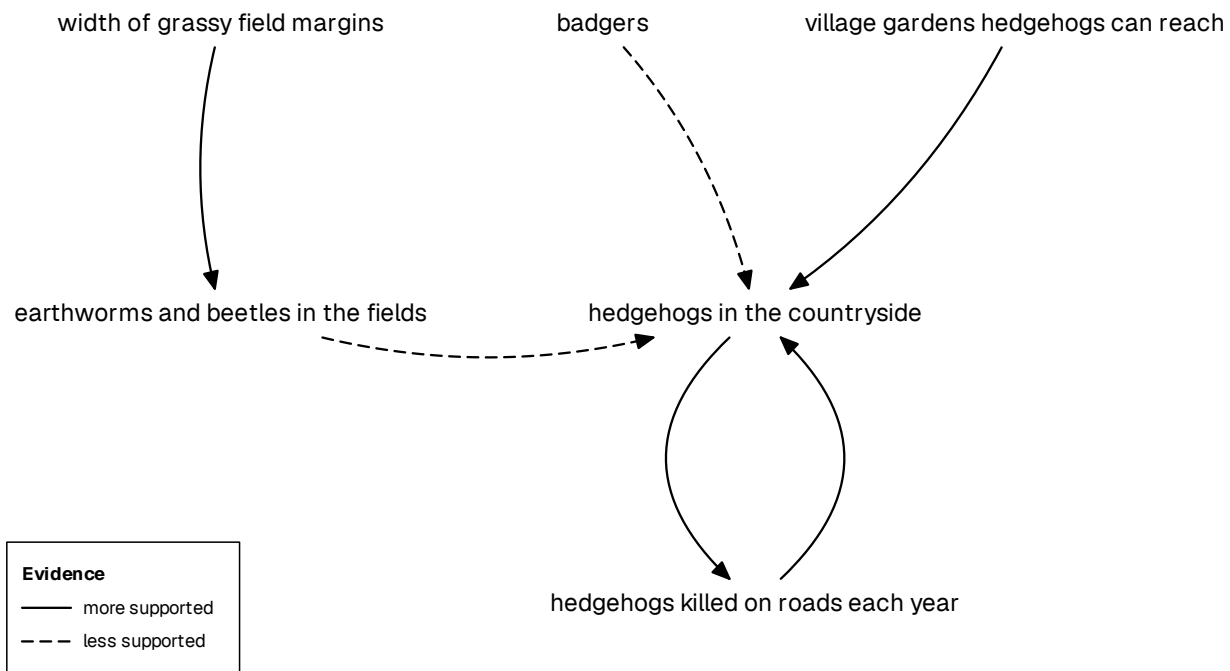
- Four quantities, each able to rise or fall
- The one effect Esther draws solid, on the calendar's count of the visits alongside the move: hours of driving to Esther's → visits a year
- Esther's three beliefs dashed, the two that close a circle among them
- The solid effect is the one Esther and her son agree on; every dashed one is hers alone
- Legend on, listing the dashed line as less supported

Step by step

1. Hours of driving to Esther's and visits a year, with a solid effect between them, before anything dashed: the calendar is the one count in the paragraph, and Esther draws the effect solid on it.
2. Hours the eldest works on Saturdays, with a dashed effect on visits a year, and the legend with this, the one dashed line so far: Esther hasn't set the calendar beside the bakery shifts, so she dashes it.
3. Children's eagerness to visit, with a dashed effect into it from visits a year and another from it back to them, the circle drawn whole in one step because Esther believes it both ways at once; she hasn't asked the children, so she dashes both.

What another defensible answer might vary

Another answer might draw the Saturday job's effect on the children's eagerness to visit instead of on the visits, still dashed, since Esther hasn't asked the eldest either. What stays is one solid effect from the drive to the visits, every one of Esther's beliefs dashed, and the legend on.

DF 03 Hedgehogs in Britain's countryside

This is one defensible answer, not the only one. Yours can differ and still hold up: the lab's checks show whether it has the brief's structure.

This answer draws its line at a count. Four effects have a change counted alongside another and are drawn solid: wide, grassy field margins hold more earthworms and beetles; the more village gardens hedgehogs can reach, the more hedgehogs, since they are densest there; and hedgehogs and the hedgehogs killed on roads, counted falling together since 1990, change each other. Whether road deaths are behind the hedgehogs' fall, which the authors call unclear, is a question for reading that solid effect. The badgers' effect on the hedgehogs rests on the authors' word that it is likely, weaker support than a count, and the prey's on a question they are still studying, so both fall below the line and are dashed. The legend lists the dashed line as less supported.

Why it works

- Six quantities, each able to rise or fall
- Solid effects where a change was counted alongside another, the line drawn at a count: field margins on prey, gardens on hedgehogs, and hedgehogs and road deaths each on the other
- Dashed effects where the newsletter reports no count: badgers and prey, each on the hedgehogs
- Road deaths drawn both ways, both solid on the one count: which changes which is the question the authors leave unclear
- Legend on, listing the dashed line as less supported

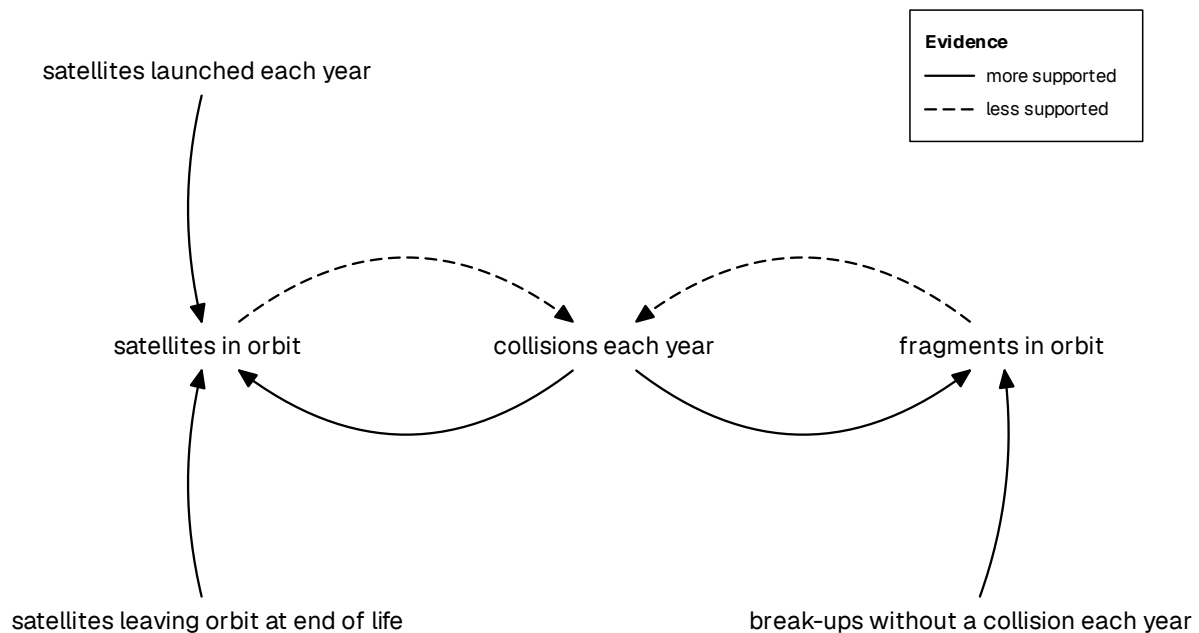
Step by step

1. Hedgehogs in the countryside and hedgehogs killed on roads each year, with a solid effect each way, the line drawn at a count: the newsletter opens with these two counts, both falling.
2. Width of grassy field margins and earthworms and beetles in the fields, with a solid effect between them from the studies of margins; nothing counted joins the prey to the hedgehogs, so no solid effect does.

3. Village gardens hedgehogs can reach, with a solid effect on the hedgehogs, from the researchers' count of hedgehogs densest in village gardens on arable land.
4. Badgers, with a dashed effect on the hedgehogs, and the legend with this, the one dashed line so far: the authors call the effect likely, testimony weaker than a count, so it falls below the line.
5. A dashed effect from earthworms and beetles to the hedgehogs joins the field margins to the rest of the drawing, on a question the authors list as still being studied.

What another defensible answer might vary

Another answer might dash the gardens' effect, since the studies found where hedgehogs feed and are densest, not how many more a hole in a fence adds. Another might add badgers → earthworms and beetles in the fields, dashed, for the food the two compete for, which the newsletter doesn't count. What stays is the badgers' and the prey's effects dashed, and the legend on.

DF 04 Objects in orbit

This is one defensible answer, not the only one. Yours can differ and still hold up: the lab's checks show whether it has the brief's structure.

Five effects rest on counts and are drawn solid: satellites launched each year add to the satellites in orbit, and satellites leaving at the end of their life take from them; collisions each year take satellites out and add fragments, as Iridium 33 and Cosmos 2251 did; and break-ups without a collision each year add more fragments. Two effects come from models, Kessler and Cour-Palais's in 1978 and ESA's now: more satellites and more fragments in orbit bring more collisions. Those two dashed effects close both circles through collisions, so the cascade in the models runs on two less supported effects. The legend lists the dashed line as less supported.

Why it works

- Six quantities, satellites in orbit and fragments in orbit apart
- Five effects the counts support, solid: launches, departures at end of life, the collision's two, and break-ups
- The two modelled effects, satellites in orbit → collisions each year and fragments in orbit → collisions each year, dashed
- Each circle closes through a dashed effect
- Legend on, listing the dashed line as less supported

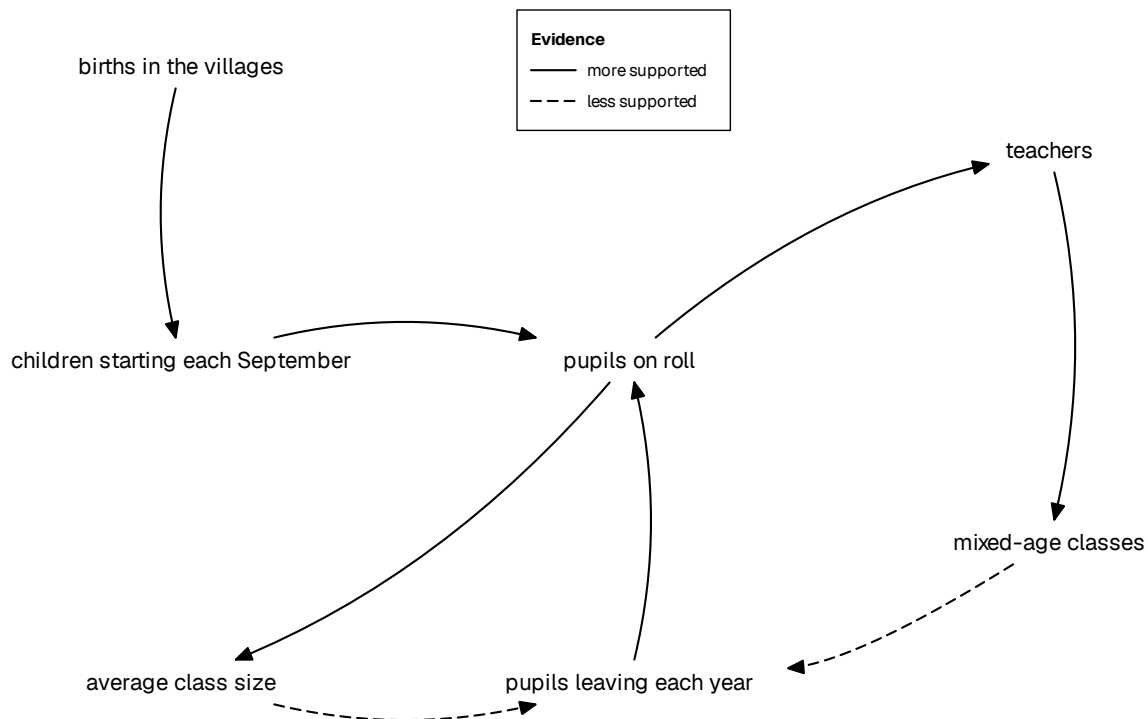
Step by step

1. Satellites in orbit, with solid effects from satellites launched each year and satellites leaving orbit at end of life, the two counts the notes open with.
2. Collisions each year and fragments in orbit, with solid effects from collisions to satellites in orbit and to fragments in orbit: Iridium 33 and Cosmos 2251 broke apart into 823 catalogued fragments.
3. Break-ups without a collision each year, with a solid effect on fragments in orbit: ESA counts them as the largest source of fragments today.

4. Dashed effects from satellites in orbit and from fragments in orbit to collisions each year, with the legend, after every solid effect: these two alone turn the chain of counts into two circles.

What another defensible answer might vary

Another answer might draw one variable, objects in orbit, for satellites and fragments together, with one dashed effect on collisions; this brief keeps the two apart, since launches and departures change the satellites and break-ups the fragments. Another might leave out collisions each year → satellites in orbit, since one collision took out two satellites. What stays is the effects on collisions dashed, the rest solid, and the legend on.

CS 01 Kelsham Primary School: the head teacher's letter

This is one defensible answer, not the only one. Yours can differ and still hold up: the lab's checks show whether it has the brief's structure.

Six effects rest on counts and are drawn solid: the births in the villages changed the children starting each September four years later; the starters and the pupils leaving each year changed the pupils on roll; the roll, through the funding each October's count sets, changed the teachers, and fewer teachers made Years 3 and 4 one mixed-age class; and the roll in four classes set the average class size. The parents' two reasons, mixed-age classes and average class size each changing the pupils leaving each year, rest on their word and are dashed, and each closes a circle back through the pupils on roll. The legend lists the dashed line as less supported.

Why it works

- Seven quantities, the starters and the pupils leaving each year apart
- Six effects the counts support, solid: births on the starters, the starters and the leavers on the roll, the roll on teachers and on average class size, and teachers on mixed-age classes
- The parents' two reasons dashed: mixed-age classes → pupils leaving each year, and average class size → pupils leaving each year
- Each circle through the pupils on roll closes through a dashed effect
- Legend on, listing the dashed line as less supported

Step by step

1. Births in the villages, children starting each September and pupils on roll, with a solid effect from each to the next, the first counts in the letter: the county council's records and the roll.
2. Pupils leaving each year, with a solid effect on pupils on roll: each October's roll is the last one's plus the starters, less those who left.

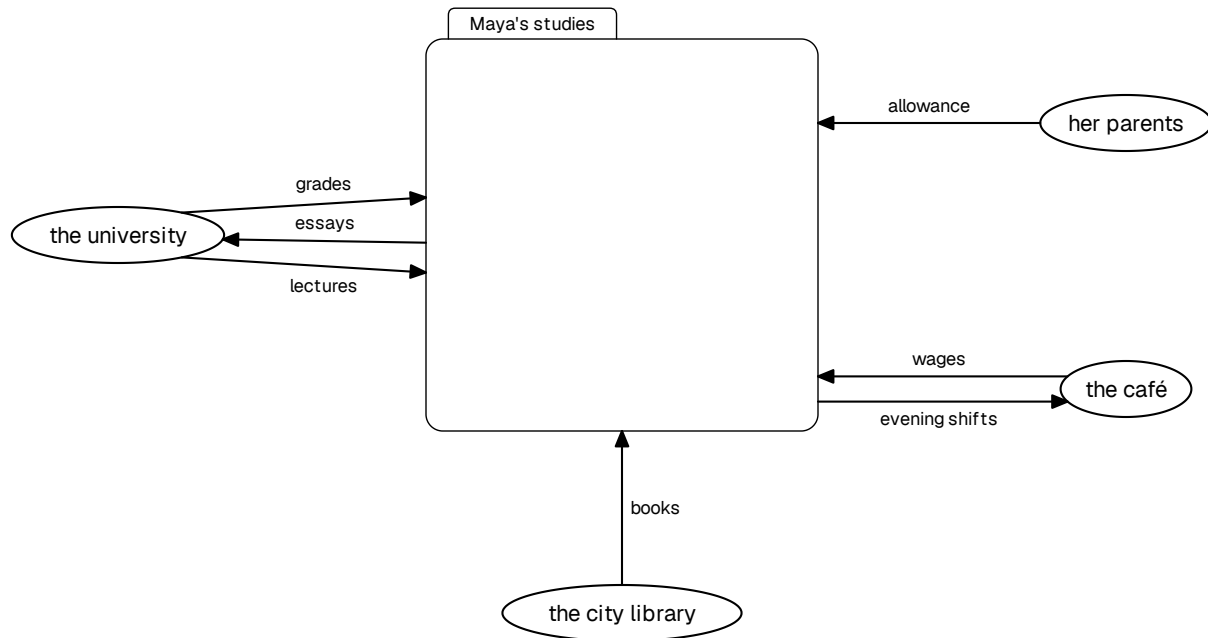
3. Teachers and mixed-age classes, with solid effects from the roll to teachers and from teachers to mixed-age classes: in 2023 the roll paid for four teachers, and Years 3 and 4 became one class.
4. Average class size, with a solid effect from the roll: 88 pupils in four classes, counted this October.
5. Dashed effects from mixed-age classes and from average class size to pupils leaving each year, with the legend, after every solid effect: the parents' two reasons, resting on their word, close both circles.

What another defensible answer might vary

Another answer might draw school funding between the pupils on roll and the teachers, since the count sets the funding and the funding pays the teachers, or draw the parents' reasons on the children starting each September as well, still dashed. What stays is the counts' effects solid, the parents' reasons dashed, and the legend on.

Chapter 2 · Drawing the Boundary

SC 01 A first term away from home



This is one defensible answer, not the only one. Yours can differ and still hold up: the lab's checks show whether it has the brief's structure.

One boundary, Maya's studies, with four parties outside it: the university, her parents, the café and the city library. Seven named exchanges cross the boundary. Lectures and grades come in from the university and essays go out to it; the café takes her evening shifts and pays wages.

Why it works

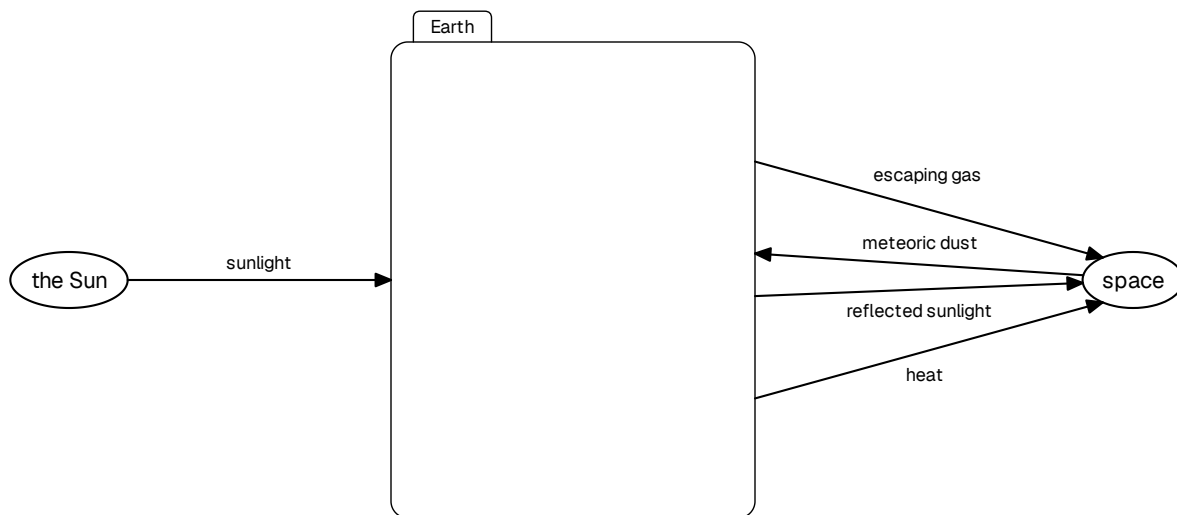
- One boundary, named for the system
- Four parties, each outside the boundary
- Every party gives or receives at least one thing
- Each exchange named for the one thing it carries
- Housemates and friends left out

Step by step

1. The boundary, Maya's studies, before any party, since every party goes outside it.
2. The university, the party the paragraph opens with, with lectures and grades crossing in and essays crossing out.
3. Her parents, with the allowance crossing in, and the café, with evening shifts out and wages back: the two parties that pay her, in the paragraph's order.
4. The city library, with books crossing in, the last party the paragraph names.

What another defensible answer might vary

Another defensible answer might draw her whole first term as the system, with a landlord as a fifth party, or name the café's exchanges as time and money. What stays the same is one named boundary, parties outside it, and a name on every exchange.

SC 02 Earth

This is one defensible answer, not the only one. Yours can differ and still hold up: the lab's checks show whether it has the brief's structure.

Earth is the boundary, with the Sun and space outside it. Energy crosses as sunlight in from the Sun, and as heat and reflected sunlight out to space. Matter crosses as meteoric dust in from space and escaping gas out to it.

Why it works

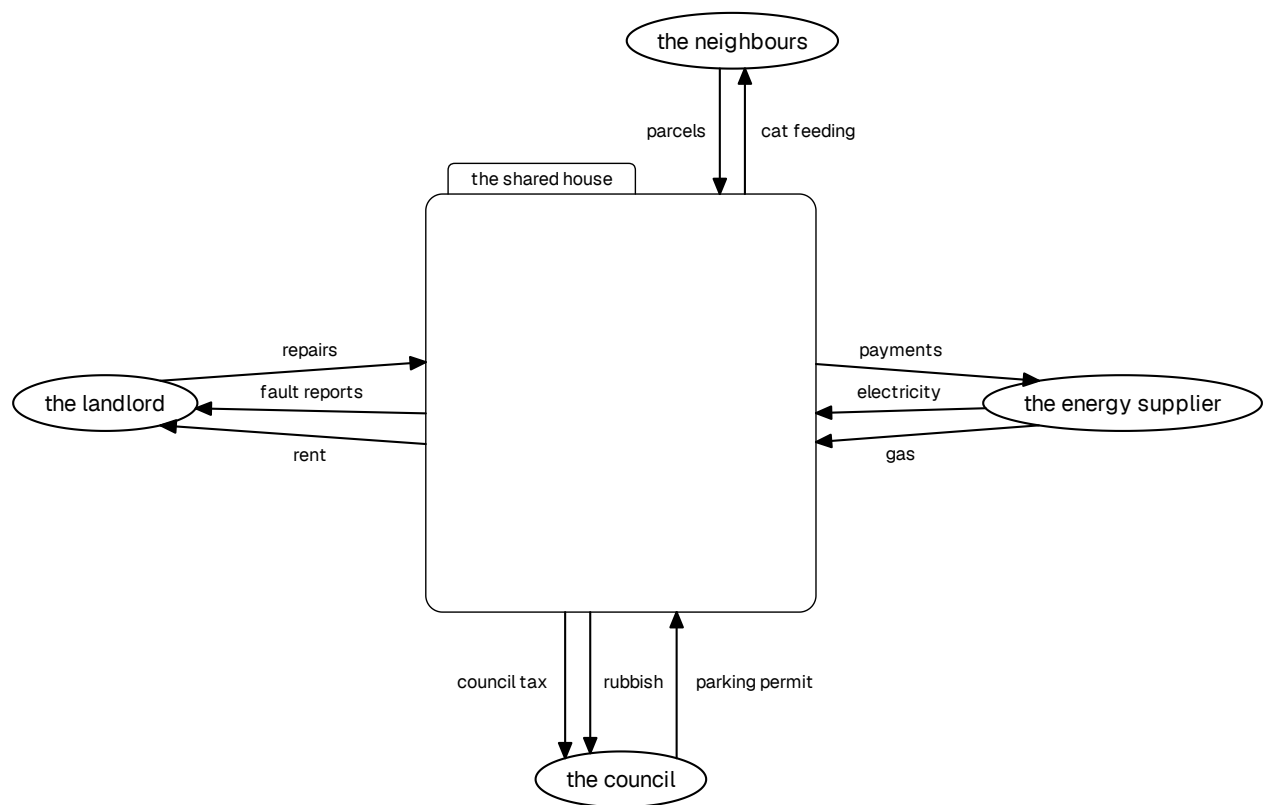
- One boundary around the planet, named Earth
- The Sun only gives; space both gives and receives
- Reflected sunlight and heat drawn as two exchanges, since they are two things
- Sunlight, heat and reflected sunlight are energy; meteoric dust and escaping gas are matter

Step by step

1. The boundary, Earth, before the Sun and space, since every crossing after it goes in or out across this line.
2. The Sun, with sunlight crossing in: the energy that the heat and reflected sunlight going out both start from.
3. Space, with heat and reflected sunlight crossing out to it as two exchanges, the energy leaving after the energy arriving.
4. Meteoric dust in from space and escaping gas out to it, the matter crossings, after the energy ones, as the paragraph lists them.

What another defensible answer might vary

Another defensible answer might name the heat as infrared radiation, or draw the escaping gas as two exchanges, hydrogen and helium. What stays the same is two parties, five things crossing, and each exchange carrying one thing one way.

SC 03 A shared house

This is one defensible answer, not the only one. Yours can differ and still hold up: the lab's checks show whether it has the brief's structure.

One boundary, the shared house, with four parties outside it: the landlord, the energy supplier, the council and the neighbours. Eleven named exchanges cross it, and every party both gives and receives. Rent and fault reports go to the landlord and repairs come back; gas and electricity come in from the supplier and payments go out; council tax and rubbish go to the council and a parking permit comes back; parcels come in from the neighbours and cat feeding goes out.

Why it works

- One boundary, named for the household
- The five students are the system, so none of them is drawn as a party
- Rent and repairs drawn as two exchanges, one each way
- Gas and electricity drawn as two exchanges, since they are two things
- Every party gives and receives at least one thing

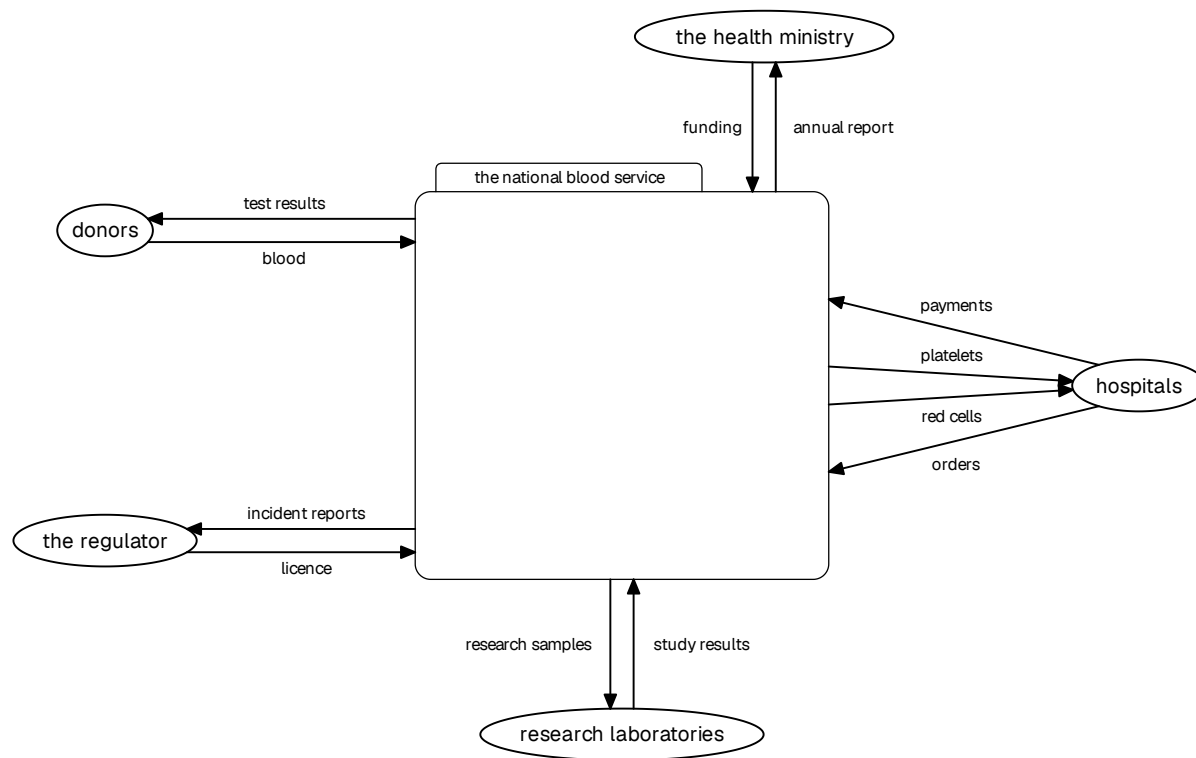
Step by step

1. The boundary, the shared house, with the five students inside it, before any of the parties they deal with.
2. The landlord, with rent and fault reports going out and repairs coming back, as the paragraph's second sentence lists them.
3. The energy supplier, with gas and electricity coming in as two exchanges and payments going out by direct debit.
4. The council, with council tax and rubbish going out and a parking permit coming back, one exchange for each thing it collects, empties or issues.

5. The neighbours, with parcels coming in and cat feeding going out, the last party and the only one paid in favours.

What another defensible answer might vary

Another defensible answer might leave out the parking permit, or add the supplier's quarterly bills as a further exchange. What stays the same is one named boundary, the four parties outside it, and one thing per exchange.

SC 04 A national blood service

This is one defensible answer, not the only one. Yours can differ and still hold up: the lab's checks show whether it has the brief's structure.

One boundary, the national blood service, with five parties outside it: donors, hospitals, the health ministry, the regulator and research laboratories. Twelve named exchanges cross it, and every party both gives and receives. Blood comes in from donors and test results go back; orders and payments come in from hospitals, and red cells and platelets go out to them; funding and a licence come in, and an annual report and incident reports go out; research samples go to the laboratories and study results come back.

Why it works

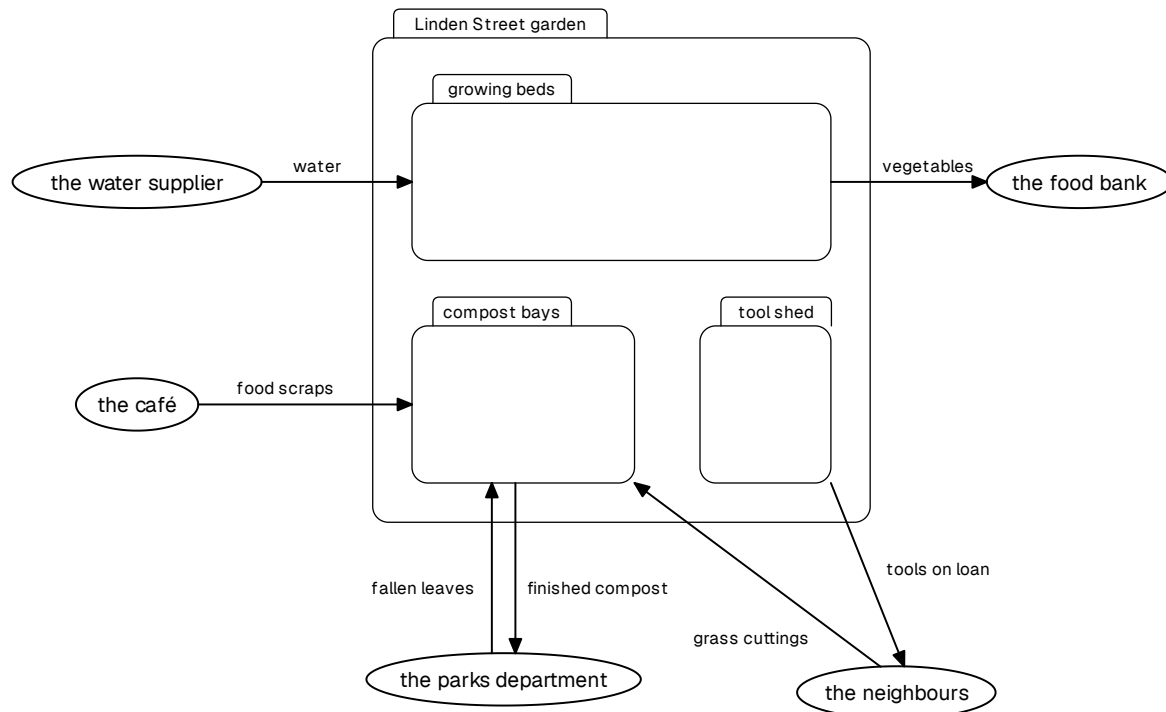
- One boundary around the service, named for it
- Donors outside the boundary, since the service doesn't run them
- Red cells and platelets drawn as two exchanges, since they are two things
- Every party gives and receives, each direction its own exchange

Step by step

1. The boundary, the national blood service, before any party, so that every party, donors included, goes outside it.
2. Donors, with blood coming in and test results going back, where the blood's path starts.
3. Hospitals, where the blood's path ends, with orders and payments coming in and red cells and platelets going out as two exchanges.
4. The health ministry and the regulator, the two parties that oversee the service, with funding and a licence coming in and an annual report and incident reports going out.
5. Research laboratories, with research samples going out and study results coming back: the donations unfit for transfusion, which leave the blood's path.

What another defensible answer might vary

Another defensible answer might add plasma as a third product, sent to a maker of medicines as a sixth party, or draw the regulator's inspections as an exchange beside the licence. What stays the same is one named boundary, donors and hospitals outside it, and one thing per exchange.

SC 05 A community garden

This is one defensible answer, not the only one. Yours can differ and still hold up: the lab's checks show whether it has the brief's structure.

One outer boundary, Linden Street garden, holds three parts: growing beds, compost bays and the tool shed. Five parties sit outside it. Each of the seven exchanges reaches the part that handles it: water and vegetables reach the growing beds; food scraps, fallen leaves, grass cuttings and finished compost reach the compost bays; tools on loan leave from the tool shed.

Why it works

- One outer boundary, named for the garden
- Three parts, each named for what it does
- Every exchange reaches one part, none the garden as a whole
- The neighbours exchange with two parts: grass cuttings go to the compost bays and tools come from the tool shed
- The parks department both gives and receives through the compost bays

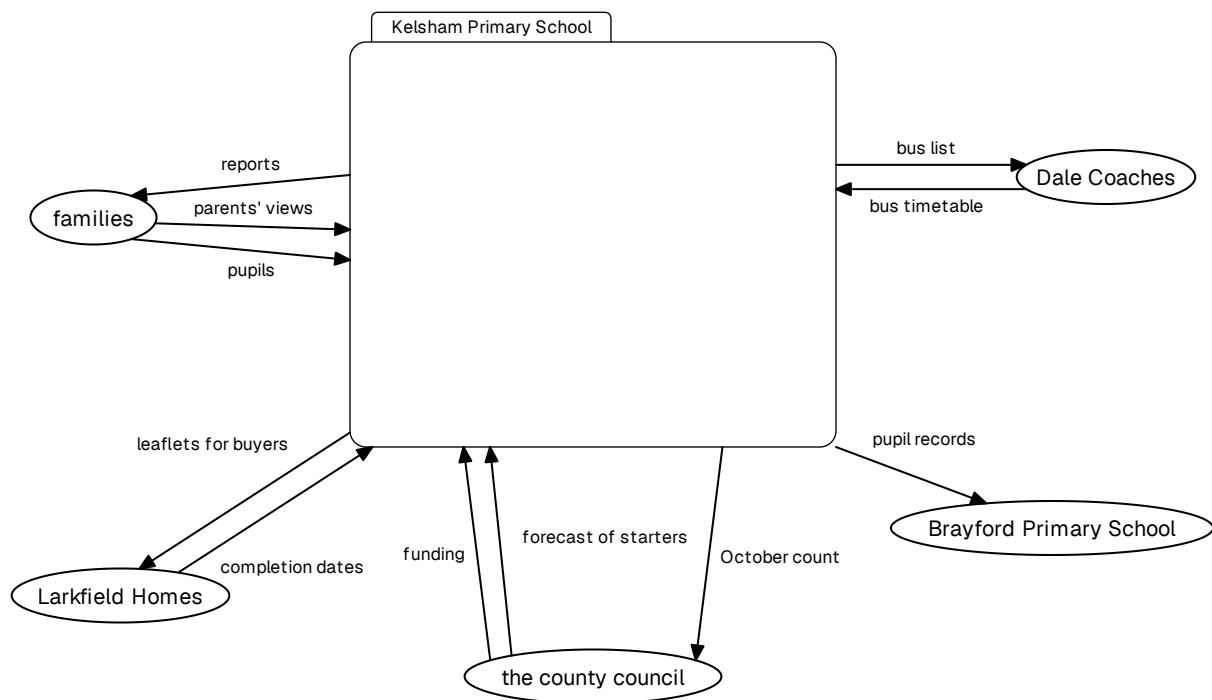
Step by step

1. The outer boundary, Linden Street garden, before its parts, which sit inside it.
2. Its three parts, growing beds, compost bays and the tool shed, each a boundary inside it, before any party, since each exchange ends at a part.
3. The water supplier and the food bank, with water in to the growing beds and vegetables out from them, as the paragraph opens.
4. The café and the parks department, at the compost bays: food scraps and fallen leaves in, and finished compost back out to the parks department.

5. The neighbours last, since they reach two parts, with grass cuttings in to the compost bays and tools on loan out from the tool shed.

What another defensible answer might vary

Another defensible answer might draw the tools' return as a second exchange with the tool shed, or add a seed store as a fourth part. What stays the same is one outer boundary named for the garden, parts named for what they do, and every exchange reaching one part.

CS 02 Kelsham Primary School and the parties it deals with

This is one defensible answer, not the only one. Yours can differ and still hold up: the lab's checks show whether it has the brief's structure.

One boundary, Kelsham Primary School, with five parties outside it: families, the county council, Dale Coaches, Brayford Primary School and Larkfield Homes. Eleven named exchanges cross it. Pupils and parents' views come in from families and reports go out; funding and a forecast of starters come in from the county council and the October count goes out; the bus timetable comes in from Dale Coaches and the bus list goes out; pupil records go out to Brayford Primary School; completion dates come in from Larkfield Homes and leaflets for buyers go out.

Why it works

- One boundary, named for the school
- Funding, the forecast and the October count drawn as three exchanges with the county council, one thing each
- Four parties both give and receive; Brayford Primary School only receives, since nothing in the paragraph comes back from it
- The county council's contract with Dale Coaches left off: it crosses no part of the school's boundary

Step by step

1. The boundary, Kelsham Primary School, alone: every exchange in the paragraph crosses it.
2. Families, with pupils and parents' views coming in and reports going out, the party the paragraph names first.
3. The county council, with funding and a forecast of starters coming in and the October count going out: three exchanges, since each carries one thing.
4. Dale Coaches, with the bus timetable coming in and the bus list going out.
5. Brayford Primary School, with pupil records going out, the one party that sends the school nothing.

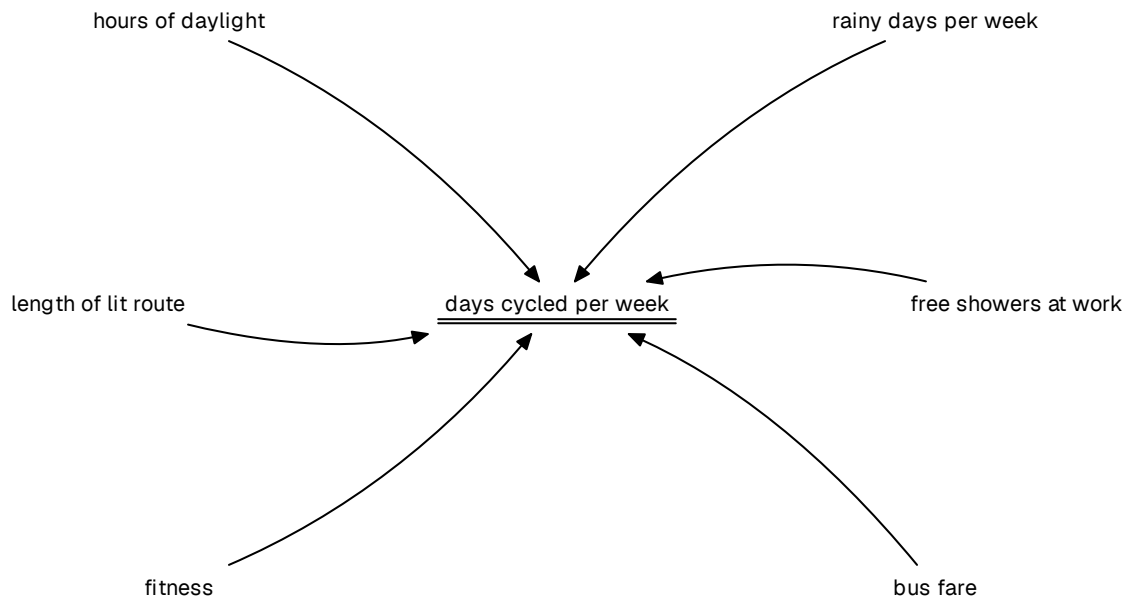
6. Larkfield Homes, with completion dates coming in and leaflets for buyers going out, the party whose 60 homes are not yet lived in.

What another defensible answer might vary

Another defensible answer might draw David Brennan as a party of his own beside the county council, or add pupils going out to Brayford Primary School beside their records. What stays the same is one boundary named for the school, the five parties outside it, and one thing per exchange.

Chapter 3 · Surfacing Influences

IM 01 Cycling to work through the winter



This is one defensible answer, not the only one. Yours can differ and still hold up: the lab's checks show whether it has the brief's structure.

Days cycled per week, double-underlined as the central outcome, with six variables acting on it straight: hours of daylight, rainy days per week, length of lit route, free showers at work, fitness and bus fare. Every influence is an influence claim with no + or –.

Why it works

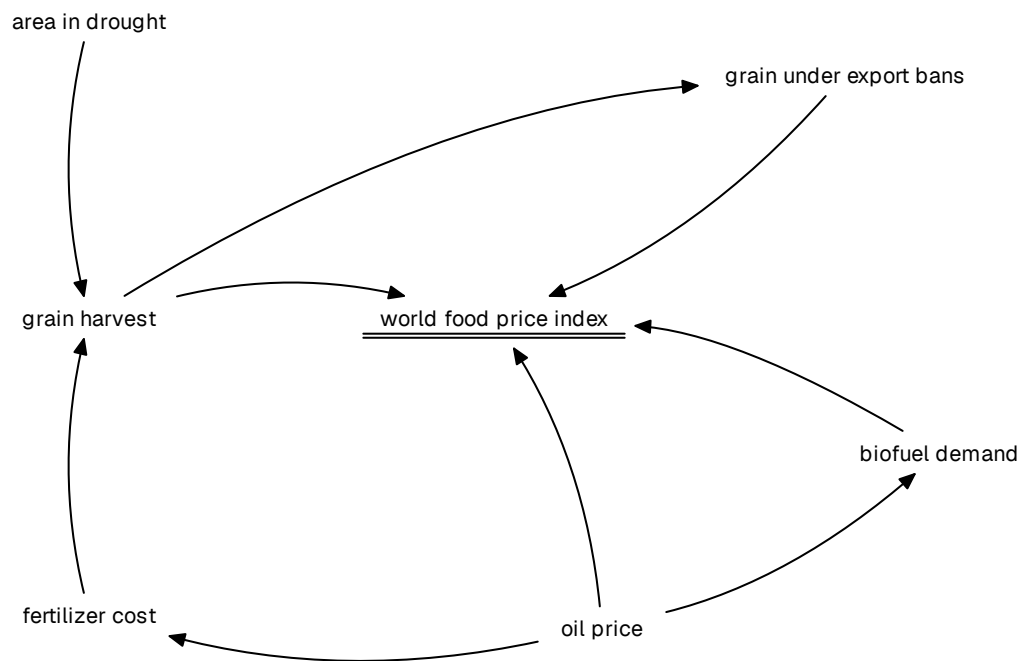
- One central outcome, the number Tomás counts
- Six direct influences and no indirect ones
- No polarity: nothing in the situation was measured
- Each variable a quantity: free showers at work, not the showers

Step by step

1. Days cycled per week, double-underlined as the central outcome, alone before any influence claim, since every claim in the brief ends at it.
2. Hours of daylight and rainy days per week, each with an influence claim on days cycled per week: the two the autumn moves, one falling and one rising.
3. Length of lit route and free showers at work, each with an influence claim: the route and the office, which change with the council's work and the morning's rush.
4. Fitness and bus fare, each with an influence claim: what Tomás brings to the ride and what the other way to work costs.

What another defensible answer might vary

Another defensible answer might leave out the bus fare, draw morning temperature as a seventh variable, or name rainy days per week as hours of rain. What stays the same is one central outcome, each variable a quantity, and every influence claim drawn straight to it with no + or –.

IM 02 World food prices

This is one defensible answer, not the only one. Yours can differ and still hold up: the lab's checks show whether it has the brief's structure.

The world food price index as the central outcome, with four direct influences: grain harvest, oil price, biofuel demand and grain under export bans. Area in drought and fertilizer cost reach the index through the grain harvest, the oil price also acts on fertilizer cost and biofuel demand, and the grain harvest acts on grain under export bans. Every influence is an influence claim with no + or –.

Why it works

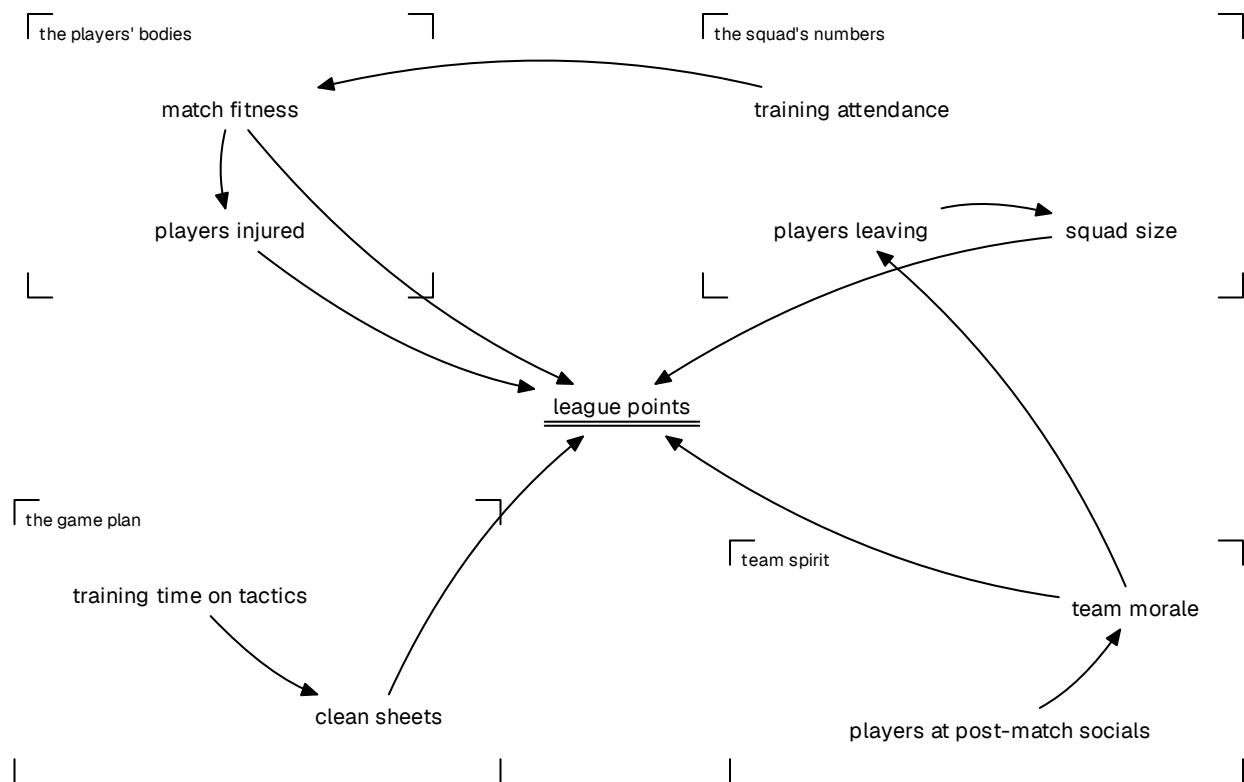
- One central outcome: the world food price index
- Four direct influences, each ending at the index
- Five indirect influences, each drawn to the variable it acts on
- The oil price on three paths: straight, through fertilizer cost and through biofuel demand
- Every variable has a path to the index

Step by step

1. The world food price index, double-underlined as the central outcome, alone before any influence claim, since every path in the drawing ends at it.
2. Grain harvest, oil price, biofuel demand and grain under export bans, each with an influence claim on the index, before anything indirect: a variable acting through another comes after it.
3. Area in drought and fertilizer cost, each with an influence claim on the grain harvest, the variable both act through.
4. Three influence claims among variables already drawn: the oil price on fertilizer cost and on biofuel demand, and the grain harvest on grain under export bans.

What another defensible answer might vary

Another defensible answer might draw fertilizer cost straight to the index as a cost of farming, add grain stocks between the harvest and the index, or leave out the influence claim from the grain harvest to grain under export bans. What stays the same is one central outcome, and the area in drought reaching it only through the grain harvest.

IM 03 An amateur football team's season

This is one defensible answer, not the only one. Yours can differ and still hold up: the lab's checks show whether it has the brief's structure.

League points as the central outcome, in no cluster, with four clusters around it: the players' bodies (match fitness, players injured), the squad's numbers (training attendance, players leaving, squad size), the game plan (training time on tactics, clean sheets) and team spirit (team morale, players at post-match socials). Match fitness, players injured, squad size, clean sheets and team morale act on league points straight; the other four reach it through one of them. Every influence is an influence claim with no + or –.

Why it works

- One central outcome, league points, outside every cluster
- Four clusters, each labeled for what its variables share
- Every other variable in one cluster, and two or more in each
- Five direct influences and six indirect ones
- No polarity: nobody at the club measured any of them

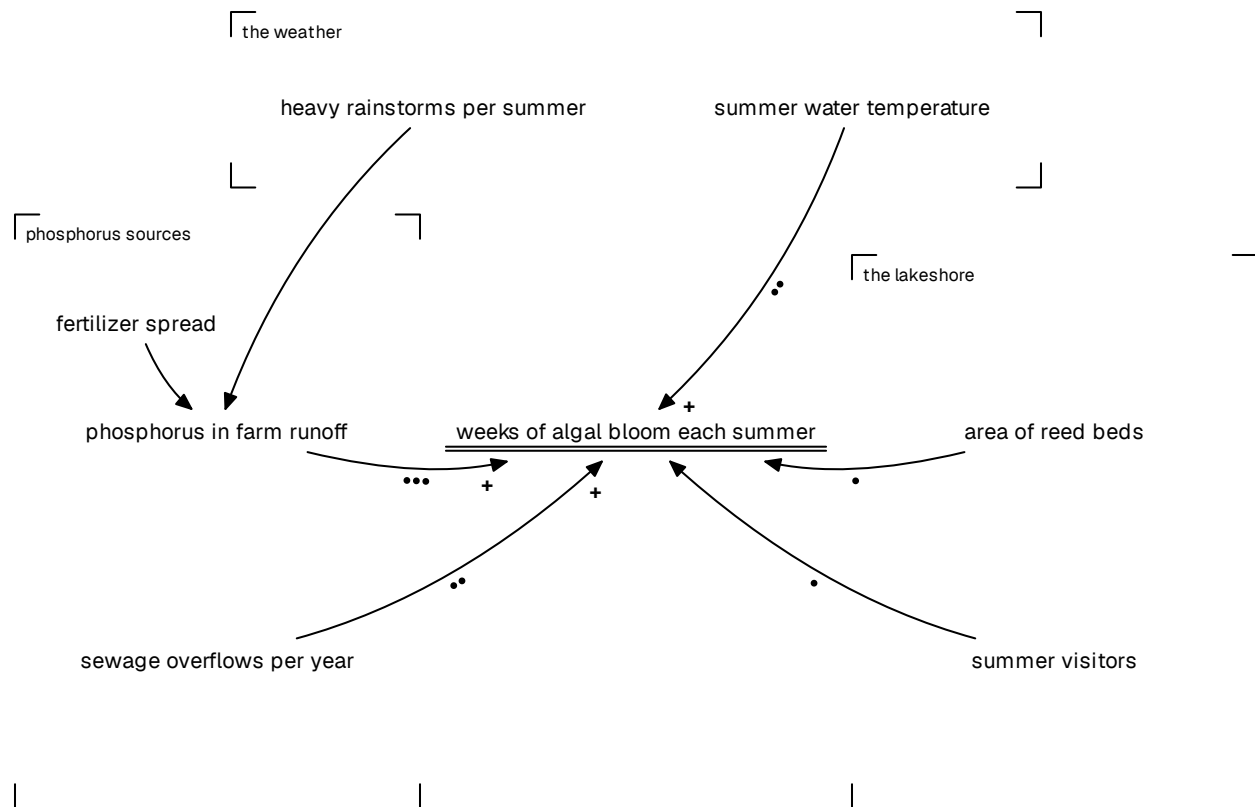
Step by step

1. League points, double-underlined as the central outcome, alone before any influence claim, as the score every other variable reaches.
2. Match fitness, players injured, squad size, clean sheets and team morale, each with an influence claim on league points: the five that act on it straight.
3. Training attendance, training time on tactics and players at post-match socials, each with an influence claim on the direct influence it acts through: match fitness, clean sheets and team morale.

4. Players leaving, with an influence claim into it from team morale and one from it to squad size, and the claim from match fitness to players injured: the last claims, each between variables drawn.
5. The four clusters, the players' bodies, the squad's numbers, the game plan and team spirit, drawn last because each goes round variables already in place.

What another defensible answer might vary

Another defensible answer might put training attendance with the players' bodies, label the squad's numbers as who is available, or label the game plan as defending. What stays the same is league points outside every cluster, and each cluster holding two or more variables that share what its label names.

IM 04 Algal blooms in a lake

This is one defensible answer, not the only one. Yours can differ and still hold up: the lab's checks show whether it has the brief's structure.

Weeks of algal bloom each summer as the central outcome, with five direct influences, each weighted. Each of the three the authority measured is a causal claim with a +: phosphorus in farm runoff (weight 3), sewage overflows per year (weight 2) and summer water temperature (weight 2). The area of reed beds and summer visitors, blamed but not measured, each stays an influence claim of weight 1. Fertilizer spread and heavy rainstorms reach the blooms through farm runoff. Three clusters hold every variable but the central outcome: phosphorus sources, the weather and the lakeshore.

Why it works

- A causal claim with a + for each of the three the authority measured, and for nothing else
- The reed beds and the visitors each kept as an influence claim: blamed, not measured
- A weight on every direct influence, the most on farm runoff, which carries two-thirds of the phosphorus
- Three clusters, the central outcome in none

Step by step

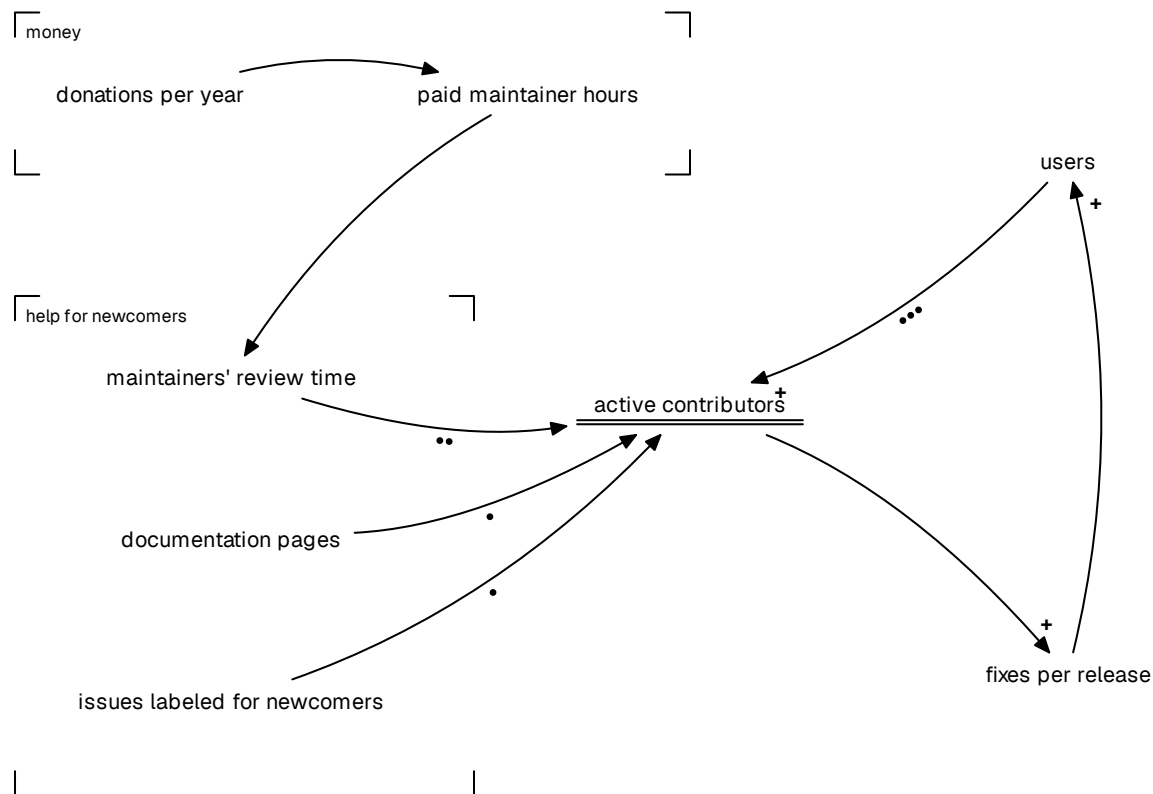
1. Weeks of algal bloom each summer, double-underlined as the central outcome, alone before any claim.
2. Area of reed beds and summer visitors, each an influence claim of weight 1 on the blooms: the anglers' and the boat operators' blame.
3. Phosphorus in farm runoff, sewage overflows per year and summer water temperature, each drawn upgraded, a causal claim with a +, weighted 3, 2 and 2: ten years of the authority's counts rise and fall with the blooms.
4. Fertilizer spread and heavy rainstorms per summer, each with an influence claim on phosphorus in farm runoff, after it, since they reach the blooms only through the runoff.

5. The three clusters, phosphorus sources, the weather and the lakeshore, drawn last around variables already in place.

What another defensible answer might vary

Another defensible answer might give summer water temperature a weight of 3 or sewage overflows a weight of 1, draw heavy rainstorms to sewage overflows as well, or name phosphorus sources as what reaches the water.

What stays the same is a causal claim for each of the three the authority measured, and every other claim an influence claim.

IM 05 An open-source project's contributors

This is one defensible answer, not the only one. Yours can differ and still hold up: the lab's checks show whether it has the brief's structure.

Active contributors as the central outcome. The three claims the records show are causal claims, each with a +, and they close a path: active contributors → fixes per release → users → active contributors. Maintainers' review time, documentation pages and issues labeled for newcomers each act on active contributors as an influence claim, in a cluster, help for newcomers; donations per year reach review time through paid maintainer hours, the two in a cluster, money. Every direct influence has a weight, 3 on users. The conversion to a causal loop diagram carries the eight variables and the three causal claims, and leaves behind five influence claims, two clusters, four weights and the central outcome's mark.

Why it works

- A causal claim with a + for each of the three the records show, and for nothing else
- One closed path of causal claims, active contributors → fixes per release → users → active contributors, with no – claims: reinforcing by the parity rule
- Review time, documentation, newcomer issues and donations each kept as an influence claim: believed, not measured
- Two clusters, the central outcome in neither, and a weight on every direct influence

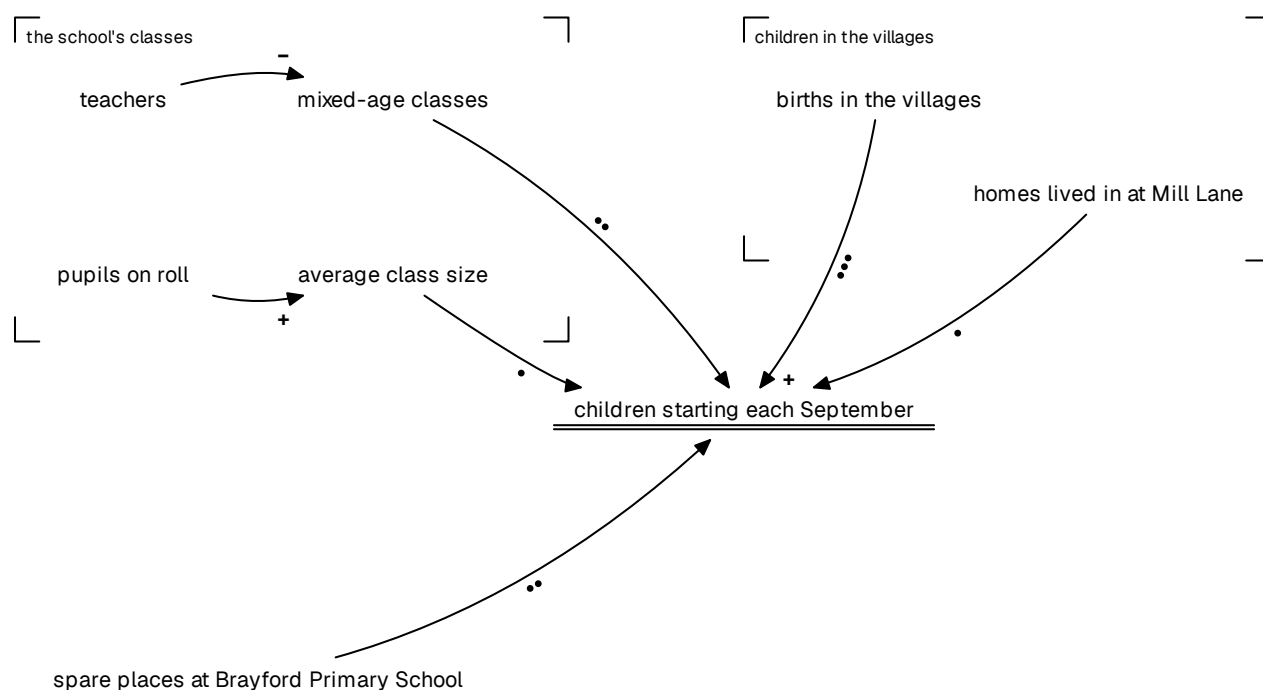
Step by step

1. Active contributors, double-underlined as the central outcome, the number the maintainers count each month, alone before any claim.
2. Maintainers' review time, documentation pages and issues labeled for newcomers, each an influence claim on active contributors, weighted 2, 1 and 1: what the maintainers believe keeps newcomers.

3. Donations per year and paid maintainer hours, with influence claims from donations to the hours and from the hours to review time, the review the money pays for.
4. Fixes per release and users, with three causal claims, each a +, running from active contributors through fixes and users and back, weight 3 on the last: the upgrades, drawn once every influence claim is in place.
5. The two clusters, money and help for newcomers, drawn last around variables already in place.

What another defensible answer might vary

Another defensible answer might make users the central outcome, draw paid maintainer hours to fixes per release as well, or put fixes per release and users in a third cluster. What stays the same is a causal claim with a + for each of the three the records show, closing one path, and every other claim an influence claim.

CS 03 Kelsham Primary School: what decides where a child starts

This is one defensible answer, not the only one. Yours can differ and still hold up: the lab's checks show whether it has the brief's structure.

Children starting each September as the central outcome, with five direct influences, each weighted. Births in the villages, counted against the starters four years later, is a causal claim with a +, weight 3. Mixed-age classes and average class size, the parents' reasons, spare places at Brayford Primary School and homes lived in at Mill Lane each stay an influence claim: told, said or forecast, never counted against the starters. Teachers reach the starters through mixed-age classes, with a –, and pupils on roll through average class size, with a +: two causal claims the school has counted. A count of each September's starters beside the mixed-age classes, the class sizes or Brayford's spare places would upgrade that claim. Two clusters: the school's classes and children in the villages.

Why it works

- A causal claim for each of the three changes someone counted, and for nothing else
- Births weighted 3: every September's starters have followed them
- The parents' two reasons, Brayford's places and the new homes each kept as an influence claim
- Teachers and pupils on roll reach the starters only through the parents' reasons, so the outcome still rests on influence claims
- Two clusters, the central outcome and spare places at Brayford Primary School in neither

Step by step

1. Children starting each September, double-underlined as the central outcome, alone before any claim: the number Tom Hale asks about.

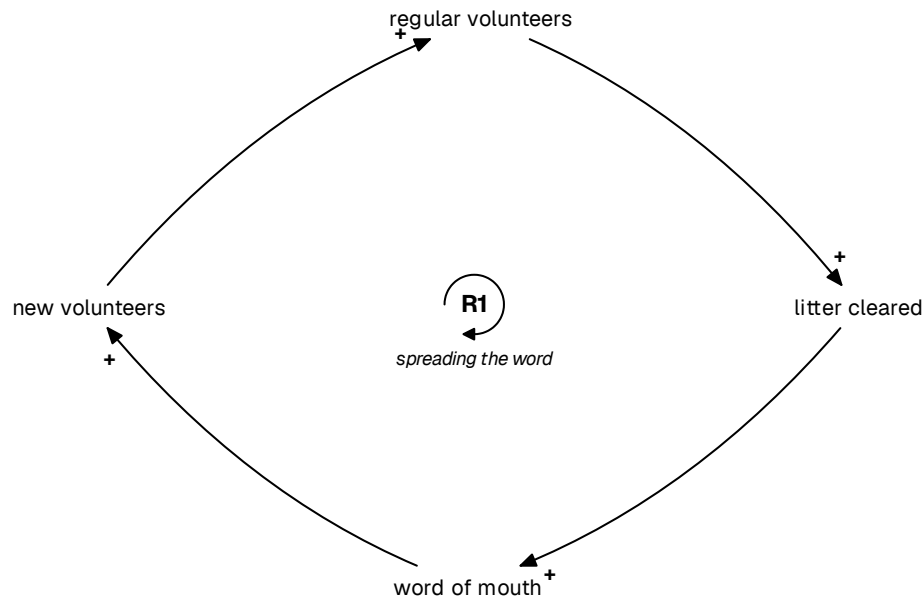
2. Mixed-age classes, average class size, spare places at Brayford Primary School and homes lived in at Mill Lane, each an influence claim on the starters, weighted 2, 1, 2 and 1: what parents tell, what Helen Marsh says and what David Brennan forecasts.
3. Births in the villages, with a causal claim with a + on the starters, weight 3, drawn after the influence claims as the one upgrade among the direct influences: the county council counts both.
4. Teachers and pupils on roll, with a causal claim with a – on mixed-age classes and one with a + on average class size, each reaching the starters through a parent's reason: the school counts both.
5. The two clusters, the school's classes and children in the villages, drawn last around variables already in place.

What another defensible answer might vary

Another defensible answer might weight the parents' reasons 3 and the births 2, draw pupils on roll as a variable the starters change, or put spare places at Brayford Primary School in a third cluster with a variable such as the bus journey's minutes. What stays the same is a causal claim for each of the three counted changes, and every other claim an influence claim.

Chapter 4 · Loops That Amplify, Loops That Correct

CL 01 A riverbank cleanup that grows by word of mouth



This is one defensible answer, not the only one. Yours can differ and still hold up: the lab's checks show whether it has the brief's structure.

Four variables close one chain of + effects. More regular volunteers clear more litter, the cleared riverbank gets talked about, and the talk brings new volunteers, so a change compounds in the direction it starts.

Why it works

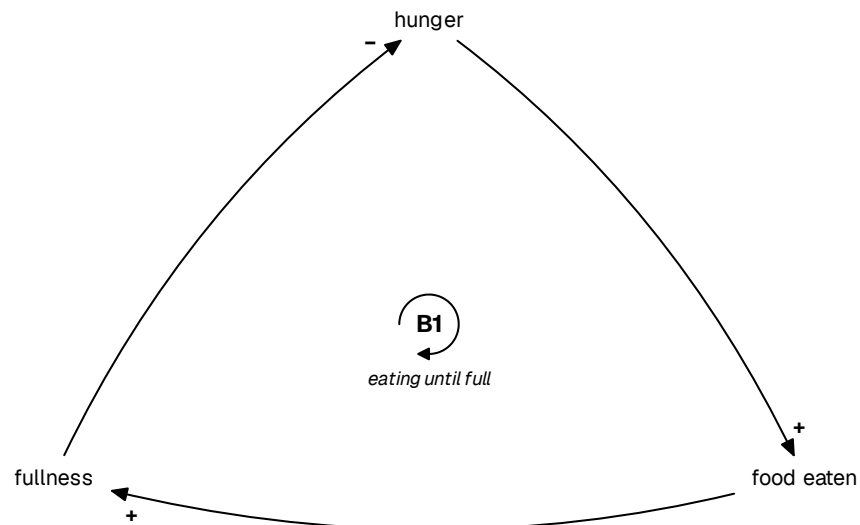
- Four quantities that can rise or fall
- Closed chain
- All effects +
- Loop named by its behavior

Step by step

1. Regular volunteers and litter cleared, the two quantities the paragraph opens with, and the + effect between them: more volunteers clear more litter.
2. Word of mouth, with a + effect into it from litter cleared: each cleared stretch shows from the footpath, and people who walk there talk about it.
3. New volunteers, with a + effect into them from word of mouth: some of the people who hear about the cleanup come to the next one.
4. The loop closes with a + effect from new volunteers back to regular volunteers, since some newcomers keep coming; with no – effect it is reinforcing, R1, named spreading the word.

What another defensible answer might vary

Another defensible answer might take a different step between the regular volunteers and the newcomers, such as invitations to friends in place of litter cleared, or start the chain at a different variable. What stays the same is four quantities that can rise or fall, closed into one loop of + effects.

CL 02 Hunger and eating

This is one defensible answer, not the only one. Yours can differ and still hold up: the lab's checks show whether it has the brief's structure.

Hunger raises the food eaten; food eaten raises fullness; fullness lowers hunger. One – effect makes the loop balancing: after each meal it brings hunger back down.

Why it works

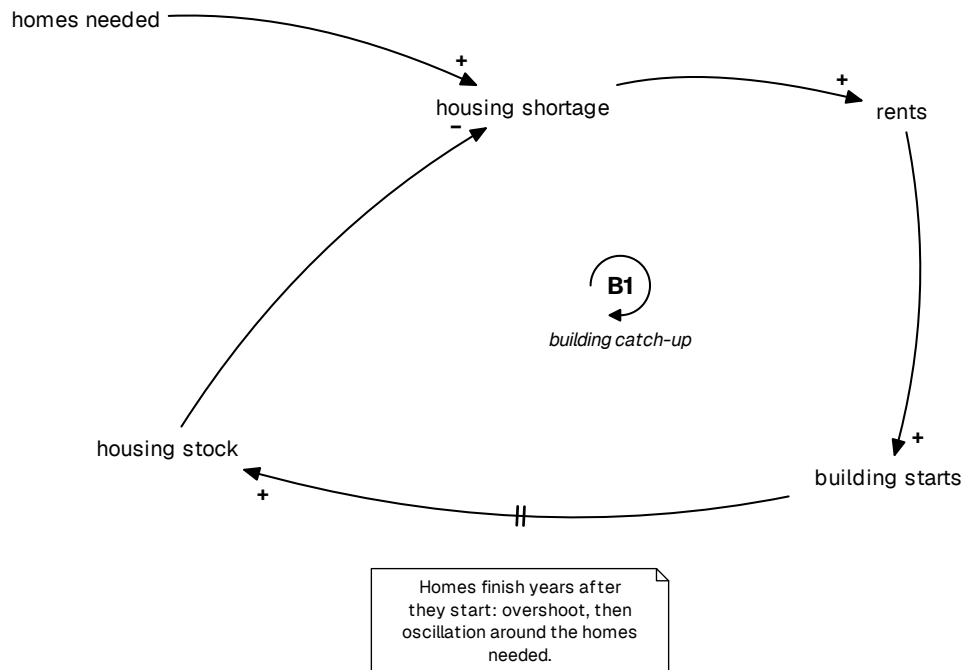
- Hunger is a quantity
- One opposite-direction effect
- Closed correction loop
- No meal-by-meal steps

Step by step

1. Hunger and food eaten, with a + effect between them: when hunger rises, a person eats.
2. Fullness, with a + effect into it from food eaten, since food fills the stomach.
3. The loop closes with a – effect from fullness back to hunger, and its label goes on with it: balancing, B1, eating until full.

What another defensible answer might vary

Another defensible answer might add a fourth variable, as the brief allows, such as stomach stretch between food eaten and fullness, or start the chain at a different variable. What stays the same is a single – effect closing one balancing loop around hunger.

CL 03 A housing shortage and the building boom that overshoots it

This is one defensible answer, not the only one. Yours can differ and still hold up: the lab's checks show whether it has the brief's structure.

Rising rents draw new building that closes the shortage, but homes finish years after they start. Starts made during the delay overshoot the need, and building then falls off: oscillation.

Why it works

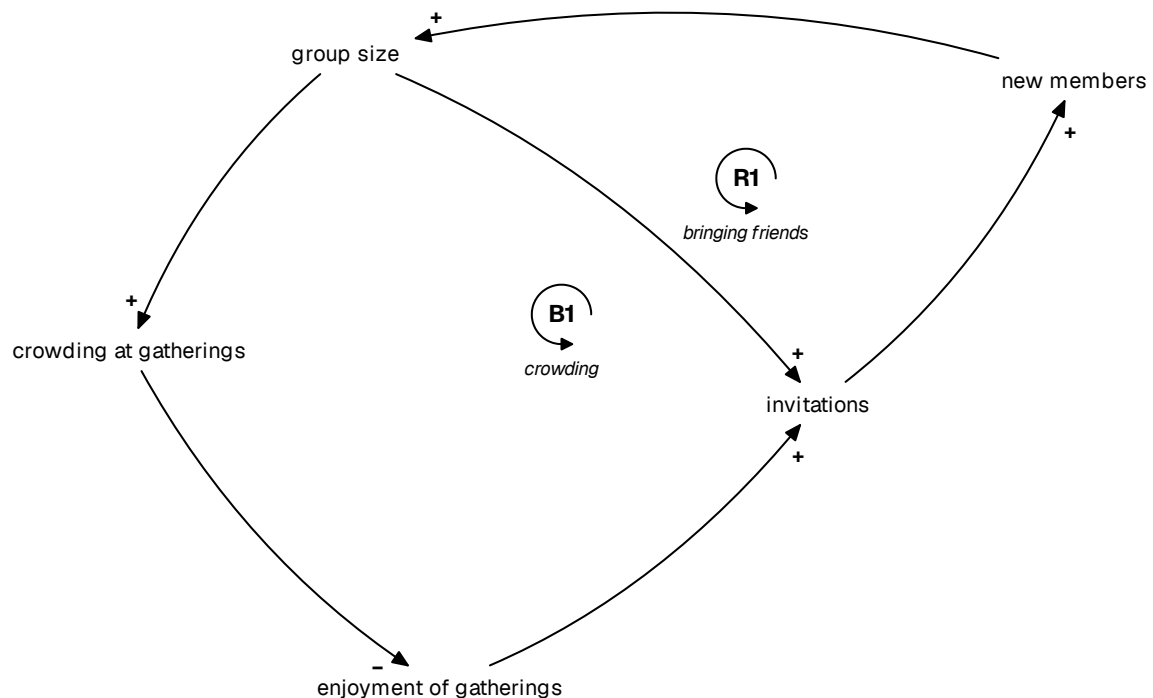
- Target and gap are separate
- Delay sits on building starts → housing stock
- Housing stock is a quantity, not an action
- Behavior note names oscillation

Step by step

1. Homes needed and the housing shortage, with a + effect between them: the need the city's households set, and how far the homes fall short of it.
2. Rents and building starts, with + effects from the shortage to rents and from rents to starts, the developers' answer to high rents.
3. Housing stock, with a + effect from building starts delayed by the two to three years a building takes, and a – effect back to the shortage that closes the loop: balancing, B1, building catch-up.
4. The behavior note, beside the loop once the loop and its delay are both drawn, since the overshoot it names comes from the two together.

What another defensible answer might vary

Another defensible answer might drop rents and let the shortage raise building starts directly, or split the housing stock into homes under construction and homes finished. What stays the same is the homes needed feeding the shortage from outside the loop, one balancing loop through the shortage, the delay on the effect that carries starts into the stock, and a note naming oscillation.

CL 04 A friendship group that grows until gatherings feel crowded

This is one defensible answer, not the only one. Yours can differ and still hold up: the lab's checks show whether it has the brief's structure.

Group size sits on two loops: invitations bring in new members and grow the group, while crowding lowers enjoyment of gatherings and, with it, the invitations.

Why it works

- Group size is shared
- R and B loops touch
- Crowding path is readable
- Crossings avoided

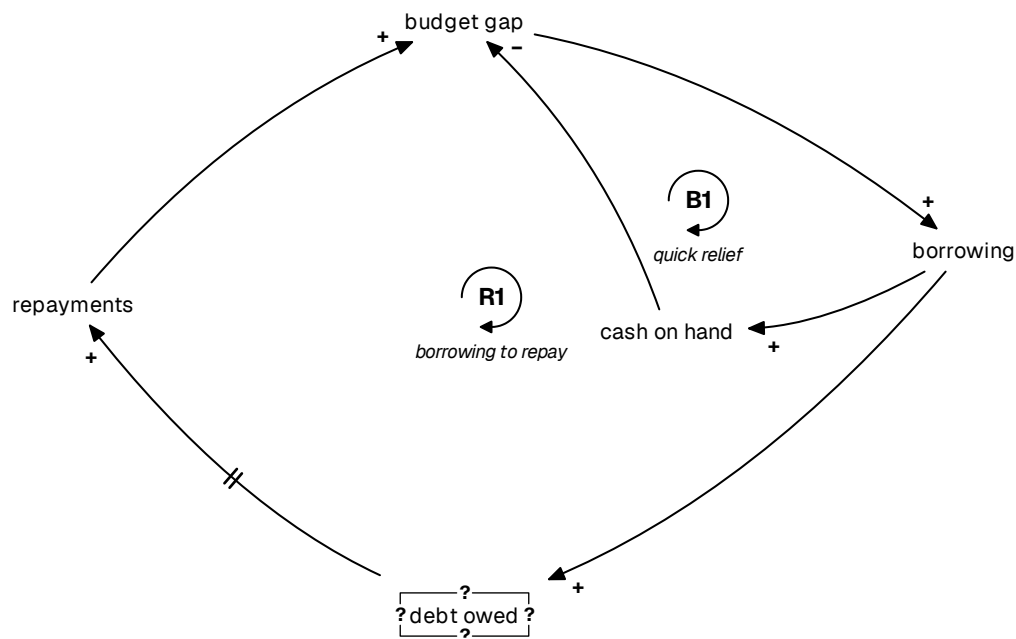
Step by step

1. Group size and invitations, with a + effect between them: members invite friends of their own.
2. New members, with + effects from invitations and on into group size, closing a loop with no – effect: reinforcing, R1, bringing friends.
3. Crowding at gatherings, with a + effect from group size, which both loops pass through.
4. Enjoyment of gatherings, with a – effect from crowding and a + effect into invitations, which closes a second loop through R1's invitations and new members: one – effect, so balancing, B1, crowding.

What another defensible answer might vary

Another defensible answer might carry the limit through a different quantity, such as time with each friend in place of enjoyment, or let crowding lower how many new members stay rather than the invitations. What stays

the same is one reinforcing and one balancing loop passing through group size, with the single – effect on the crowding path.

CL 05 Borrowing to get to the end of the month

This is one defensible answer, not the only one. Yours can differ and still hold up: the lab's checks show whether it has the brief's structure.

Borrowing closes this month's gap at once, while the debt it adds comes back as repayments in later months and widens the gap again.

Why it works

- Fast and slow paths separated
- Effect on repayments delayed
- Trap closes as a reinforcing loop
- Debt owed rises before repayments do: the leverage point

Step by step

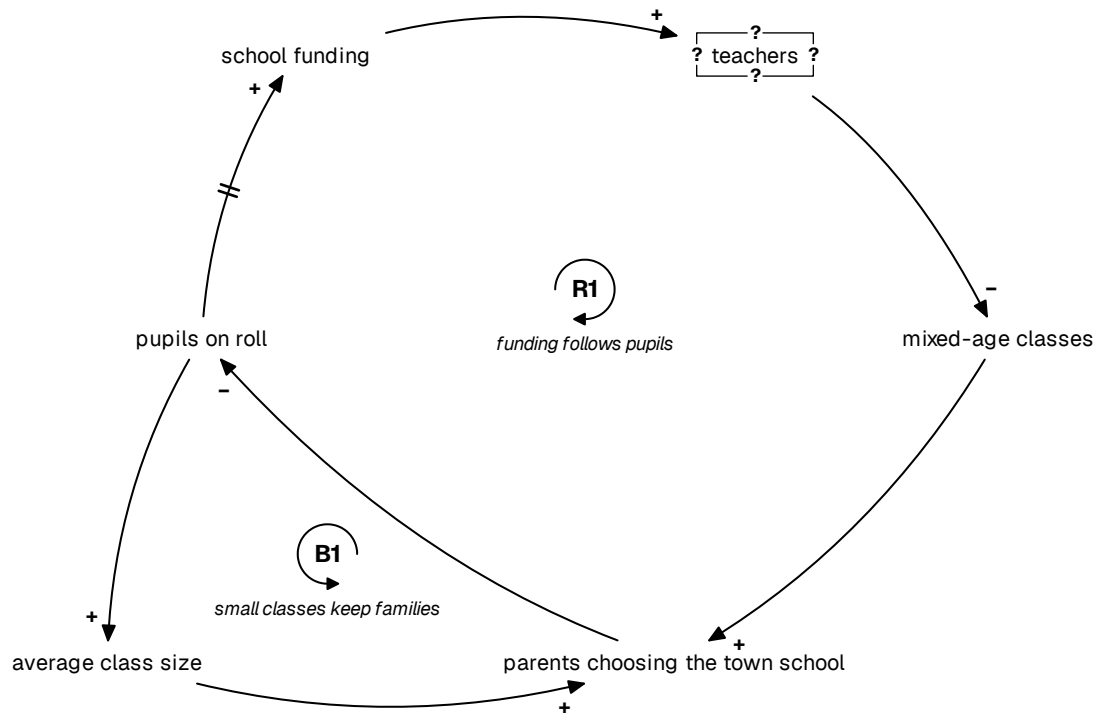
1. Budget gap and borrowing, with a + effect between them: the household covers the month's gap with a credit card.
2. Cash on hand, with a + effect from borrowing and a – effect back to the budget gap, closing the fast loop: balancing, B1, quick relief.
3. Debt owed, with a + effect from borrowing, marked as the leverage point, the variable to monitor first.
4. Repayments, with a + effect from debt owed delayed by the weeks before they start, and a + effect back to the budget gap, closing the slow loop: reinforcing, R1, borrowing to repay.

What another defensible answer might vary

Another defensible answer might put the delay on borrowing → debt owed, as interest builds, or make repayments the leverage point, since they show in the budget each month. What stays the same is a fast

balancing loop of relief and a slower reinforcing loop, through the debt, that reopens the gap.

CS 04 Kelsham Primary School: funding that follows its pupils



This is one defensible answer, not the only one. Yours can differ and still hold up: the lab's checks show whether it has the brief's structure.

The pupils on roll sit on two coupled loops. Through funding, teachers and mixed-age classes, fewer pupils bring fewer pupils still, a year behind each count; through average class size, fewer pupils make smaller classes, which keep some families from the town school and slow the fall.

Why it works

- Every name passes the more test: more pupils on roll, more mixed-age classes
- R1 has two – effects and B1 one, as the parity rule gives
- The delay on pupils on roll → school funding: the October count
- Both loops share pupils on roll, parents choosing the town school and the effect between them
- Teachers, the leverage point, sit on R1 only: holding their number up weakens R1 and leaves B1

Step by step

1. Pupils on roll, which both loops pass through, and school funding, joined by a + effect with a delay: each October's count sets the funding for the school year after it.
2. Teachers, with a + effect from the funding that pays them, marked as the leverage point: holding their number up cuts the path from the count to the classes.
3. Mixed-age classes, more of them as teachers fall (–), and parents choosing the town school, more of them as classes are mixed (+).
4. A – effect from parents choosing the town school back to pupils on roll closes R1: two – effects, an even number, so it is reinforcing, and a fall in pupils brings a further fall.

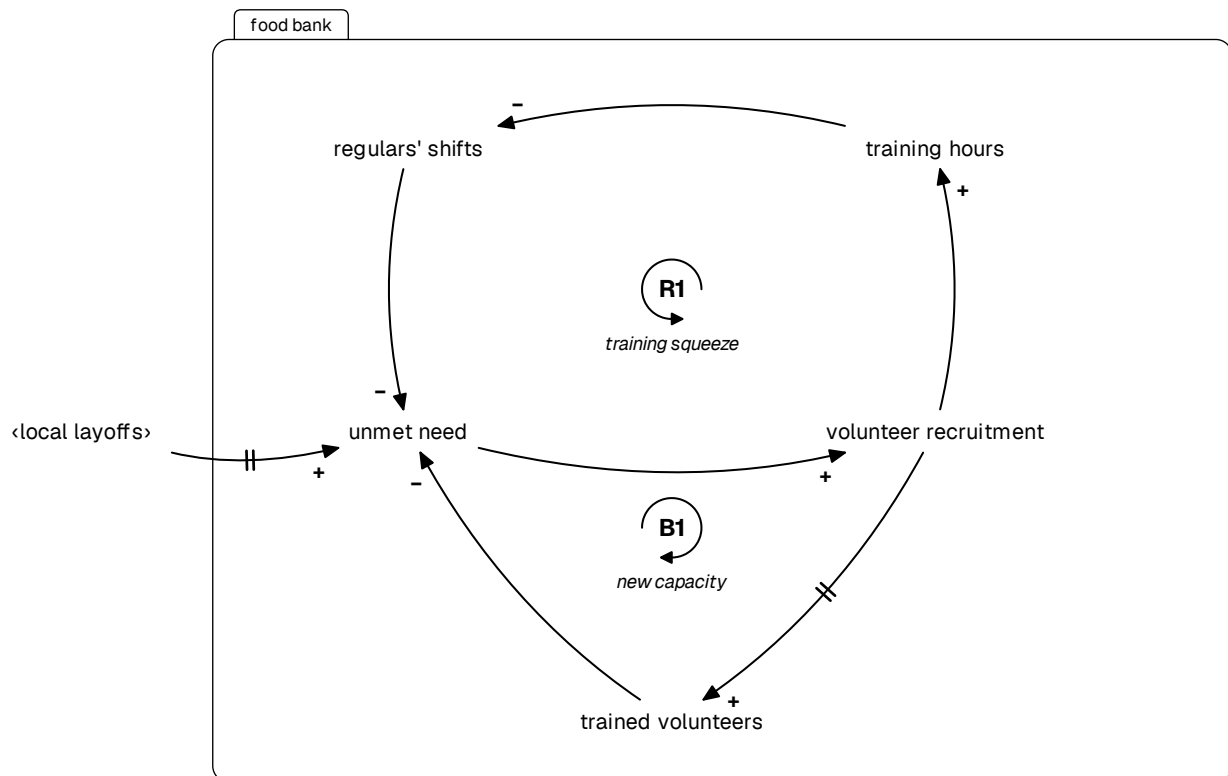
5. Average class size, rising with pupils on roll (+) and sending parents to the town school (+), closes B1 through the same – effect: one – effect, so it is balancing, and it slows the fall.

What another defensible answer might vary

Another defensible answer might propose mixed-age classes as the leverage point, keeping Years 3 and 4 apart with a teacher paid from the reserve, or parents choosing the town school, through what families hear about Kelsham. It might also draw a + effect from mixed-age classes to average class size, closing a second reinforcing loop. What stays the same is a reinforcing loop through funding and a balancing loop through class size, coupled at the pupils on roll, with the delay on the funding.

Chapter 5 · Delays, External Drivers, and Competing Loops

CL 06 A food bank in a downturn



This is one defensible answer, not the only one. Yours can differ and still hold up: the lab's checks show whether it has the brief's structure.

Layoffs raise unmet need months later. Recruiting answers it, but training takes the regulars off their shifts before trained volunteers arrive, so unmet need grows before it falls.

Why it works

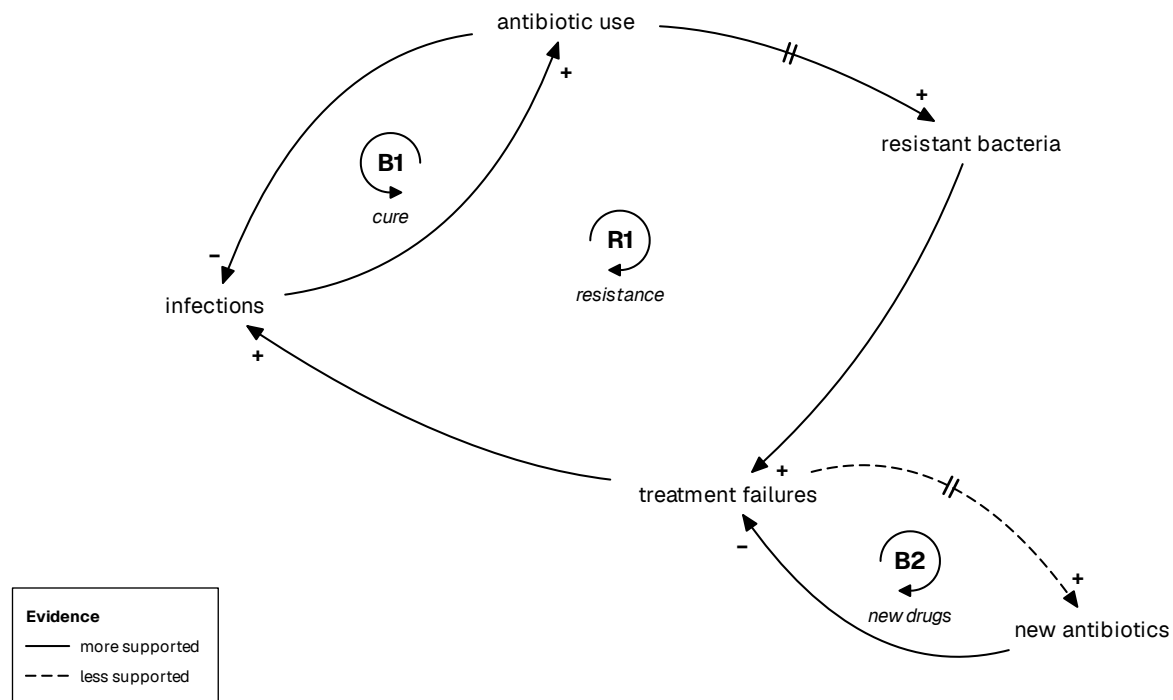
- Layoffs outside the boundary, with no effect into them
- Two delays: savings running out, and training
- Training squeeze reinforcing, new capacity balancing
- The squeeze has no delay, so it leads

Step by step

1. The boundary, food bank, with local layoffs outside it and unmet need inside, joined by a + effect delayed by the months families' savings last.
2. Volunteer recruitment, with a + effect from unmet need: the food bank's response, which both loops pass through.
3. Training hours and regulars' shifts, with a + effect from recruitment to training hours, a – effect on to the regulars' shifts and a – effect back to unmet need: two – effects, so reinforcing, R1, training squeeze.
4. Trained volunteers, with a + effect from recruitment delayed by the weeks of training, and a – effect on unmet need: one – effect, so balancing, B1, new capacity, drawn after the squeeze it follows in time.

What another defensible answer might vary

Another answer might put the first delay on unmet need → volunteer recruitment instead, add a variable such as shifts covered between trained volunteers and unmet need, or name the boundary differently. What stays is training hours arriving before trained volunteers, so unmet need grows first: a reinforcing loop through the regulars' shifts, a balancing loop through trained volunteers, and layoffs outside the boundary with no effect running into them.

CL 07 Antibiotics and the resistance they breed

This is one defensible answer, not the only one. Yours can differ and still hold up: the lab's checks show whether it has the brief's structure.

Prescribing cures infections, and over years breeds the resistant bacteria that make them harder to cure. New antibiotics would balance the failures a decade later, if drug makers develop them.

Why it works

- Three loops share infections, antibiotic use and treatment failures
- The uncertain effect, treatment failures → new antibiotics, dashed
- Legend lists the dashed line as less supported
- Resistance and new antibiotics both arrive after a delay

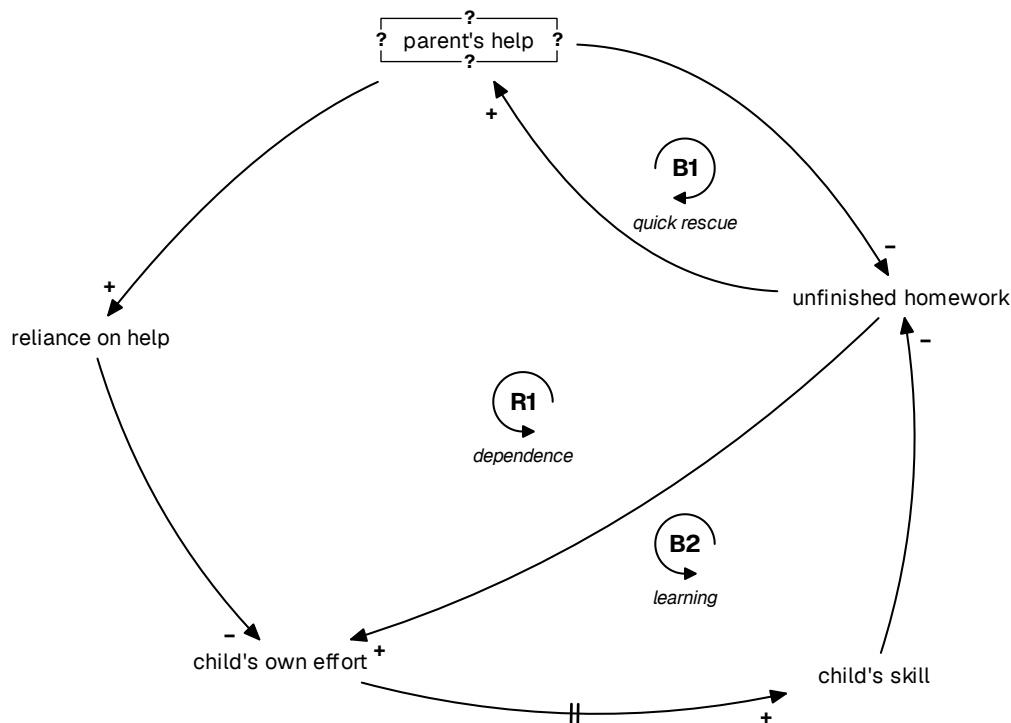
Step by step

1. Infections and antibiotic use, with a + effect from infections to use and a - effect back as cures bring infections down: balancing, B1, cure.
2. Resistant bacteria and treatment failures, with a + effect from antibiotic use delayed by years of heavy use, and + effects on to treatment failures and back to infections: no - effect, so reinforcing, R1, resistance.
3. New antibiotics, with a + effect from treatment failures delayed by a decade and dashed as a hypothesis, and a - effect back on failures: balancing, B2, new drugs, with the legend for the one dashed line.

What another defensible answer might vary

Another answer might add a stewardship loop in which treatment failures cut antibiotic use, route resistance through broader prescribing rather than through spreading infections, or code a different effect as the hypothesis.

What stays is a balancing cure loop undone by a reinforcing resistance loop, a slower balancing loop through new antibiotics, and the hypothesis dashed and declared in the legend.

CL 08 A parent who finishes the homework

This is one defensible answer, not the only one. Yours can differ and still hold up: the lab's checks show whether it has the brief's structure.

The parent's help clears tonight's homework at once. It also builds the child's reliance on help, which cuts the child's own effort, so skill builds slower and the next assignment gets help too.

Why it works

- Quick rescue at the top, read first
- Skill arrives after a delay
- Reliance on help cuts the child's own effort: a – effect
- Dependence is the reinforcing loop the rescue feeds

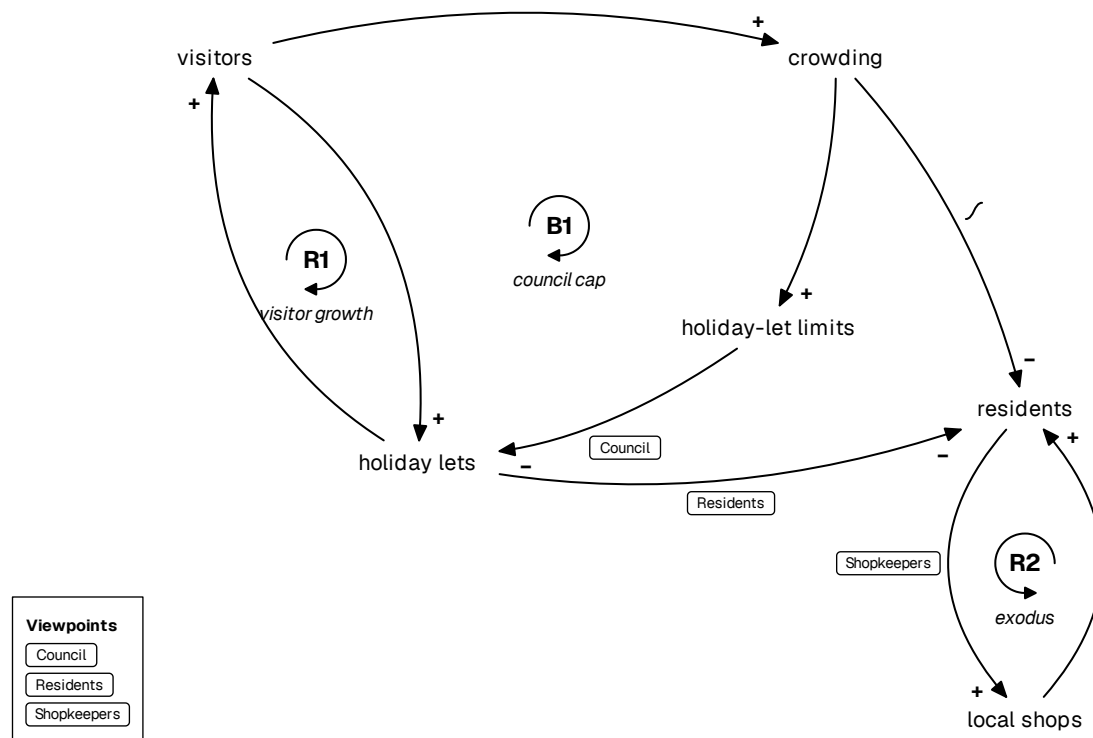
Step by step

1. Unfinished homework and parent's help, marked as the leverage point, with a + effect to the help and a – effect back: balancing, B1, quick rescue, the part of the story each rushed evening starts with.
2. Child's own effort and child's skill, with a + effect from unfinished homework to effort, a + effect from effort to skill delayed by weeks, and a – effect from skill back to unfinished homework: balancing, B2, learning.
3. Reliance on help, with a + effect from parent's help and a – effect on the child's own effort, closing a loop through the rescue and the learning: two – effects, so reinforcing, R1, dependence.

What another defensible answer might vary

Another answer might run the – effect straight from parent's help to the child's own effort and leave reliance out, or make the child's own effort the leverage point instead of the parent's help. What stays is the shifting-the-

burden shape: a fast balancing rescue, a slower balancing loop through the child's skill, and a reinforcing dependence that the help feeds by crowding out the child's effort.

CL 09 An old town and its visitors

This is one defensible answer, not the only one. Yours can differ and still hold up: the lab's checks show whether it has the brief's structure.

Visitors and holiday lets feed each other, and the council's limits balance them through crowding. Past the threshold, residents leave fast, and the local shops they keep open close, so more leave.

Why it works

- Visitor growth, council cap and exodus
- Threshold marked on crowding → residents
- Council, residents and shopkeepers tagged
- Legend lists the three viewpoints

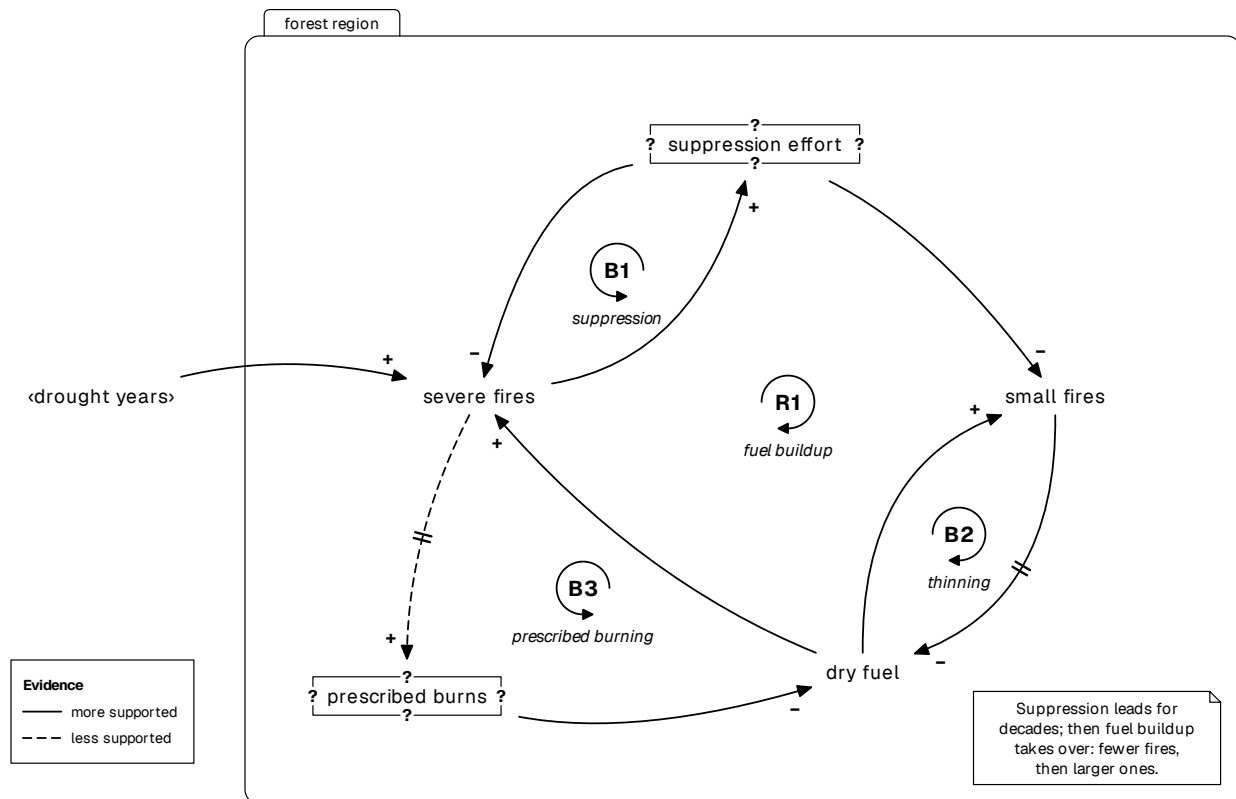
Step by step

1. Visitors and holiday lets, with a + effect each way, since visitors fill lets and lets draw visitors: reinforcing, R1, visitor growth.
2. Crowding and holiday-let limits, with + effects from visitors to crowding and on to the limits, and a – effect from the limits on holiday lets, tagged Council: one – effect, so balancing, B1, council cap, with the legend, since the Council tag is the one viewpoint drawn so far.
3. Residents, with a – effect from holiday lets, tagged Residents, and a – effect from crowding, marked nonlinear for the point where summer visitors outnumber them.
4. Local shops, with a + effect from residents, tagged Shopkeepers, and a + effect back to residents: reinforcing, R2, exodus, drawn last as the situation's third sentence has it.

What another defensible answer might vary

Another answer might put the threshold on holiday lets → residents instead, tag different effects with the three viewpoints, or add visitor spending, which keeps shops for visitors open while local shops close. What stays is two reinforcing loops, visitor growth and the exodus, a balancing loop through the council's limits, one nonlinear effect, and three viewpoints that differ in emphasis, not structure.

CL 10 A forest region and its fires



This is one defensible answer, not the only one. Yours can differ and still hold up: the lab's checks show whether it has the brief's structure.

Suppression puts out severe fires quickly, and the small fires that thin the fuel too, so fuel builds and severe fires return larger. Prescribed burns would balance the buildup after a delay, if severe fires lead to their funding.

Why it works

- Four named loops share severe fires and dry fuel
- Drought years outside the boundary, with no effect into them
- The funding effect dashed and declared in the legend
- Leverage points on suppression effort and prescribed burns
- Behavior note: suppression leads first, fuel buildup later

Step by step

1. The boundary, forest region, with dry fuel and small fires inside it, a + effect from fuel to small fires and a - effect back, delayed as the fires thin the undergrowth: balancing, B2, thinning, the forest before suppression.
2. Severe fires, with a + effect from dry fuel, and suppression effort, marked as a leverage point, with a + effect from severe fires and a - effect back on them: balancing, B1, suppression.
3. A - effect from suppression effort on small fires closes a loop back through dry fuel to severe fires: two - effects, so reinforcing, R1, fuel buildup.
4. Drought years, the external driver, outside the boundary, with a + effect on severe fires, drawn once the fires it acts on are in place.
5. Prescribed burns, marked as a leverage point, with a + effect from severe fires, delayed and dashed as a hypothesis, and a - effect on dry fuel: balancing, B3, prescribed burning, with the legend for the one dashed

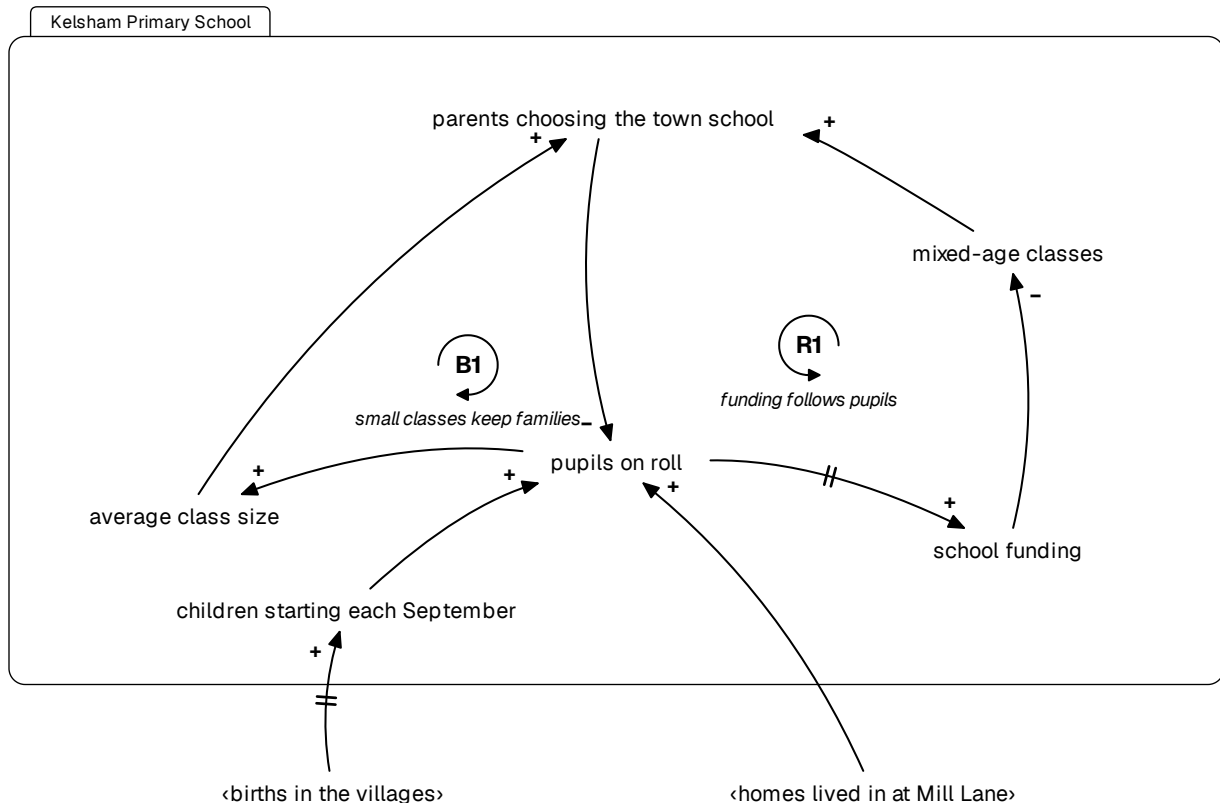
line.

6. The behavior note, once all four loops are drawn, since it is about two of them: B1 leading, R1 taking over.

What another defensible answer might vary

Another answer might add homes built in the forest, which raise suppression effort, mark dry fuel → severe fires as nonlinear past a fuel threshold, or code a different effect as the hypothesis. What stays is four named loops sharing severe fires and dry fuel, drought years outside a named boundary with no effect running into them, and the evidence coding declared in the legend.

CS 05 Kelsham Primary School: births, new homes and two loops



This is one defensible answer, not the only one. Yours can differ and still hold up: the lab's checks show whether it has the brief's structure.

Births in the villages and homes lived in at Mill Lane sit outside the boundary as external drivers: nothing the school does changes either. Births reach the starters four years later, so the fall from 22 births to 11 reaches the starters until 2029. Inside, two loops compete through the roll: R1, funding follows pupils, carries a fall in the roll further, a school year behind each October count, and B1, small classes keep families, slows it. The new homes raise the roll from 2027, and R1 then carries the rise further while B1 resists it as classes fill.

Why it works

- Births and the new homes outside the boundary, with no effect into either
- Two delays: the four years from births to starters, and the October count on the funding
- R1 has two – effects and B1 one, as the parity rule gives
- The loops share the roll, parents choosing the town school and the – effect between them, so a change in the roll runs through both
- The new homes act on the roll, not the starters: their children join every year group

Step by step

1. The boundary, Kelsham Primary School, with births in the villages outside it and children starting each September inside, joined by a + effect with a delay: a child born in the villages starts four Septembers later.
2. Pupils on roll, with + effects from the starters and from homes lived in at Mill Lane, the second external driver, whose children join every year group.
3. School funding, with a + effect from the roll and a delay: each October count sets the funding for the school year after it.

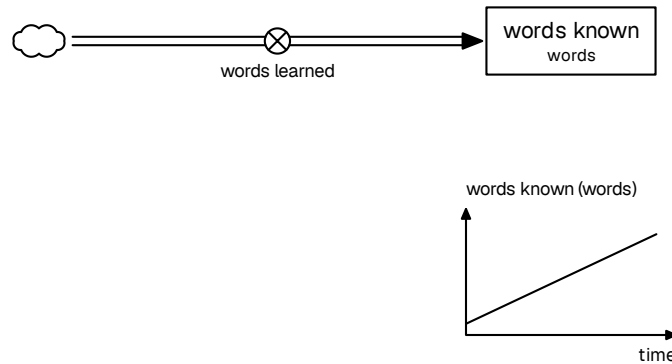
4. Mixed-age classes and parents choosing the town school, with a – effect from the funding, a + effect between them and a – effect back to the roll: two – effects, so reinforcing, R1, funding follows pupils.
5. Average class size, with + effects from the roll and on parents choosing the town school: one – effect on the way back, so balancing, B1, small classes keep families, competing with R1 for the roll.

What another defensible answer might vary

Another defensible answer might keep teachers between school funding and mixed-age classes, as CS 04 draws them, or draw parents choosing the town school on the children starting each September as well, since most families choose a school when a child starts. What stays the same is two external drivers outside a named boundary, the delay from births to starters, and a reinforcing loop through funding competing with a balancing loop through class size.

Chapter 6 · What Accumulates

SF 01 Words a language learner knows



This is one defensible answer, not the only one. Yours can differ and still hold up: the lab's checks show whether it has the brief's structure.

One stock, words known, counted in words, filled from a cloud by one flow, words learned. The time unit is a week, so words learned is counted in words per week. Nothing drains the stock and about forty words arrive each week, so the graph of words known rises steadily.

Why it works

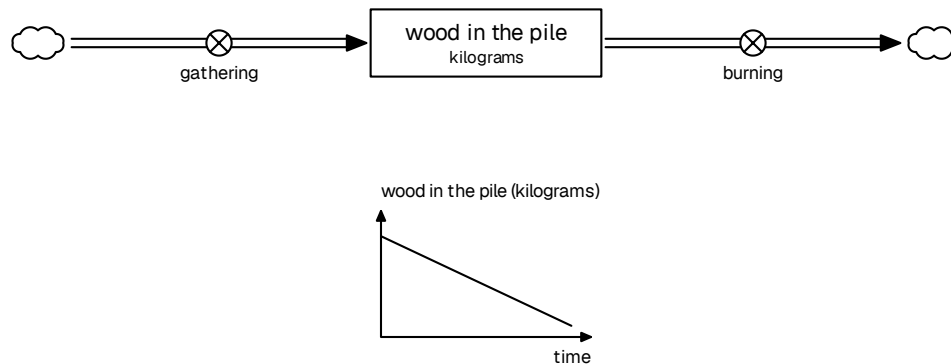
- Words known is the stock: it could be counted on any day, and would still be there if Lena stopped studying
- Words learned is the flow that fills it, counted in words per week
- The cloud is where new words come from, outside what the model holds
- Forgetting is left out, so the graph rises in a straight line

Step by step

1. Words known, the stock, counted in words, with the time unit a week: about 300 words today, the count that the flow fills and the graph follows.
2. Words learned, the flow that fills the stock, drawn with its cloud, since a flow has an end on each side: the words Lena has yet to meet lie outside what the model counts.
3. A behavior-over-time graph of words known, rising in a straight line: forty words a week arrive, and with forgetting left out, none leave.

What another defensible answer might vary

Another defensible answer might name the stock Portuguese words known, or the flow new words learned. What stays the same is one stock with its units, one inflow from one cloud, the time unit a week, and a graph that rises steadily.

SF 02 Firewood at a scout camp

This is one defensible answer, not the only one. Yours can differ and still hold up: the lab's checks show whether it has the brief's structure.

One stock, wood in the pile, counted in kilograms, filled from a cloud by gathering and drained to another by burning. The time unit is an hour, so both flows are counted in kilograms per hour. After dark the fire burns about twelve kilograms an hour and the scouts gather about five, so the pile falls by about seven kilograms an hour: a straight line down.

Why it works

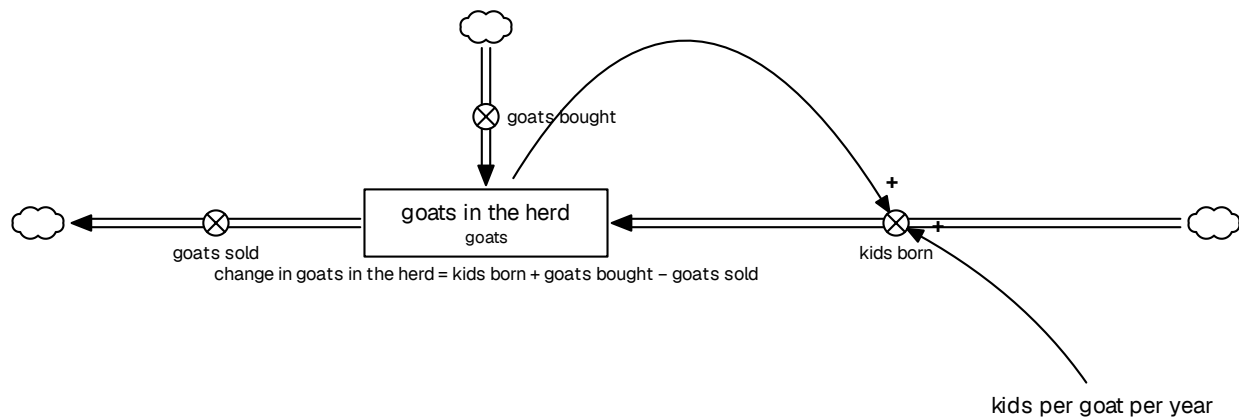
- The pile is the stock: it could be weighed at any moment
- The pile changes only through gathering and burning
- One cloud for the branches still lying in the field, one for the smoke and ash: both outside what the model holds
- The graph covers the evening, when burning outpaces gathering by a steady seven kilograms an hour

Step by step

1. Wood in the pile, the stock, counted in kilograms, with the time unit an hour: the branches the scouts gather wait here until the fire burns them.
2. Gathering, the inflow, with a cloud at its start, since a fallen branch counts only once it reaches the pile: about thirty kilograms an hour in the afternoon, five after dark.
3. Burning, the outflow, with a cloud at its end for what leaves the fire: about twelve kilograms an hour.
4. A behavior-over-time graph of the pile through the evening, falling in a straight line: twelve kilograms burned against five gathered leaves the pile seven kilograms lighter each hour.

What another defensible answer might vary

Another defensible answer might count the wood in logs, or name the flows wood gathered and wood burned. What stays the same is one stock, one inflow and one outflow, a cloud at each end, the time unit an hour, and a graph that falls steadily.

SF 03 Goats on a family smallholding

This is one defensible answer, not the only one. Yours can differ and still hold up: the lab's checks show whether it has the brief's structure.

One stock, goats in the herd, counted in goats, filled by kids born and goats bought and drained by goats sold, each flow with a cloud at its other end. The time unit is a year. Signals from the herd and from kids per goat per year, an auxiliary, end at the valve of kids born, both +: a bigger herd has more kids. The stock equation reads change in goats in the herd = kids born + goats bought - goats sold.

Why it works

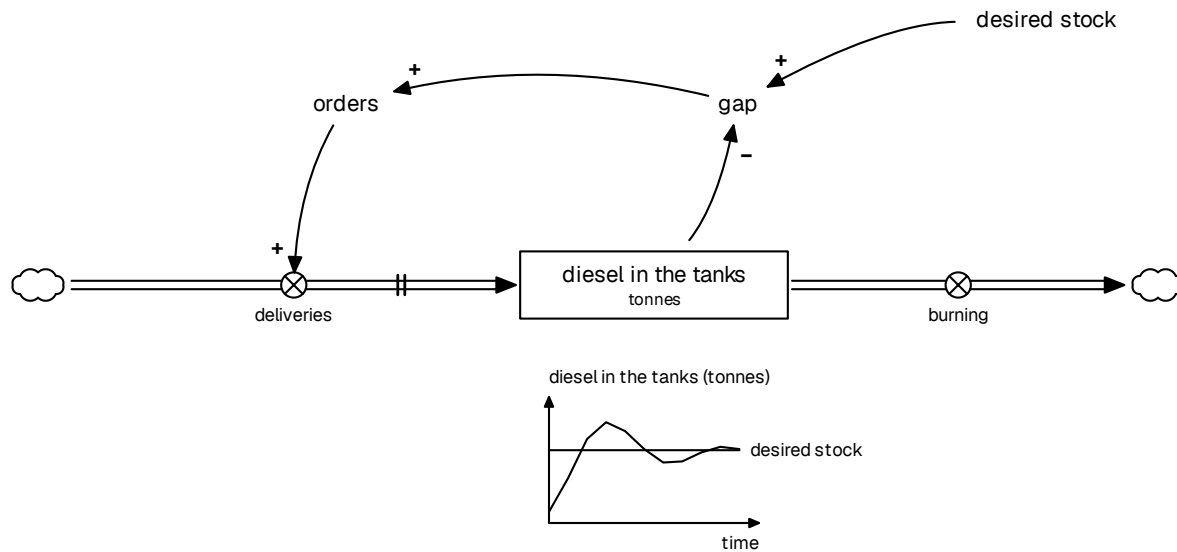
- Goats in the herd is the one stock: it could be counted on any day
- Kids born, goats bought and goats sold are its flows, each counted in goats per year
- Kids per goat per year is an auxiliary: it holds nothing and moves nothing
- The signal from the herd ends at the valve of kids born, not at the stock: the herd changes only through its flows
- The stock equation is written out from the three flows

Step by step

1. Goats in the herd, the stock, counted in goats, with the time unit a year and its stock equation beneath it, which gains a term with each flow drawn: twenty goats at the start of the year.
2. Kids born, an inflow from a cloud, since a kid enters the count only when it is born.
3. Goats bought and goats sold, an inflow from a cloud for the market and an outflow to a cloud for the buyers: about two in and fifteen out each year, the last terms of the stock equation.
4. Kids per goat per year, an auxiliary, and + signals from it and from the herd to the valve of kids born: twenty goats with about one kid each bring about twenty kids a spring, and forty bring forty.

What another defensible answer might vary

Another defensible answer might put a second auxiliary, does in the herd, between the herd and kids born, or name the flows births, purchases and sales. What stays the same is one stock with two inflows and one outflow, a path of signals from the herd to kids born, and the stock equation shown.

SF 04 Diesel for an island's power station

This is one defensible answer, not the only one. Yours can differ and still hold up: the lab's checks show whether it has the brief's structure.

One stock, diesel in the tanks, counted in tonnes, filled from a cloud by deliveries and drained to another by burning; the time unit is a week. Signals run from the stock (–) and from desired stock (+) to the gap, from the gap to orders (+), and from orders to the valve of deliveries (+). Deliveries carry a material delay: each order arrives four weeks after it is placed. Orders keep rising while the ordered diesel is still at sea, so the tanks rise past 250 tonnes to about 340, fall back to about 190, and swing closer each time: the graph oscillates around the line at desired stock.

Why it works

- Orders are an auxiliary: an order placed moves no diesel until its tanker arrives
- Deliveries are the flow, and the four weeks are a material delay on it
- The gap reads the stock and desired stock, and sets orders
- The path from the stock to deliveries ends at the flow's valve: the tanks change only through their flows
- The graph's line is drawn at the desired stock auxiliary, solid

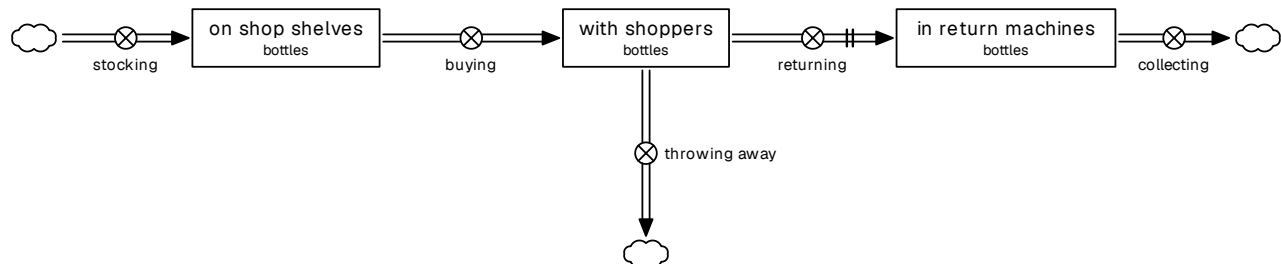
Step by step

1. Diesel in the tanks, the stock, counted in tonnes, with the time unit a week: 100 tonnes after the storms, against the 250 the manager aims to keep.
2. Burning, the outflow to a cloud: the power station burns about 40 tonnes a week, whatever the tanks hold.
3. Deliveries, the inflow from a cloud, with a material delay, since a tanker brings each order four weeks after the manager places it.
4. Desired stock and the gap, two auxiliaries, with a + signal from desired stock and a – signal from the tanks into the gap: the lower the tanks run below 250 tonnes, the larger the gap.
5. Orders, an auxiliary, with a + signal from the gap and a + signal to the valve of deliveries: each week's order is 40 tonnes plus a quarter of the gap, and its diesel reaches the tanks only through deliveries.
6. A behavior-over-time graph of the tanks, with a solid line at desired stock: with four weeks of orders still at sea when the tanks reach 250 tonnes, they rise on to about 340, fall to about 190, and swing closer each time.

What another defensible answer might vary

Another defensible answer might add a signal from burning to orders, for the 40 tonnes ordered each week, or name the stock fuel stock. What stays the same is orders as an auxiliary, deliveries as the flow with one material delay, a path of signals from the stock through the gap to deliveries, and an oscillating graph with its line at the desired stock.

SF 05 Bottles in a deposit-return scheme



This is one defensible answer, not the only one. Yours can differ and still hold up: the lab's checks show whether it has the brief's structure.

Three stocks in a row, each counted in bottles: on shop shelves, with shoppers, in return machines. Stocking fills the shelves from a cloud; buying and returning are transfers, so a bottle leaving one stock arrives in the next; throwing away drains the shoppers' stock to a cloud, and collecting drains the machines to another. The time unit is a week. Bottles wait longest with shoppers, about five weeks, so the material delay is on returning.

Why it works

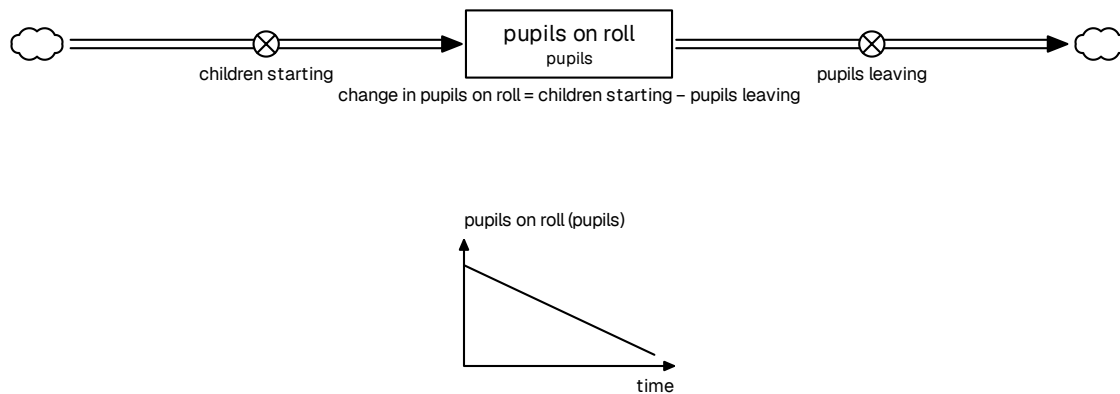
- Each stock is a place where bottles could be counted at an instant
- Buying and returning run from stock to stock, so no bottle appears or vanishes between stages
- Every stock is counted in bottles, so both transfers keep their units
- Throwing away and collecting end at clouds: where a bottle goes after the bin or the recycling lorry lies outside the model
- One delay, on returning: about five weeks with shoppers, against two on a shelf and half a week in a machine

Step by step

1. Three stocks in a row, each counted in bottles, with the time unit a week, in the order a bottle passes through them: on shop shelves, with shoppers, in return machines.
2. Stocking, the inflow to the shelves, from a cloud: a bottle enters the count when the bottlers deliver it to a shop.
3. Buying and returning, two transfers, each from one stock into the next, returning with the material delay: a shopper keeps a bottle about five weeks, longer than it waits anywhere else.
4. Throwing away, out of the shoppers' stock, and collecting, out of the machines, each to a cloud: about one bottle in ten goes in a bin, and the machines are emptied twice a week.

What another defensible answer might vary

Another defensible answer might add a flow from the shelves to a cloud for bottles broken in shops, or name the stocks bottles on sale, bottles at home and bottles awaiting collection. What stays the same is three stocks in bottles in a row, transfers between them, bottles thrown away to a cloud, and one material delay, on returning.

CS 06 Kelsham Primary School: the roll, filled and drained

This is one defensible answer, not the only one. Yours can differ and still hold up: the lab's checks show whether it has the brief's structure.

One stock, pupils on roll, counted in pupils, filled from a cloud by children starting and drained to a cloud by pupils leaving, both in pupils per year. The time unit is a year, and the stock equation reads $\text{change in pupils on roll} = \text{children starting} - \text{pupils leaving}$: in the year to October 2026, 9 – 16, taking the roll from 95 to 88. Every year from 2020 more pupils left than started, so the graph of the roll falls, from 126 to 88.

Why it works

- Pupils on roll is the stock: it could be counted on any day, and the October count is one such count
- Children starting and pupils leaving are its flows, each counted in pupils per year
- The two clouds are the villages' children not yet at school and the schools pupils leave for, outside what the model counts
- Each October's roll is the last one's plus its starters less its leavers, so the stock equation balances in every year the counts give
- The graph falls because leaving runs above starting every year, though both flows fall

Step by step

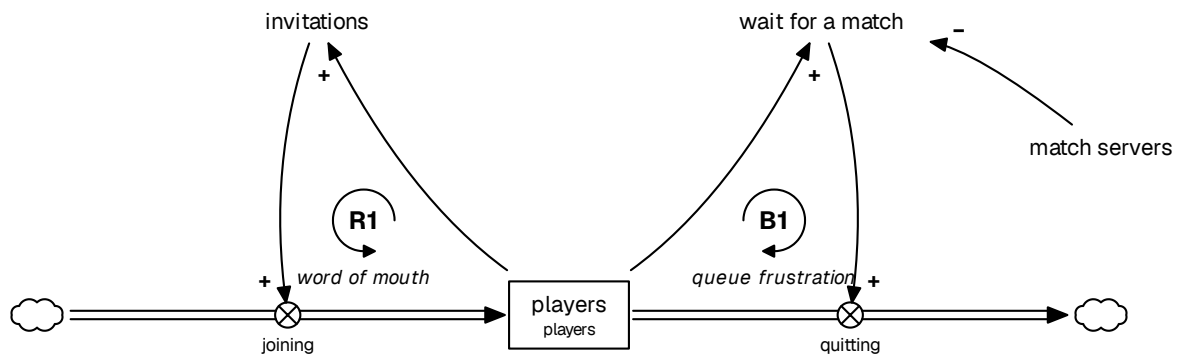
1. Pupils on roll, the stock, counted in pupils, with the time unit a year and its stock equation beneath it, which gains a term with each flow drawn: 126 pupils in October 2020.
2. Children starting, an inflow from a cloud, since a child enters the count only in the September they start in Reception: 9 in the year to October 2026.
3. Pupils leaving, an outflow to a cloud for secondary schools and other schools: 16 in the year to October 2026, so the equation takes 95 pupils to 88.
4. A behavior-over-time graph of pupils on roll, falling close to a straight line from 126 to 88: in every year more pupils left than started.

What another defensible answer might vary

Another defensible answer might draw two outflows, Year 6 leaving for secondary school and pupils moving to other schools, or name the inflow starters. What stays the same is one stock in pupils filled by the children starting and drained by those leaving, the time unit a year, the stock equation shown, and a graph of the roll falling.

Chapter 7 · Stocks Inside Feedback

SF 06 Players of an online game



This is one defensible answer, not the only one. Yours can differ and still hold up: the lab's checks show whether it has the brief's structure.

One stock, players, filled from a cloud by joining and drained to another by quitting; the time unit is a day. R1, word of mouth, runs from players to invitations (+), to the valve of joining (+), and along joining, which fills players: no – step, so reinforcing. B1, queue frustration, runs from players to the wait for a match (+), to the valve of quitting (+), and along quitting, which drains players: one – step, so balancing. Match servers shorten the wait (–) and sit on no loop.

Why it works

- Each loop closes through a flow and the stock it fills or drains, never through a signal into the stock
- Joining fills players, counted +; quitting drains them, counted –
- B1 has one – step, the drained stock, so it is balancing; R1 has none, so it is reinforcing
- Invitations and the wait for a match are auxiliaries: they hold no players
- Each loop's name says what goes around it

Step by step

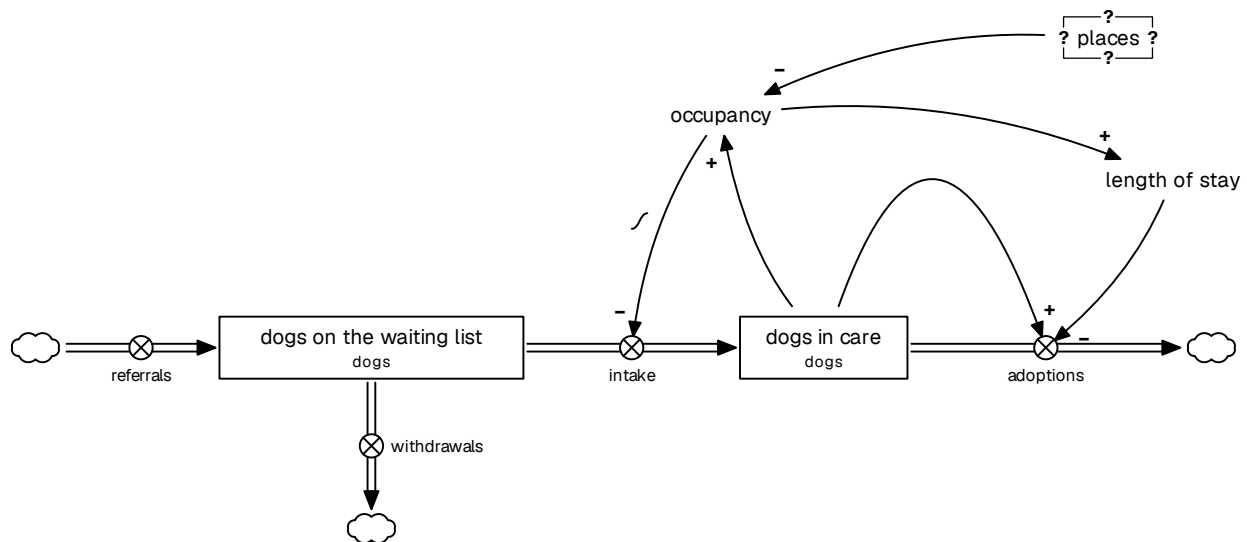
1. Players, the stock, counted in players, with the time unit a day: players join only by invitation and quit when matches are slow to start, so both loops run through this count.
2. Joining and quitting, an inflow and an outflow, each with a cloud: invited friends enter the count when they join, and players who quit leave it.
3. Invitations, an auxiliary, with + signals from players to it and from it to the valve of joining, which close R1, word of mouth, through joining: about one player in fifty invites a friend each day, so more players bring in more.
4. The wait for a match, an auxiliary, with + signals from players to it and from it to the valve of quitting, which close B1, queue frustration, through quitting: the more players, the longer each waits, and the more quit each day.
5. Match servers, an auxiliary on neither loop, with a – signal to the wait for a match: their number is fixed, and it sets how long a given number of players waits.

What another defensible answer might vary

Another defensible answer might draw the signal from players straight to the valve of joining, with no invitations auxiliary, or leave match servers out. What stays the same is one stock with an inflow and an outflow, a reinforcing

loop through joining, and a balancing loop through quitting.

SF 07 Dogs at a rescue shelter



This is one defensible answer, not the only one. Yours can differ and still hold up: the lab's checks show whether it has the brief's structure.

Two stocks, counted in dogs: dogs on the waiting list, filled by referrals from a cloud and drained by withdrawals to another, and dogs in care, drained by adoptions to a third. Intake is a transfer from the list into care. The time unit is a week. Occupancy reads dogs in care (+) and places (-); its signal to the valve of intake is - and nonlinear, weak while places are free and sudden as they run out. Occupancy also lengthens stays (+), and a longer stay means fewer adoptions a week (-), while more dogs in care means more (+). Places, which foster homes would add to, is the leverage point.

Why it works

- Intake runs from the waiting list straight into care, so no dog appears or vanishes between them
- The capacity effect is a signal, from occupancy to the valve of intake, marked nonlinear: weak, then sudden
- Crowding reaches adoptions through length of stay, and no signal ends at a stock
- Places is an auxiliary: foster homes would raise it, so it is the leverage point, a box with question marks
- Every flow and both stocks are in dogs, so intake keeps its units

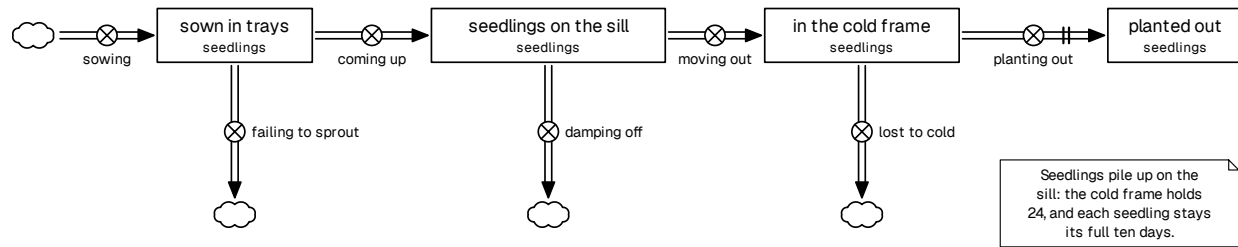
Step by step

1. Two stocks, each counted in dogs, with the time unit a week: dogs on the waiting list and dogs in care, the two places a referred dog waits.
2. Intake, a transfer from the waiting list into care, with no cloud: staff take each dog in from the list.
3. Referrals and withdrawals on the waiting list, and adoptions out of care, each with a cloud at its open end: about eight dogs a week are referred, and about one a week is withdrawn when its owner finds a home elsewhere.
4. Places and occupancy, two auxiliaries, occupancy rising with dogs in care (+) and falling with places (-), and places marked as the leverage point, since each foster home the manager proposes would add one.
5. A - signal from occupancy to the valve of intake, marked nonlinear: about six dogs a week come in while 30 are in care, and almost none at 38.
6. Length of stay, an auxiliary, with a + signal from occupancy and a - signal to the valve of adoptions, beside a + signal from dogs in care to the same valve: a dog waits about four weeks for adoption while the shelter is half

full, and seven while it is full.

What another defensible answer might vary

Another defensible answer might add a signal from the waiting list to intake, since no dog can be taken in from an empty list, or draw dogs in foster homes as a third stock fed from care. What stays the same is two stocks joined by intake, one nonlinear signal from occupancy to intake, and one leverage point on places.

SF 08 Seedlings raised on a windowsill

This is one defensible answer, not the only one. Yours can differ and still hold up: the lab's checks show whether it has the brief's structure.

Four stocks in a chain, each counted in seedlings: sown in trays, seedlings on the sill, in the cold frame, planted out. Sowing fills the trays from a cloud; coming up, moving out and planting out are transfers down the chain; failing to sprout, damping off and lost to cold drain the first three stages to clouds. The time unit is a day. Planting out carries the material delay: a seedling leaves the cold frame exactly ten days after it arrives. In the note: seedlings pile up on the sill, since the cold frame holds 24 and empties only as seedlings finish their ten days.

Why it works

- Each stage is a stock, where seedlings could be counted on any day
- Three transfers chain the four stocks, so no seedling appears or vanishes between stages
- Losses leave each of the first three stages by a flow of their own, to a cloud
- The ten days are a material delay on planting out, the flow out of the cold frame, not a separate shape
- The behavior note names where seedlings pile up and why

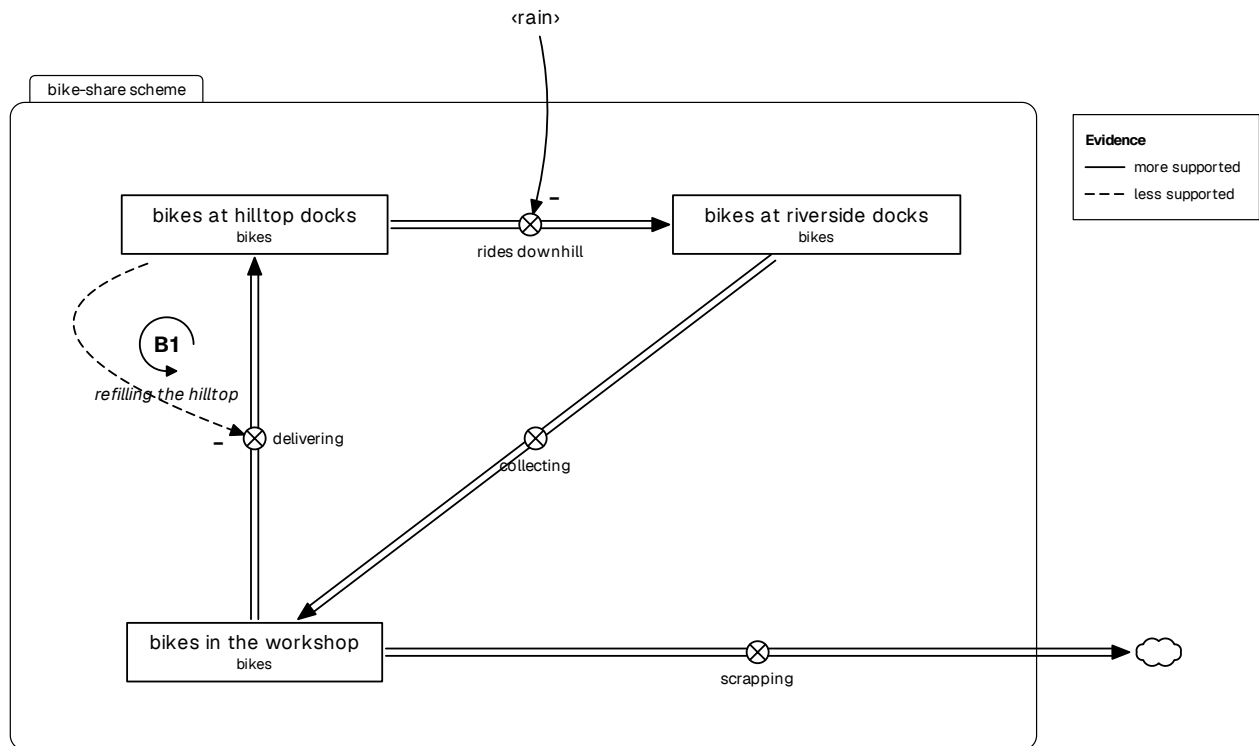
Step by step

1. Four stocks in a chain, each counted in seedlings, with the time unit a day, in the order a seedling passes through them: sown in trays, seedlings on the sill, in the cold frame, planted out.
2. Sowing, the inflow to the trays, from a cloud: about 60 seeds each spring, each counted from the day it is sown.
3. Coming up, moving out and planting out, three transfers down the chain, planting out with the material delay: a seedling leaves the cold frame exactly ten days after it arrives.
4. Failing to sprout, damping off and lost to cold, an outflow from each of the first three stages, each to a cloud: about one seed in five never comes up, and a few seedlings die on the sill and in the cold frame.
5. A behavior note on where seedlings pile up: moving out can run no faster than planting out frees places in the cold frame, 24 at most, so seedlings wait on the sill.

What another defensible answer might vary

Another defensible answer might add losses after planting out, to slugs, or split the sill's stock into tomatoes and peppers. What stays the same is four stocks in seedlings chained by transfers, a loss flow from each stage before planting out, one material delay on planting out, and a note on where seedlings pile up.

SF 09 A city's bike-share fleet



This is one defensible answer, not the only one. Yours can differ and still hold up: the lab's checks show whether it has the brief's structure.

Three stocks, each counted in bikes: at hilltop docks, at riverside docks, in the workshop. Rides downhill, collecting and delivering are transfers around them, so every bike that leaves one stock arrives in another; scrapping drains the workshop to a cloud. The time unit is a day. Rain, an external driver outside the bike-share scheme's boundary, cuts rides downhill (–), a solid signal resting on the ride counts. B1, refilling the hilltop, runs from the hilltop docks to the valve of delivering (–) and along delivering, which fills them (+): one – step, so balancing. That signal, the vans' response, is coded as the hypothesis and drawn dashed, and the legend shows the coding.

Why it works

- Each place a bike waits is a stock, and every flow between two of them is a transfer, so the count of bikes is kept
- No signal ends at a stock: rain and the hilltop docks reach the valves of rides downhill and delivering
- The balancing loop closes through delivering, which fills the hilltop docks
- Rain sits outside the boundary with no signal into it, and the one cloud, where scrapped bikes go, sits outside too
- The legend shows the coding: rain's signal solid, the vans' response dashed

Step by step

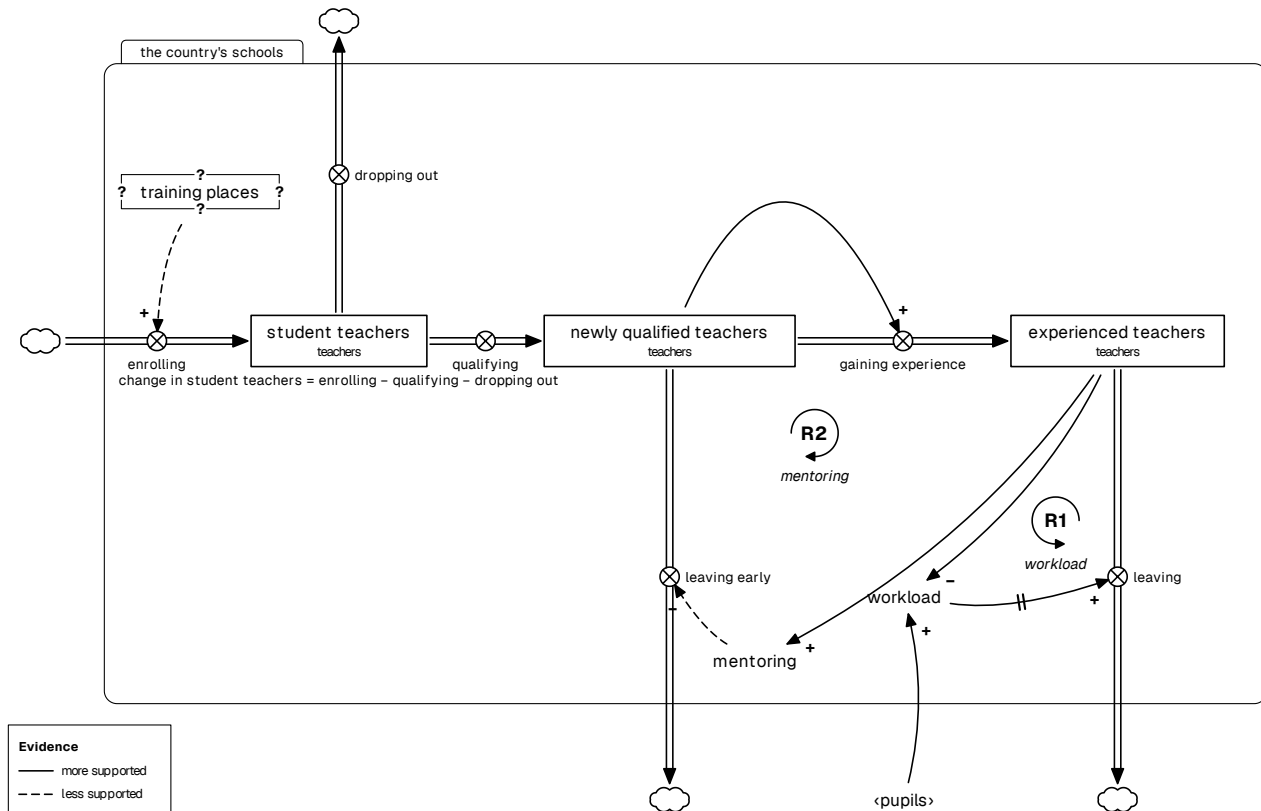
1. Three stocks, each counted in bikes, with the time unit a day: bikes at hilltop docks, at riverside docks and in the workshop, each a count staff could take on any day.
2. Rides downhill, collecting and delivering, three transfers around the stocks: a bike rides from the hilltop to the river, goes by van to the workshop, and returns by van to the hilltop.

3. Scrapping, an outflow from the workshop to a cloud, for the bikes beyond repair that leave the scheme.
4. A – signal from the hilltop docks to the valve of delivering, the staff's belief, coded as a hypothesis and dashed, which closes B1, refilling the hilltop, through delivering: the emptier the hilltop docks, the more bikes the vans bring back to them.
5. The boundary, bike-share scheme, with rain outside it as an external driver, its – signal to the valve of rides downhill solid, since staff count rides every day and about a third fewer bikes are ridden in rain, and the legend for the coding.

What another defensible answer might vary

Another defensible answer might add a signal from the riverside docks to collecting, a few rides uphill as a flow of their own drawn apart from rides downhill, or a stock of bikes on the vans between collecting and delivering. What stays the same is three stocks in bikes joined by transfers, a balancing loop through delivering coded as the hypothesis, rain outside a named boundary, and the legend on.

SF 10 Teachers in a country's schools



This is one defensible answer, not the only one. Yours can differ and still hold up: the lab's checks show whether it has the brief's structure.

Three stocks in a chain, each counted in teachers: student teachers, newly qualified teachers, experienced teachers, joined by qualifying and gaining experience, two transfers. Enrolling fills the first stock from a cloud; dropping out, leaving early and leaving drain each stage to a cloud. The time unit is a year, and the student teachers' stock equation is shown. R1, workload, runs from experienced teachers to workload (-), to the valve of leaving (+, with a delay), and along leaving, which drains them: two – steps, so reinforcing. R2, mentoring, runs from experienced teachers to mentoring (+), to the valve of leaving early (-), along leaving early, which drains newly qualified teachers, then to the valve of gaining experience (+) and along it, which fills experienced teachers: two – steps, so reinforcing. Pupils, an external driver outside the schools' boundary, raise workload (+). Training places, the leverage point, and mentoring's signal are coded as hypotheses, and the legend shows the coding.

Why it works

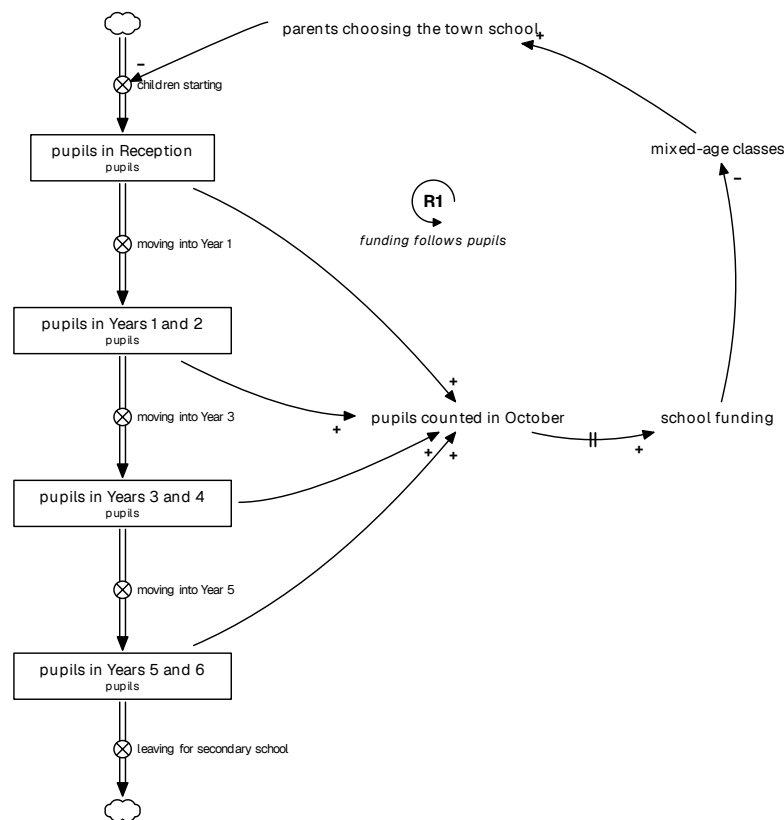
- Each stage is a stock in teachers, and the two transfers keep every teacher counted between stages
- Both loops run through flows, so the parity rule counts each drained stock as a – step
- Workload and mentoring reach the valves of leaving and leaving early: no signal ends at a stock
- The delay is on the signal from workload to leaving: resignations rise a year or two after workload does
- Pupils sit outside the boundary with no signal into them, and every cloud sits outside it too
- Mentoring's and the training places' signals are dashed, and the legend shows the coding

Step by step

1. Three stocks in a chain, each counted in teachers, with the time unit a year: student teachers, whose stock equation is shown, newly qualified teachers and experienced teachers.
2. Qualifying and gaining experience, two transfers down the chain: a student teacher qualifies after the one-year course, and a newly qualified teacher counts as experienced after three years.
3. Enrolling from a cloud, and dropping out, leaving early and leaving, one out of each stage to a cloud: about one student teacher in ten drops out, one newly qualified teacher in eight leaves each year, and one experienced teacher in fourteen.
4. Workload, an auxiliary, with a – signal from experienced teachers and a + signal to the valve of leaving, delayed a year or two, which close R1, workload, through leaving: fewer experienced teachers each carry more work, more of them resign, and fewer still remain.
5. Mentoring, an auxiliary, with a + signal from experienced teachers, a – signal to the valve of leaving early, dashed as a hypothesis, the head teachers' belief, and a + signal from newly qualified teachers to the valve of gaining experience, which close R2, mentoring: new teachers kept by mentoring become experienced teachers who mentor.
6. The boundary, the country's schools, with pupils outside it as an external driver, its + signal to workload: pupil numbers are rising, and nothing in the schools sets them.
7. Training places, an auxiliary and the leverage point the ministry proposes to fund, with a + signal to the valve of enrolling, dashed as a hypothesis, the ministry's expectation that the places would fill, and the legend for the coding.

What another defensible answer might vary

Another defensible answer might add a signal from workload to leaving early, a signal from newly qualified teachers to workload, a behavior note or a graph of experienced teachers falling, or a material delay on qualifying for the one-year course. What stays the same is three stocks in teachers joined by transfers, two loops through stocks, mentoring's and the training places' signals coded as hypotheses, training places as the leverage point, and a delay on the signal from workload to leaving.

CS 07 Kelsham Primary School: four classes in a chain

This is one defensible answer, not the only one. Yours can differ and still hold up: the lab's checks show whether it has the brief's structure.

Four stocks in a chain, each counted in pupils: pupils in Reception, in Years 1 and 2, in Years 3 and 4 and in Years 5 and 6, joined by moving into Year 1, Year 3 and Year 5, three transfers each September. Children starting fills Reception from a cloud, and leaving for secondary school drains Years 5 and 6 to a cloud. The time unit is a year. Pupils counted in October, an auxiliary, reads all four stocks (+) and sets school funding (+) a school year later; less funding brings more mixed-age classes (-), more parents choosing the town school (+), and fewer children starting (-). R1, funding follows pupils, runs from Reception through the count, the funding and the parents' choice to the valve of children starting, which fills Reception: two – steps, so reinforcing.

Why it works

- Each class is a stock in pupils, and the transfers keep every pupil counted as they move up
- Only Reception fills from a cloud and only Years 5 and 6 drain to one: with moves during a school year left out, the chain has no other ends
- The October count reads every stock, since the funding follows every pupil, not only the youngest
- The delay sits on the signal from the count to the funding: each count sets the school year after it
- R1 reaches the chain at the valve of children starting, never at a stock, and its two – steps make it reinforcing

Step by step

1. Four stocks in a chain, each counted in pupils, with the time unit a year: pupils in Reception, in Years 1 and 2, in Years 3 and 4 and in Years 5 and 6, the four classes since 2023.
2. Moving into Year 1, Year 3 and Year 5, three transfers down the chain: each September the pupils finishing Reception, Year 2 and Year 4 move into the next class.

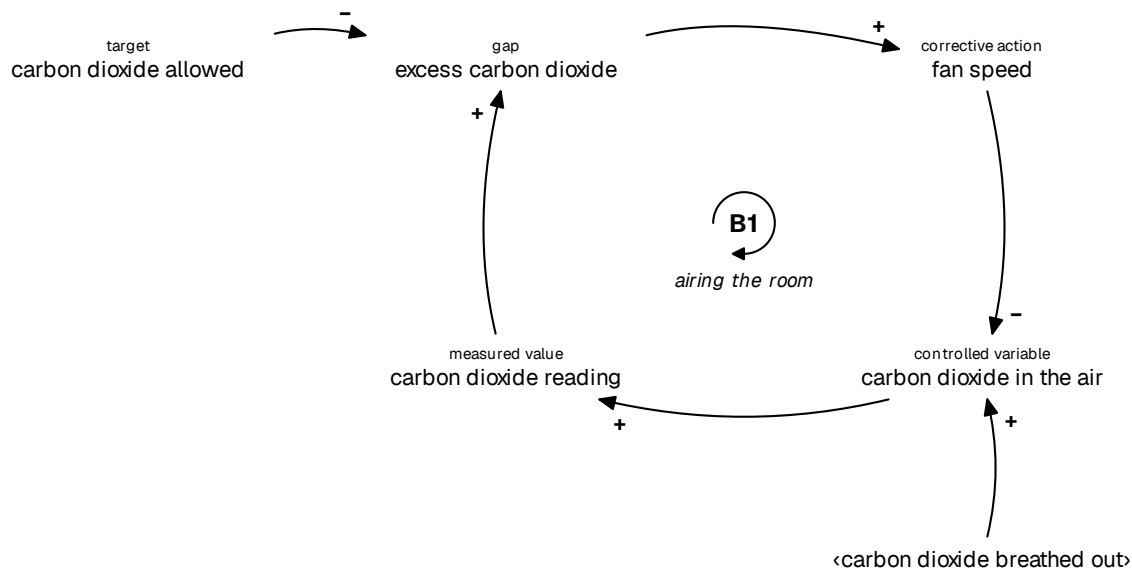
3. Children starting, into Reception from a cloud, and leaving for secondary school, out of Years 5 and 6 to a cloud: with moves during a school year left out, these are the chain's two ends.
4. Pupils counted in October, an auxiliary with a + signal from each class, and school funding, with a + signal from the count delayed a school year: each October's count sets the funding for the year after it, at £4,800 a pupil.
5. Mixed-age classes, with a – signal from the funding, and parents choosing the town school, with a + signal from them and a – signal to the valve of children starting, which close R1, funding follows pupils: fewer children start, the count falls, and the funding with it.

What another defensible answer might vary

Another defensible answer might draw seven stocks, one for each year group, or five, one for each class before 2023, with Years 3 and 4 apart; or let parents choosing the town school drain each class through a flow to a cloud as well. What stays the same is a chain of stocks in pupils joined by transfers, one inflow into Reception, a reinforcing loop from the count through the funding to the flow of children starting, and the delay between the count and the funding.

Chapter 8 · Sense, Compare, Correct

FC 01 Fresh air in a choir's rehearsal room



This is one defensible answer, not the only one. Yours can differ and still hold up: the lab's checks show whether it has the brief's structure.

Five variables, each with its part: carbon dioxide allowed is the target, excess carbon dioxide the gap, fan speed the corrective action, carbon dioxide in the air the controlled variable, and carbon dioxide reading the measured value. The gap rises with the reading (+) and falls as the target rises (-). A larger gap speeds the fan (+), a faster fan lowers the carbon dioxide in the air (-), and the reading follows the air (+): one - signal on the loop, so B1 is balancing. Carbon dioxide breathed out is an external driver acting on the air, off the loop.

Why it works

- The gap is the difference between the reading and the target, so the two signals into it have opposite polarities
- The reading is a variable apart from the air: the fan answers the meter, and the singers breathe into the air
- Fan speed is the corrective action; the carbon dioxide in the air is the controlled variable it changes
- The singers' breath acts on the air, never on the gap or the target: the caretaker sets the target
- One - signal on the loop makes it balancing, as declared

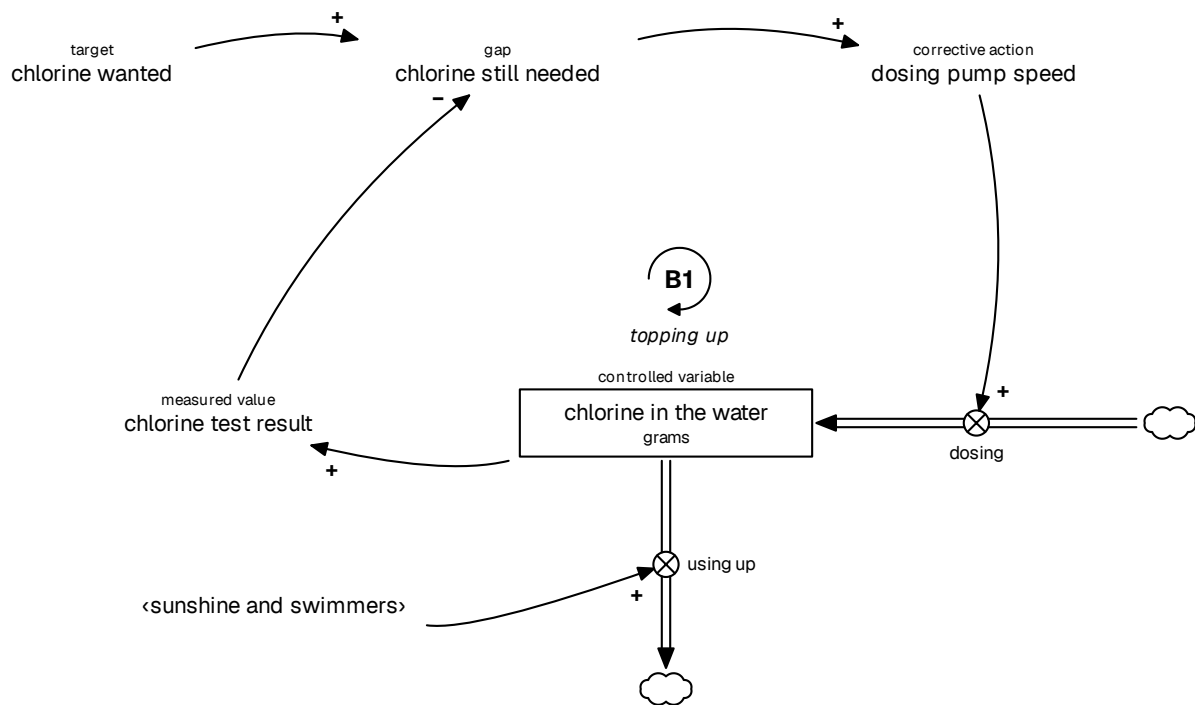
Step by step

1. Carbon dioxide in the air, the controlled variable: the quantity the caretaker set the fan to hold near 1,000 parts per million.
2. Carbon dioxide reading, the measured value, with a + signal from the air: the fan runs on what the meter on the wall shows.
3. Carbon dioxide allowed, the target, and excess carbon dioxide, the gap, read from the reading (+) and the target (-): how far the meter shows above 1,000 parts per million.
4. Fan speed, the corrective action, with a + signal from the gap and a - signal to the air, which close B1, airing the room: the larger the gap, the faster the fan runs, and the more carbon dioxide it carries out.

5. Carbon dioxide breathed out, an external driver, with a + signal to the air, off the loop: forty singers breathe into the room whatever the fan does.

What another defensible answer might vary

Another defensible answer might name the gap carbon dioxide above the target, or the external driver the singers' breath. What stays the same is five variables with their parts on one balancing loop through the gap, opposite polarities into the gap, and the breath acting on the carbon dioxide in the air.

FC 02 Chlorine in a town's outdoor swimming pool

This is one defensible answer, not the only one. Yours can differ and still hold up: the lab's checks show whether it has the brief's structure.

One stock, chlorine in the water, counted in grams: the controlled variable. Dosing fills it from a cloud and using up drains it to another, both in grams per hour. Chlorine still needed is the gap, read from chlorine wanted (+) and the chlorine test result (-); the gap sets the dosing pump's speed, whose signal ends at the dosing valve. B1 runs through the dosing flow, counted + into the stock, and has one - step, so it is balancing. Sunshine and swimmers act at the valve of using up, off the loop.

Why it works

- Chlorine moves only along the two flows; every other line is a signal
- The pump's speed is the corrective action, and its signal ends at the dosing valve, never at the stock
- The test result is a variable apart from the chlorine in the water, read from it
- Sunshine and swimmers act on the controlled variable through the flow they drain it by, never on the gap
- The one - step, from the test result to the gap, makes the loop balancing

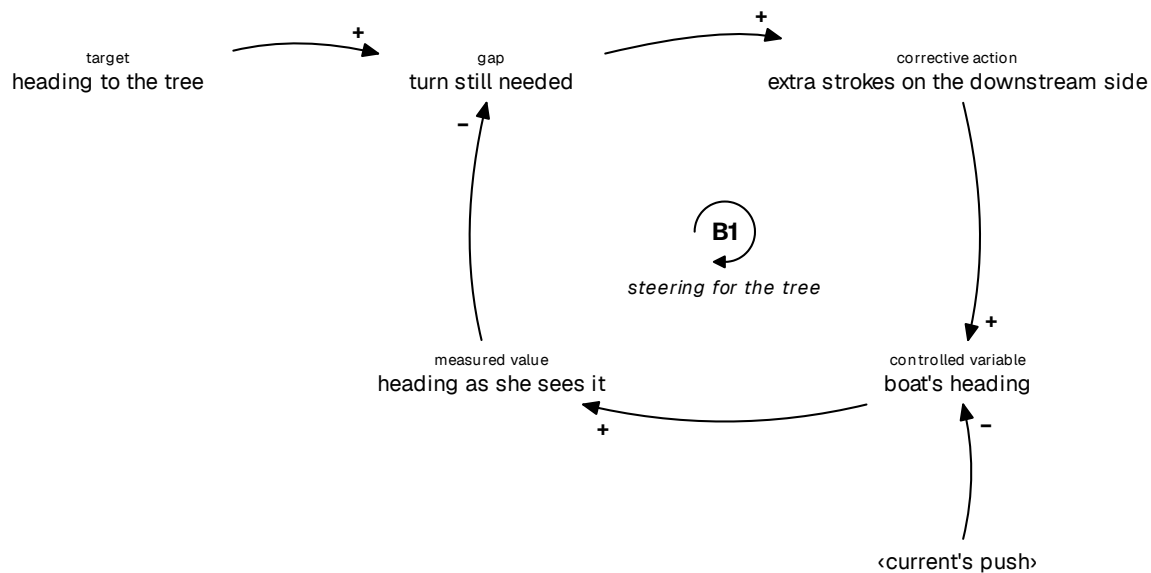
Step by step

1. Chlorine in the water, the controlled variable, a stock counted in grams, with the time unit an hour: the staff keep about 750 grams in about 500 cubic meters of water.
2. Dosing, an inflow from a cloud for the tank, and using up, an outflow to a cloud: chlorine counts from when the pump adds it until sunshine and swimmers use it up.
3. Chlorine test result, the measured value, with a + signal from the stock: the staff set the pump by a test taken every two hours.
4. Chlorine wanted, the target, and chlorine still needed, the gap, read from the target (+) and the test result (-): how far the result falls short of 750 grams.

5. Dosing pump speed, the corrective action, with a + signal from the gap and a + signal to the valve of dosing, which close B1, topping up, through the stock: the further the result falls short, the faster the pump adds chlorine.
6. Sunshine and swimmers, an external driver, with a + signal to the valve of using up, off the loop: hot, crowded afternoons use chlorine up faster.

What another defensible answer might vary

Another defensible answer might name the gap chlorine short, or draw the staff's test as the measured value. What stays the same is one stock in grams with one inflow and one outflow, the time unit an hour, a balancing loop through the dosing flow, and the external driver at the valve of the flow that uses chlorine up.

FC 03 A kayaker crossing a river

This is one defensible answer, not the only one. Yours can differ and still hold up: the lab's checks show whether it has the brief's structure.

The boat's heading is the controlled variable, and the heading to the tree the target. Turn still needed is the gap, read from the target (+) and the heading as she sees it (-). The gap sets her extra strokes on the downstream side (+), the strokes turn the boat's heading upstream (+), and she sees the heading against the tree (+). B1 has one - step, so it is balancing. The current's push acts on the boat's heading (-), off the loop. When she picks a new tree, the target changes by her choice, and no signal reaches it.

Why it works

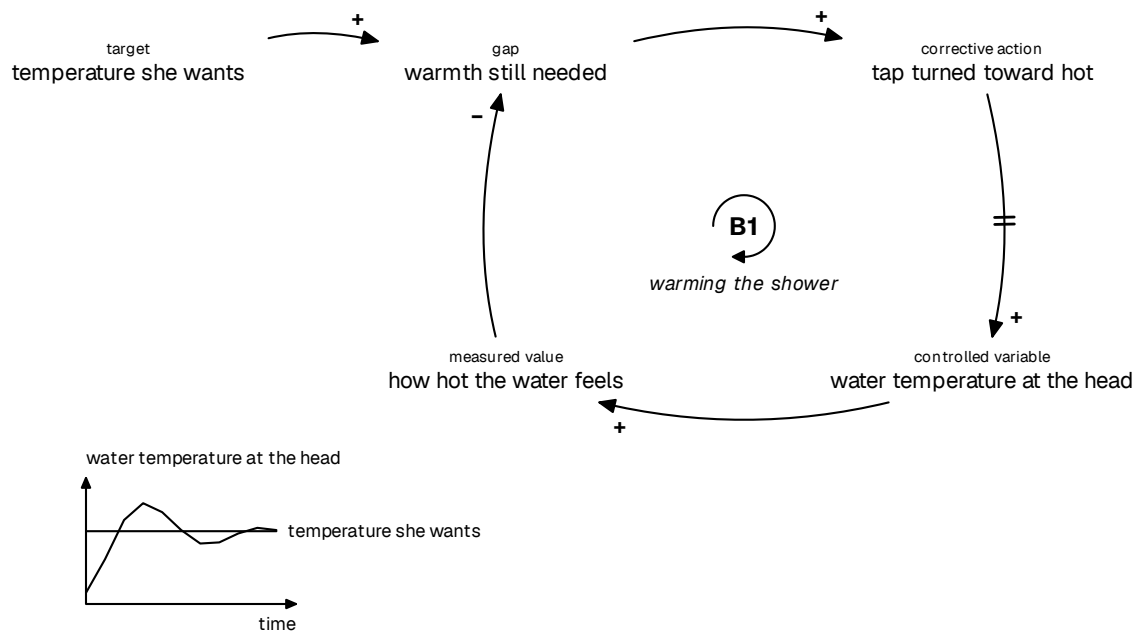
- The gap reads the target + and the heading as she sees it -: their difference is which way, and how far, she still has to turn
- The current's push acts on the boat's heading, never on the gap: a push from outside, not a change of target
- The heading as she sees it is a variable apart from the boat's heading, read from it against the tree
- No signal reaches the target: picking a new tree is her choice
- The one - step, from the heading as she sees it to the gap, makes the loop balancing

Step by step

1. The boat's heading, the controlled variable, counted as an angle that grows the further upstream the bow points.
2. Heading as she sees it, the measured value, with a + signal from the boat's heading: she judges the heading by where the bow points against the tree.
3. Heading to the tree, the target, and turn still needed, the gap, read from the target (+) and the heading as she sees it (-): the angle between where she aims and where she sees the bow pointing.
4. Extra strokes on the downstream side, the corrective action, with a + signal from the gap and a + signal to the boat's heading, which close B1, steering for the tree: she keeps stroking until the bow points at the tree again.
5. The current's push, an external driver, with a - signal to the boat's heading, off the loop: it swings the bow downstream whatever tree she aims at.

What another defensible answer might vary

Another defensible answer might count headings the other way, as how far the bow points downstream of the tree, with the gap reading the target – and the heading as she sees it +, and the current's push +. What stays the same is one target with no signal into it, a gap read with opposite polarities, one balancing control loop, and the current's push acting on the boat's heading.

FC 04 A shower whose hot water arrives late

This is one defensible answer, not the only one. Yours can differ and still hold up: the lab's checks show whether it has the brief's structure.

The water temperature at the head is the controlled variable, and the temperature she wants the target. Warmth still needed is the gap, read from the target (+) and how hot the water feels (-); it sets how far the tap is turned toward hot (+), and the tap changes the water at the head (+) five seconds later: a delay on the forward path. B1 has one – step, so it is balancing. While the hot water is on its way she keeps turning, so the water arrives too hot; she turns back, and it arrives too cold. The graph overshoots the line at the temperature she wants and swings around it, closer each time.

Why it works

- The delay is on the signal from the tap to the water at the head: the forward path, where the correction arrives late
- How hot the water feels is read from the water at the head with no delay: she feels the water as soon as it arrives
- She keeps turning the tap while the hot water is on its way, so the water overshoots, and the graph oscillates around the target
- The graph's line is drawn at the temperature she wants, solid: a dashed line marks a hypothesis
- The one – step, from how hot the water feels to the gap, makes the loop balancing

Step by step

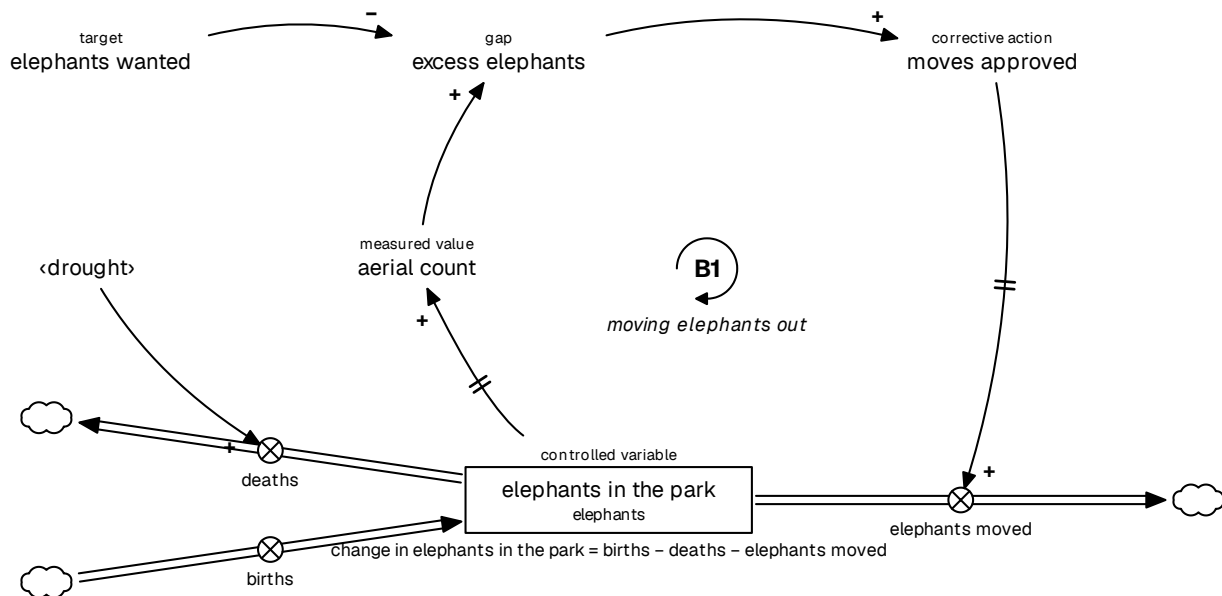
1. Water temperature at the head, the controlled variable: the water she showers in, which she wants at about 38 °C.
2. How hot the water feels, the measured value, with a + signal from the water at the head and no delay, since she stands in the water as it leaves the head.

3. Temperature she wants, the target, and warmth still needed, the gap, read from the target (+) and how hot the water feels (-): above zero while the water feels too cold, below zero once it feels too hot.
4. Tap turned toward hot, the corrective action, with a + signal from the gap and a + signal to the water at the head, delayed about five seconds while the hot water travels to the head, which close B1, warming the shower.
5. A behavior-over-time graph of the water at the head, with a solid line at the temperature she wants: each turn of the tap shows at the head only five seconds later, so the water swings too hot and too cold around the line before it settles near 38 °C.

What another defensible answer might vary

Another defensible answer might add a behavior note on the water swinging past 38 °C each way before it settles, or name the gap too cold by. What stays the same is one balancing control loop, one delay on the signal from the tap to the water at the head, and an oscillating graph of that water's temperature with a solid line at the temperature she wants.

FC 05 Elephants in a national park



This is one defensible answer, not the only one. Yours can differ and still hold up: the lab's checks show whether it has the brief's structure.

One stock, elephants in the park, counted in elephants: the controlled variable. Births fill it from a cloud; deaths and elephants moved drain it to clouds, each in elephants per year, and its stock equation is written beneath it. Excess elephants is the gap, read from elephants wanted (–) and the aerial count (+); it sets moves approved (+), whose signal reaches the valve of elephants moved a year later (+): a delay on the forward path. The aerial count reads the stock every two years: a delay on the return path. B1 runs through elephants moved, counted – out of the stock, and has one – step, so it is balancing. Drought acts at the valve of deaths, off the loop.

Why it works

- Moves approved are a variable and elephants moved the flow; the year between them is a delay on the forward path
- The aerial count is a variable apart from the elephants in the park, and the two years between counts are a delay on the return path
- Elephants enter and leave the park only along the three flows; every other line is a signal
- Drought acts on the controlled variable through the flow of deaths, never on the gap
- The one – step, elephants moved draining the stock, makes the loop balancing

Step by step

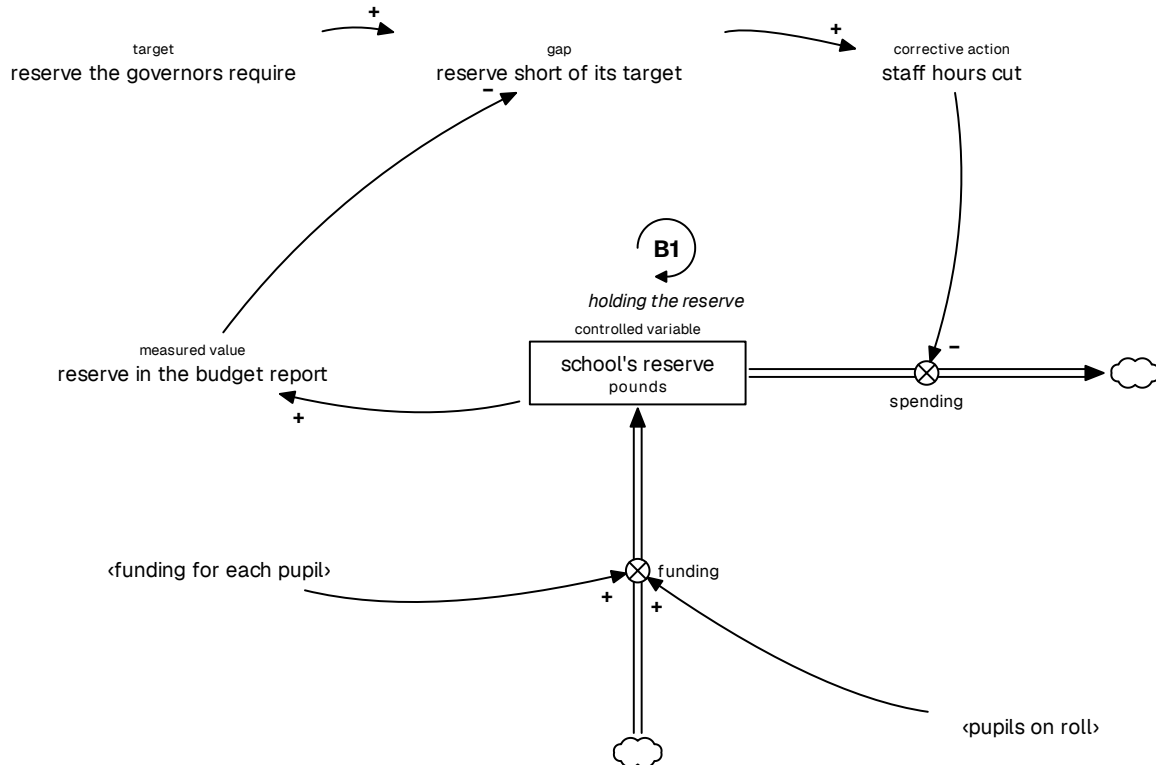
1. Elephants in the park, the controlled variable, a stock counted in elephants, with the time unit a year and its stock equation beneath it: the managers aim to hold it near 2,000.
2. Births, from a cloud, and deaths and elephants moved, each to a cloud: about 150 calves a year against about 60 deaths, so with no elephants moved the herd grows by about 90 a year.
3. Aerial count, the measured value, with a + signal from the stock, delayed since the survey plane counts the herd only every two years.

4. Elephants wanted, the target, and excess elephants, the gap, read from the aerial count (+) and the target (-): how far the latest count sits above 2,000.
5. Moves approved, the corrective action, with a + signal from the gap and a + signal to the valve of elephants moved, delayed a year while the elephants are caught and taken away by truck, which close B1, moving elephants out, through the stock.
6. Drought, an external driver, with a + signal to the valve of deaths, off the loop: more elephants die in a dry year, whatever the managers approve.

What another defensible answer might vary

Another defensible answer might add a signal from the stock to the valve of births, with a reinforcing loop of its own, or name the gap elephants over the number. What stays the same is one stock in elephants with births in and two flows out, the time unit a year, one balancing control loop through elephants moved, one delay between moves approved and elephants moved, and drought at the valve of deaths.

CS 08 Kelsham Primary School: the governors and the reserve



This is one defensible answer, not the only one. Yours can differ and still hold up: the lab's checks show whether it has the brief's structure.

One stock, the school's reserve, counted in pounds: the controlled variable. Funding fills it from a cloud and spending drains it to another, both in pounds per year. Reserve short of its target is the gap, read from reserve the governors require (+) and the reserve in the budget report (-); the gap raises staff hours cut (+), whose signal lowers the valve of spending (-). B1, holding the reserve, runs through spending, counted - out of the stock, and has three - steps, so it is balancing. Funding for each pupil and the pupils on roll act at the valve of funding, off the loop: £4,800 for each of 88 pupils and £140,000 come to £562,400 a year.

Why it works

- Money moves only along funding and spending; every other line is a signal
- Staff hours cut is the corrective action, and its signal ends at the valve of spending, never at the stock
- The reserve in the budget report is a variable apart from the reserve, read from it each term
- The two external drivers act on the reserve at the valve of funding, never on the gap
- Three - steps, from the report to the gap, from the cut to spending and along spending, make the loop balancing

Step by step

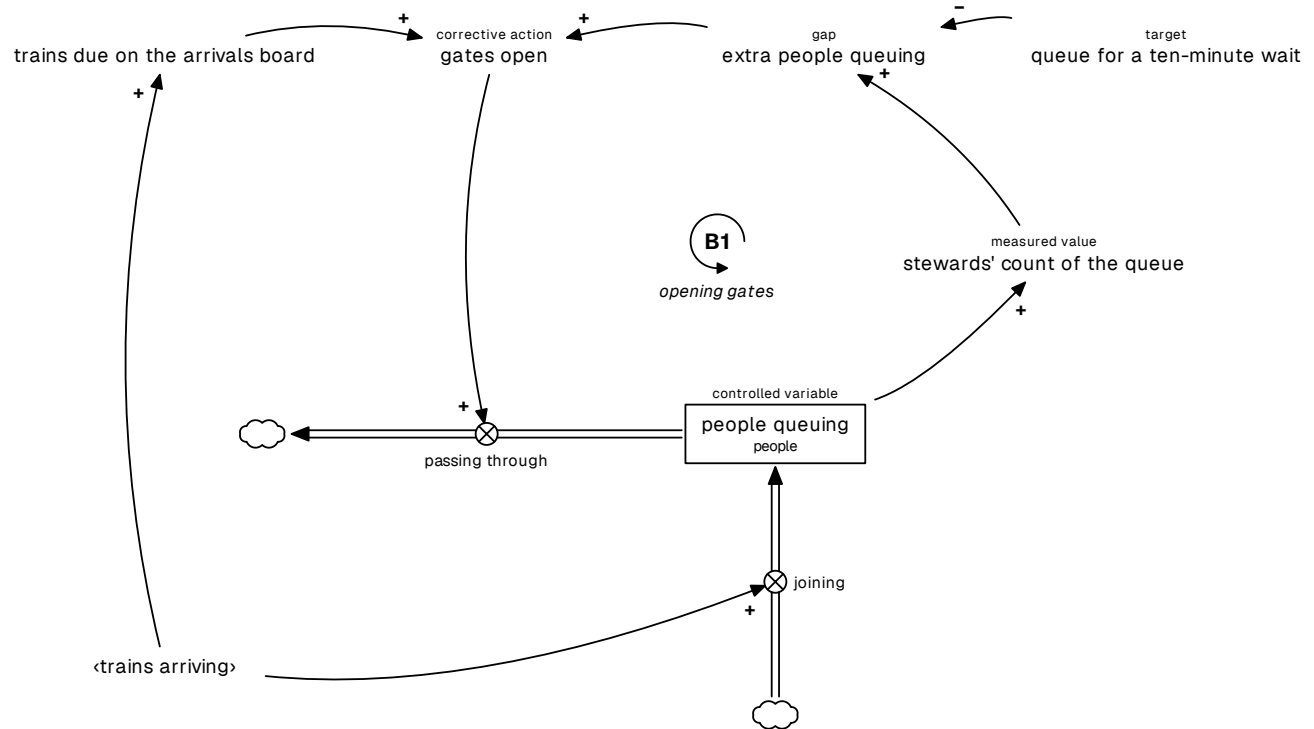
1. The school's reserve, the controlled variable, a stock counted in pounds, with the time unit a year: £96,000 in October 2026.
2. Funding, an inflow from a cloud for the county council, and spending, an outflow to a cloud for pay and bills: money counts in the reserve from when it arrives until it is spent.

3. Reserve in the budget report, the measured value, with a + signal from the stock: the governors read it each term.
4. Reserve the governors require, the target, and reserve short of its target, the gap, read from the target (+) and the report (-): how far the report reads below £60,000.
5. Staff hours cut, the corrective action, with a + signal from the gap and a – signal to the valve of spending, which close B1, holding the reserve, through the stock: the further the report reads below £60,000, the more hours the governors cut and the less the school spends.
6. Funding for each pupil and pupils on roll, two external drivers, with + signals to the valve of funding, off the loop: the county council sets the £4,800, and parents and births set the roll.

What another defensible answer might vary

Another defensible answer might draw one external driver, funding for the school year, with the rate for each pupil and the roll folded into it, or name the corrective action staff hours paid for, with a + signal to the valve of spending and the gap read the other way round. What stays the same is one stock in pounds with funding in and spending out, the time unit a year, one balancing control loop through spending, and the external drivers acting at the valve of funding.

FC 06 Entry gates at a concert as trains arrive



One stock, people queuing, counted in people: the controlled variable. Joining fills it from a cloud and passing through drains it to a cloud, both in people per minute. Extra people queuing is the gap, read from the queue for a ten-minute wait (-) and the stewards' count of the queue (+); it sets gates open (+), whose signal reaches the valve of passing through (+). B1 runs through passing through, counted - out of the stock, and has one - step, so it is balancing. Trains arriving act at the valve of joining, and reach gates open through the trains due on the arrivals board: a feedforward path, passing no gap, so the gates open before a train's fans join the queue.

- The arrivals board's signal ends at gates open, not at the gap, so it changes the gates before the queue grows
- Gates open has two signals in, from the gap and from the arrivals board, and one out, to the valve of passing through
- The stewards' count is a variable apart from the people queuing, and the target is a queue in people, so the gap compares one quantity
- Trains arriving act on the controlled variable at the valve of joining, never on the gap
- The one – step, passing through draining the stock, makes the loop balancing

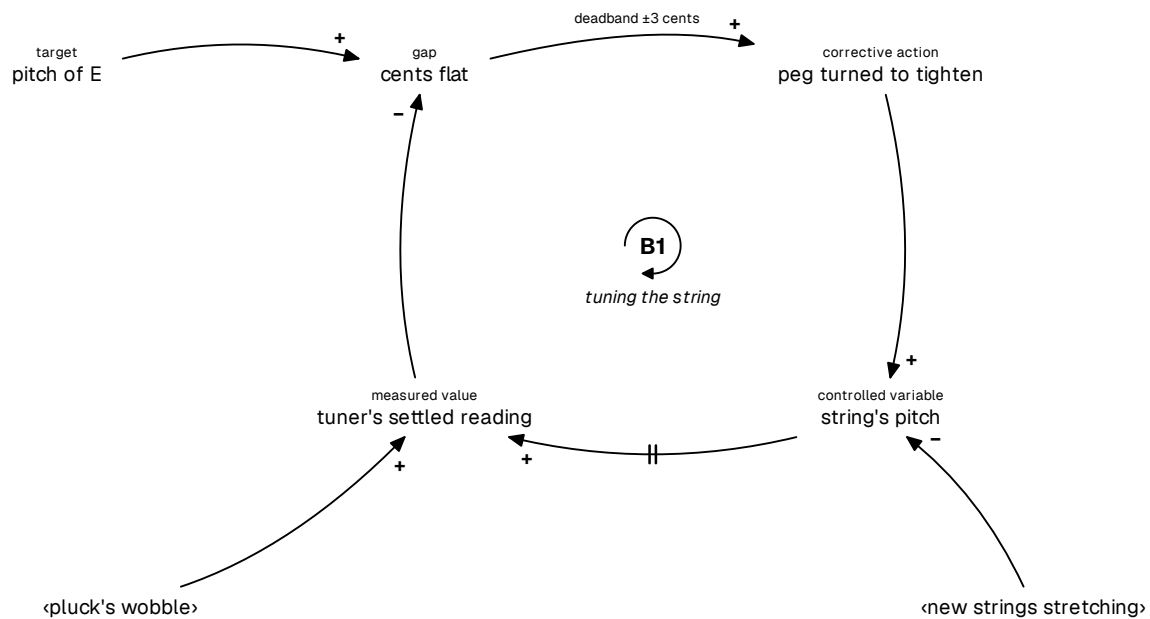
1. People queuing, the controlled variable, a stock counted in people, with the time unit a minute: the stewards aim for about 600, a ten-minute wait at the gates' pace.

2. Joining, from a cloud for the station, and passing through, to a cloud for the stadium: fans count from when they join the queue until they pass a gate.
3. Stewards' count of the queue, the measured value, with a + signal from the stock: a steward counts the queue every few minutes.
4. Queue for a ten-minute wait, the target, and extra people queuing, the gap, read from the count (+) and the target (-): how far the count runs above 600.
5. Gates open, the corrective action, with a + signal from the gap and a + signal to the valve of passing through, which close B1, opening gates, through the stock: the longer the queue, the more gates the stewards open, and the faster fans pass through.
6. Trains arriving, an external driver, with a + signal to the valve of joining, off the loop: a full train brings about 1,000 fans to the queue within a few minutes.
7. Trains due on the arrivals board, with + signals from trains arriving and to gates open, a feedforward path: the stewards open gates on the board's news of a full train, before its fans add to the count.

What another defensible answer might vary

Another defensible answer might count the target and the stewards' estimate in minutes of waiting rather than people, or draw the fans walking from the platform as a stock of their own between the station and the queue. What stays the same is one stock in people with joining in and passing through out, the time unit a minute, one balancing control loop through passing through, trains arriving at the valve of joining, and one path from trains arriving to gates open that passes no gap.

FC 07 Tuning a guitar with a clip-on tuner



This is one defensible answer, not the only one. Yours can differ and still hold up: the lab's checks show whether it has the brief's structure.

The string's pitch is the controlled variable, and the pitch of E the target. Cents flat is the gap, read from the pitch of E (+) and the tuner's settled reading (-); it sets how far she turns the peg to tighten (+), and the peg raises the string's pitch (+). The signal from the gap to the peg carries deadband ± 3 cents: inside it the peg stays put. The settled reading follows the string's pitch two seconds late: a delay on the return path. B1 has one - step, so it is balancing. New strings stretching lower the string's pitch (-); the pluck's wobble, counted in the cents it adds to the reading, sharp or flat, acts on the reading (+).

Why it works

- The deadband is written on the signal from the gap to the peg: within 3 cents either way, a change in the gap changes nothing at the peg
- The two-second wait for the reading to settle is a delay between the string's pitch and the reading: the return path
- The pluck's wobble acts on the tuner's reading, not on the string: it is noise in what she reads
- New strings stretching act on the string's pitch, the controlled variable, never on the gap
- The one - step, from the settled reading to the gap, makes the loop balancing

Step by step

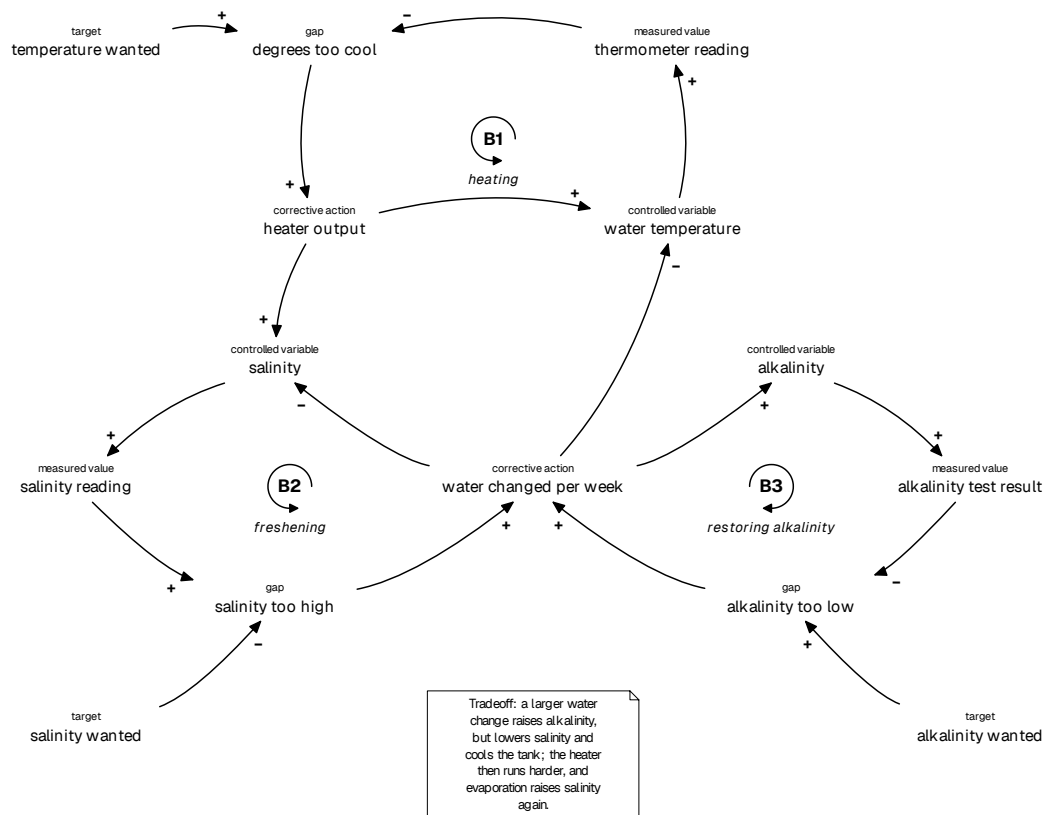
1. The string's pitch, the controlled variable: the high E string, tuned to about 330 Hz.
2. Tuner's settled reading, the measured value, with a + signal from the string's pitch, delayed about two seconds while the note rings and the reading settles: a delay on the return path.
3. Pitch of E, the target, and cents flat, the gap, read from the target (+) and the settled reading (-): a reading sharp of E puts the gap below zero.

4. Peg turned to tighten, the corrective action, with a + signal from the gap carrying deadband ± 3 cents and a + signal to the string's pitch, which close B1, tuning the string: a reading 2 cents flat leaves the peg where it is, and one 5 cents flat turns it.
5. Two external drivers, off the loop: new strings stretching, with a – signal to the string's pitch, which goes flat between tunings, and the pluck's wobble, with a + signal to the reading, which shifts what she reads but not the string.

What another defensible answer might vary

Another defensible answer might name the gap cents off E and the corrective action peg turned, a turn back counted below zero. What stays the same is one balancing control loop, one delay between the string's pitch and the reading, deadband ± 3 cents on the signal from the gap to the peg, the wobble acting on the reading, and stretching acting on the string's pitch.

FC 08 A home reef aquarium



This is one defensible answer, not the only one. Yours can differ and still hold up: the lab's checks show whether it has the brief's structure.

Three control loops, each with its target, gap, corrective action, controlled variable and measured value. B1: degrees too cool, read from temperature wanted (+) and the thermometer reading (-), sets the heater output (+), which warms the water (+). B2: salinity too high, read from salinity wanted (-) and the salinity reading (+), sets the water changed per week (+), and new water mixed at 34 parts per thousand lowers the salinity (-). B3: alkalinity too low, read from alkalinity wanted (+) and the alkalinity test result (-), sets the same water changed per week (+), which raises the alkalinity (+). Each loop has one - step, so each is balancing. Two cross-effects join the loops: heater output raises salinity through evaporation (+), and water changed cools the water (-). The behavior note names the tradeoff.

Why it works

- Water changed per week is one variable, the corrective action of B2 and of B3, drawn once with a signal in from each gap
- Each of the three loops has its own target and its own reading, so each gap compares one quantity
- The cross-effects are signals between loops that lie on no declared loop: heater output to salinity, water changed to water temperature
- The two cross-effects close a longer loop, left undeclared, through the temperature and salinity gaps: the tradeoff the behavior note names
- Each loop has one - step, so each is balancing

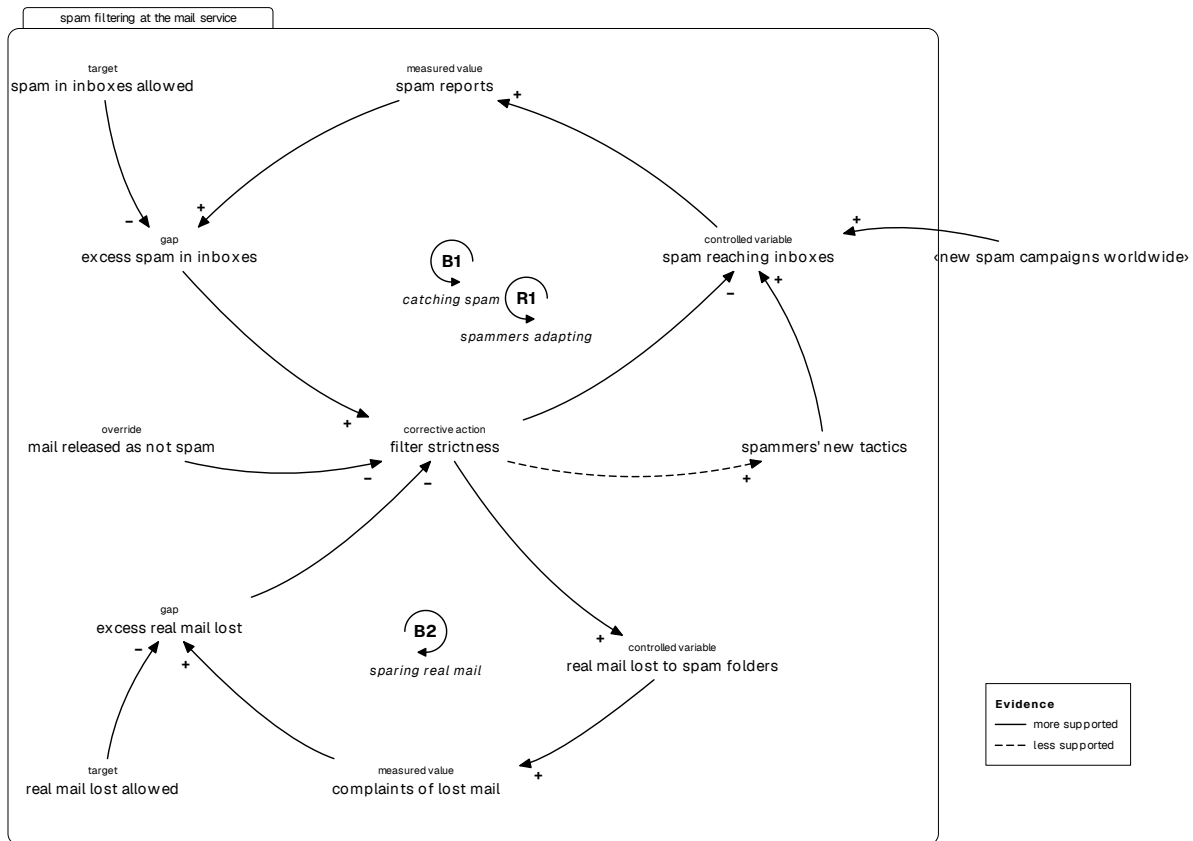
Step by step

1. Water temperature, a controlled variable, and the thermometer reading, its measured value, with a + signal from one to the other: the heater answers a thermometer in the tank, the one reading taken without her.
2. Temperature wanted, the target, degrees too cool, the gap, and heater output, the corrective action, with the signals that close B1, heating: the cooler the thermometer reads below 25 °C, the harder the heater runs.
3. Salinity and alkalinity, two more controlled variables, each with a + signal to its measured value: the refractometer's salinity reading and the kit's alkalinity test result, both taken once a week.
4. Salinity wanted with salinity too high, and alkalinity wanted with alkalinity too low, two targets and two gaps: the salinity gap grows as the reading rises above 35 parts per thousand, the alkalinity gap as the test falls below 8 dKH.
5. Water changed per week, one corrective action for both, with + signals from each gap, a – signal to salinity and a + signal to alkalinity, which close B2, freshening, and B3, restoring alkalinity: new water mixed at 34 parts per thousand and 11 dKH dilutes the salt and adds alkalinity.
6. Two cross-effects, on no declared loop: heater output raises salinity (+), since warmer water evaporates faster and leaves its salt, and water changed lowers the water temperature (–), since the new water comes from a bucket a few degrees cooler.
7. A behavior note on the tradeoff the two cross-effects make between the loops: no water change raises alkalinity without cooling the tank and, through the heater, raising its salinity.

What another defensible answer might vary

Another defensible answer might name the gaps salinity over target and alkalinity under target, or add a signal from the water temperature to salinity, a third cross-effect for evaporation. What stays the same is three targets, three readings and three gaps; one variable for the water changes, the corrective action of both the salinity loop and the alkalinity loop; and the two cross-effects, heater output to salinity and water changed to water temperature.

FC 09 A mail service's spam filter



This is one defensible answer, not the only one. Yours can differ and still hold up: the lab's checks show whether it has the brief's structure.

Filter strictness is the corrective action of two control loops. B1: excess spam in inboxes, read from spam in inboxes allowed (–) and spam reports (+), raises filter strictness (+), which lowers spam reaching inboxes (–). B2: excess real mail lost, read from real mail lost allowed (–) and complaints of lost mail (+), lowers filter strictness (–), which raises real mail lost to spam folders (+). Each has one – step, so each is balancing. R1 runs from filter strictness through spammers' new tactics to spam reaching inboxes and back through B1's gap, with no – step, so it is reinforcing; its first signal, from strictness to tactics, is coded as a hypothesis and drawn dashed, and the legend shows the coding. New spam campaigns worldwide sit outside the boundary, spam filtering at the mail service, acting on spam reaching inboxes. Messages released as not spam, the override, lower filter strictness (–).

Why it works

- Spammers' new tactics change with filter strictness, so they sit inside the boundary, on a loop, not outside it as an external driver
- New spam campaigns start whatever the filter does, so they are an external driver outside the boundary, with no signal into them
- One variable, filter strictness, is the corrective action of both balancing loops, and their gaps reach it with opposite polarities
- The override's signal ends at filter strictness, the corrective action, and is a step of no declared loop
- Only the engineers' belief, that stricter filtering brings new tactics, is dashed

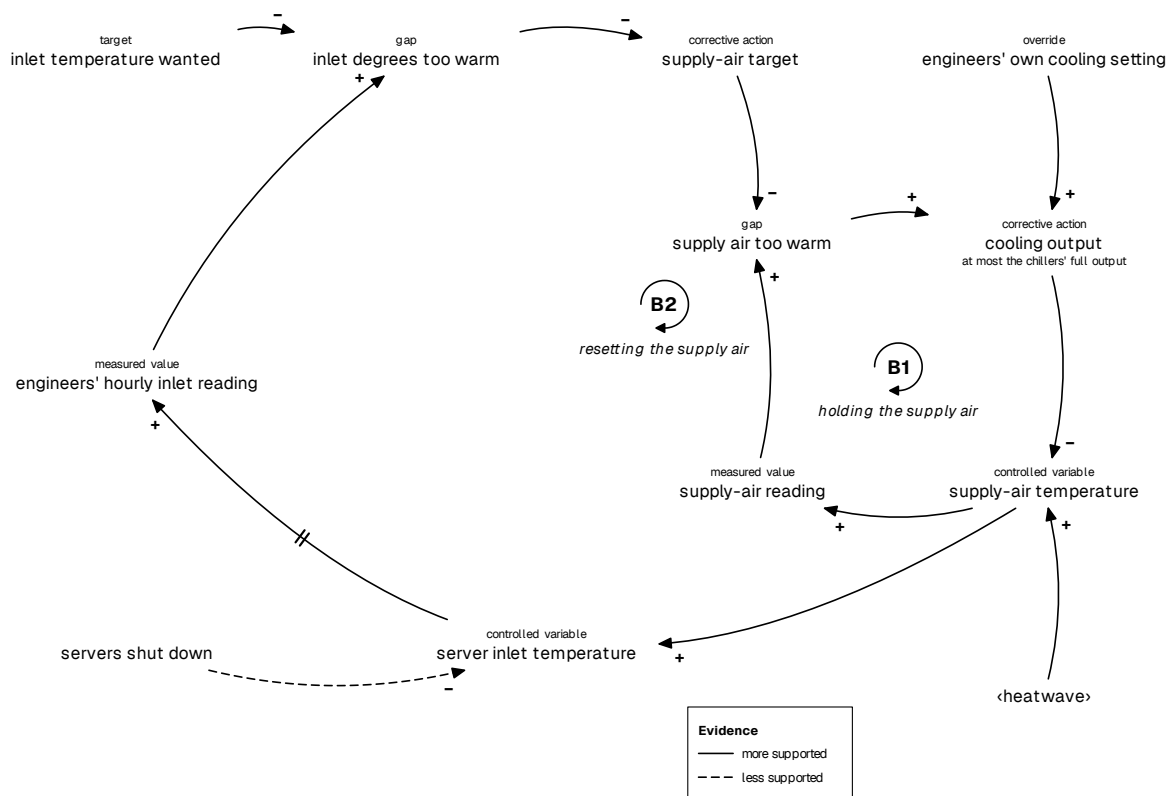
Step by step

1. Spam reaching inboxes and real mail lost to spam folders, two controlled variables, each with a + signal to its measured value: spam reports, from users who see the spam that gets through, and complaints of lost mail.
2. Two targets and two gaps, each gap read from its target (–) and its measured value (+): excess spam in inboxes, against 1 message in 1,000, and excess real mail lost, against 1 in 10,000.
3. Filter strictness, the corrective action of both, raised by excess spam (+) and lowered by excess real mail lost (–), with a – signal to spam reaching inboxes and a + signal to real mail lost, which close B1, catching spam, and B2, sparing real mail: the engineers set one filter from reports and complaints each day.
4. The boundary, spam filtering at the mail service, with new spam campaigns worldwide outside it as an external driver, its + signal to spam reaching inboxes: campaigns start every day, and nothing at the service changes how many.
5. Spammers' new tactics, with a + signal from filter strictness, the engineers' belief, coded as a hypothesis and dashed, and a + signal to spam reaching inboxes, which close R1, spammers adapting, through B1's measured value and gap, with the legend for the coding.
6. Mail released as not spam, the override, with a – signal to filter strictness: each message a user marks not spam leaves the spam folder and loosens the filter for messages like it.

What another defensible answer might vary

Another defensible answer might count both targets in messages per day, or code the signal from spammers' new tactics to spam reaching inboxes as a hypothesis too, since the same belief runs through it. What stays the same is two balancing control loops sharing filter strictness, one reinforcing loop through spammers' new tactics inside a named boundary, new spam campaigns outside it, one override ending at filter strictness, and one signal coded as a hypothesis with the legend on.

FC 10 Cooling a data center through a heatwave



This is one defensible answer, not the only one. Yours can differ and still hold up: the lab's checks show whether it has the brief's structure.

Two control loops, one inside the other. B1, the fast loop: supply air too warm, read from the supply-air target (-) and the supply-air reading (+), raises cooling output (+), which cools the supply air (-); one - step, so balancing. B2, the slow loop: inlet degrees too warm, read from inlet temperature wanted (-) and the engineers' hourly inlet reading (+), lowers the supply-air target (-), whose signal reaches B1's gap (-), and B2 runs on through cooling output and the supply air to the server inlet temperature (+), read an hour late: three - steps, so balancing. The supply-air target is B2's corrective action and B1's target, so B1 is nested inside B2. Cooling output is at most the chillers' full output. The heatwave warms the supply air (+); the engineers' own cooling setting, the override, ends at cooling output (+); servers shut down lower the inlet temperature (-), a signal coded as a hypothesis, drawn dashed, with the legend.

Why it works

- The supply-air target keeps one role, B2's corrective action, and its signal into B1's gap is B1's target: no second role is drawn
- The hour between the inlet temperature and the engineers' reading is a delay on B2's return path, so B2 is slow and B1 fast
- The saturation sits beneath cooling output, the corrective action whose limit the heatwave reaches
- The heatwave acts on the supply-air temperature, a controlled variable, never on a gap or a target
- Only the less supported signal, from servers shut down to the inlet temperature, is dashed, and the legend shows the coding

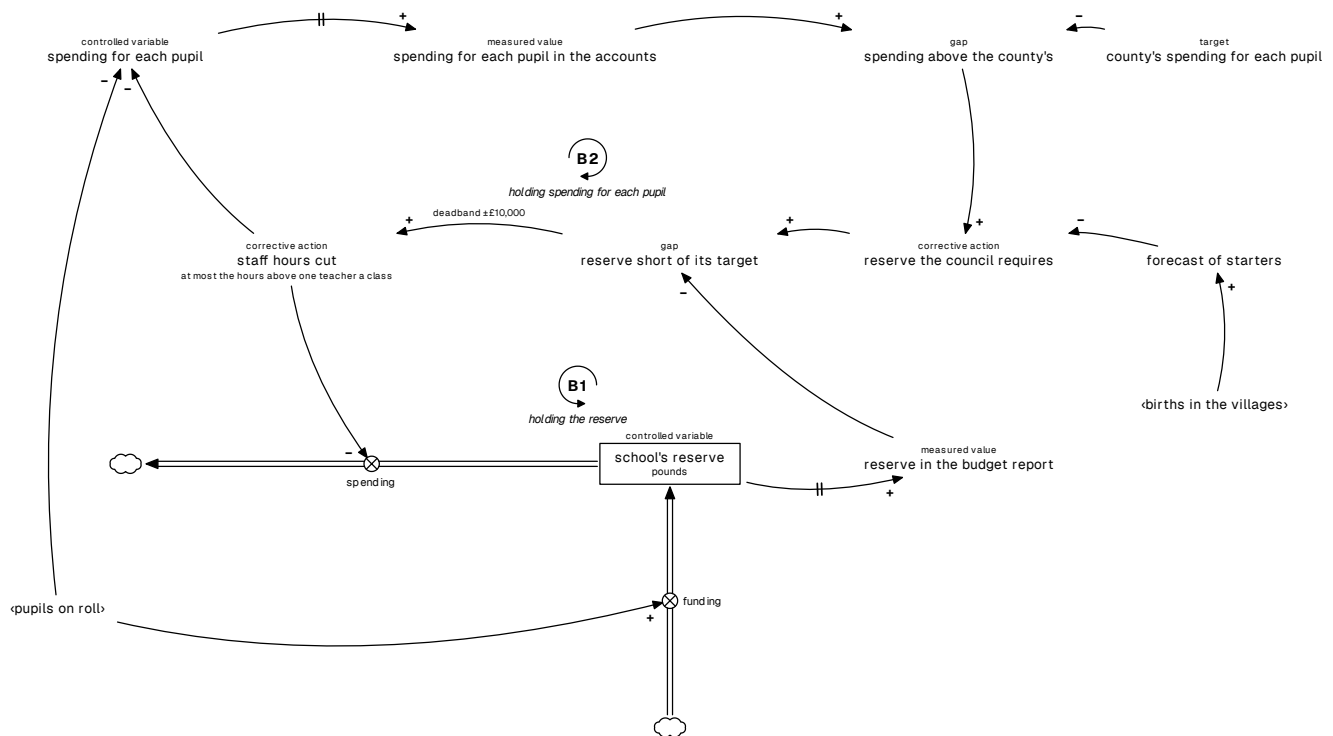
Step by step

1. Supply-air temperature, the fast loop's controlled variable, and the supply-air reading, its measured value, with a + signal from one to the other: the thermometer in the supply air reads it every few seconds.
2. Supply air too warm, the gap, read from the supply-air reading (+) and the supply-air target (–), the target drawn with its role in the slower loop, corrective action, since the engineers reset it each hour from the inlet reading.
3. Cooling output, the corrective action, with saturation at the chillers' full output, a + signal from the gap and a – signal to the supply air, which close B1, holding the supply air: the units cool harder the warmer the supply air reads, up to that limit.
4. Server inlet temperature, the slow loop's controlled variable, with a + signal from the supply air, and the engineers' hourly inlet reading, its measured value, with a + signal from the inlets delayed an hour: a delay on the return path.
5. Inlet temperature wanted, the target, and inlet degrees too warm, the gap, with a – signal from the gap to the supply-air target, which close B2, resetting the supply air, around B1: the warmer the inlets read each hour, the lower the engineers set the supply-air target.
6. The heatwave, an external driver, with a + signal to the supply-air temperature: once the chillers run at full output, the supply air warms however low the target is set.
7. The engineers' own cooling setting, the override, with a + signal to cooling output, and servers shut down, with a – signal to the inlet temperature, dashed as a hypothesis since nobody knows by how much, and the legend for the coding.

What another defensible answer might vary

Another defensible answer might draw the heatwave acting on the server inlet temperature instead, or add a behavior note on the inlet temperature climbing while cooling output sits at its limit. What stays the same is two balancing control loops, the fast one on the supply air nested inside the slow one on the inlet temperature, the supply-air target as the slow loop's corrective action, cooling output at most the chillers' full output, an override ending at cooling output, and one signal coded as a hypothesis with the legend on.

CS 09 Kelsham Primary School: a floor on staffing and the council's loop



This is one defensible answer, not the only one. Yours can differ and still hold up: the lab's checks show whether it has the brief's structure.

Two control loops, one inside the other. B1, holding the reserve: reserve short of its target, read from the reserve the council requires (+) and the reserve in the budget report (-), raises staff hours cut (+), which lowers the value of spending (-), and spending drains the school's reserve (-), read by the report a term later: three - steps, so balancing. B2, holding spending for each pupil: spending above the county's, read from spending for each pupil in the accounts (+), a year later, and the county's spending for each pupil (-), raises the reserve the council requires (+), whose signal is B1's target, and runs on through B1's gap and staff hours cut to spending for each pupil (-): one - step, so balancing, with B1 nested inside it. Staff hours cut is at most the hours above one teacher a class, and the governors leave it as it is while the gap stays within $\pm £10,000$. Births in the villages reach the reserve the council requires through the forecast of starters (+, then -), a feedforward path that passes no gap. The pupils on roll, an external driver, raise funding (+) and lower spending for each pupil (-).

Why it works

- The reserve the council requires keeps one role, B2's corrective action, and its signal into reserve short of its target makes it B1's target
- The saturation sits beneath staff hours cut: once the hours above one teacher a class are gone, a wider gap cuts no further, and neither loop can lower spending again
- The deadband sits on the signal from the gap to staff hours cut, as wide as the reserve's swing within a school year, so a term's swing changes no hours
- The forecast's path ends at a corrective action and passes no gap, so the council acts on births before the October count falls
- The two readings, each term and each year, are delays on the return paths: B1 corrects within a year, B2 over several

Step by step

1. The school's reserve, B1's controlled variable, a stock counted in pounds, with the time unit a year, filled by funding from a cloud and drained by spending to another.
2. Reserve in the budget report, the measured value, with a + signal from the stock delayed a term: the governors read the report each term, a delay on the return path.
3. Reserve short of its target, the gap, read from the report (–) and the reserve the council requires (+), the target drawn with its role in the council's loop, corrective action, since the council sets it from £60,000 up.
4. Staff hours cut, the corrective action, with saturation at the hours above one teacher a class, a + signal from the gap with a deadband of $\pm£10,000$ and a – signal to the valve of spending, which close B1, holding the reserve: a term's swing changes no hours, and no gap cuts below one teacher a class.
5. Spending for each pupil, B2's controlled variable, with a – signal from staff hours cut, and spending for each pupil in the accounts, its measured value, with a + signal from it delayed a year: David Brennan reads the accounts once a year.
6. County's spending for each pupil, the target, and spending above the county's, the gap, read from the accounts (+) and the target (–), with a + signal to the reserve the council requires, which close B2, holding spending for each pupil, around B1.
7. Pupils on roll, an external driver, with a + signal to the valve of funding and a – signal to spending for each pupil, and births in the villages, a second, read through the forecast of starters into the reserve the council requires: a feedforward path that passes no gap.

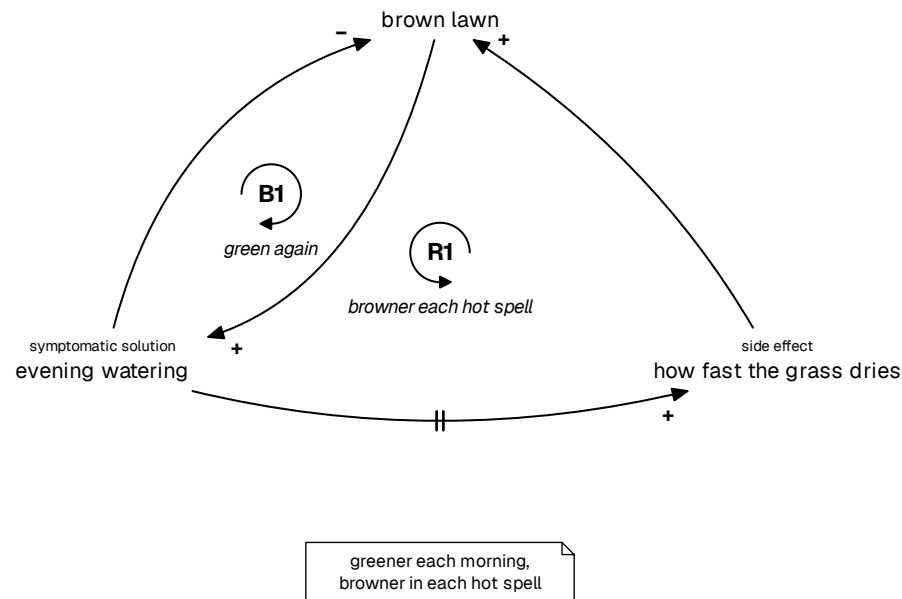
What another defensible answer might vary

Another defensible answer might draw births in the villages → pupils on roll, delayed four years, so that the roll is no longer an external driver; send the forecast to staff hours cut, the governors acting on it; or read spending for each pupil from the flow of spending. What stays the same is two balancing control loops, the governors' nested inside the council's through the reserve the council requires, staff hours cut with its limit, a deadband on the signal from the reserve's gap, one feedforward path from births, and a delay on each return path.

Chapter 10 · Structures That Recur

AR 01 Watering a lawn a little every evening

Archetype: fixes that fail



This is one defensible answer, not the only one. Yours can differ and still hold up: the lab's checks show whether it has the brief's structure.

The browner the lawn, the more Rosa waters (+), and the more she waters, the less brown the lawn by morning (-): one – effect, so B1 is balancing. Over weeks the watering keeps the roots shallow, so the grass dries faster (+, with a delay), and the faster it dries, the browner the lawn (+): R1 has no – effect, so it is reinforcing. Evening watering is the symptomatic solution and how fast the grass dries the side effect; the declared archetype is fixes that fail, which the structure matches with its delay.

Why it works

- Both loops pass through the brown lawn, the change Rosa waters to undo
- One – effect makes the morning's relief balancing
- No – effect makes the return through the drying grass reinforcing
- The delay sits on evening watering → how fast the grass dries, where weeks pass
- Each role is written above its variable: the watering's and the drying grass's

Step by step

1. Brown lawn, drawn first: it is what Rosa sees each evening, before she waters.
2. Evening watering, the symptomatic solution, with a + effect from the brown lawn and a – effect back, closing B1, green again: the relief Rosa sees by the next morning.
3. How fast the grass dries, the side effect, with a + effect from the watering, delayed over the weeks the grass keeps its roots in the top few centimeters, and a + effect to the brown lawn, closing R1, browner each hot spell:

drawn after B1, as it shows only after weeks of relief.

4. The behavior note, written once both loops are drawn, since each half of it comes from one: greener each morning from B1, browner in each hot spell from R1.

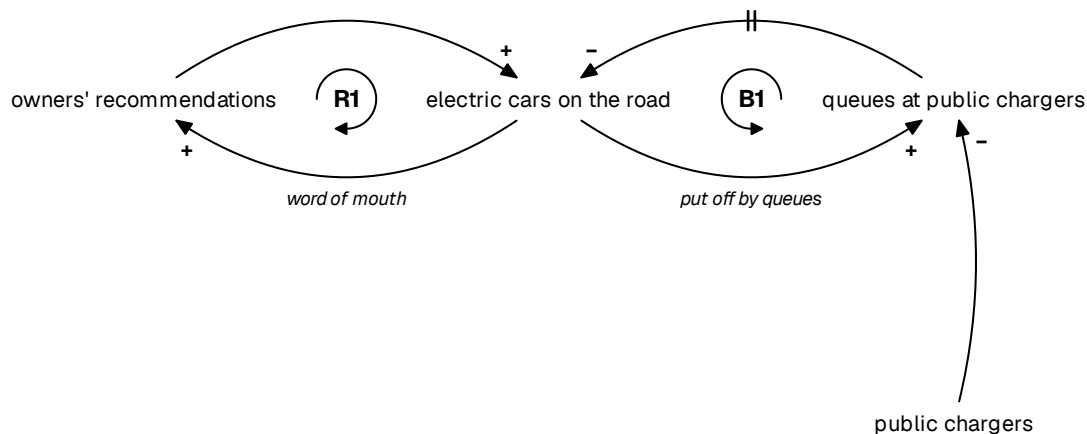
5. Fixes that fail, declared last: until R1 is drawn, the watering only fixes, and nothing fails.

What another defensible answer might vary

Another defensible answer might put the delay on how fast the grass dries → brown lawn, waiting for the next hot spell, or name the side effect how deep the grass grows, with – effects into and out of it: a variable named as its opposite, which keeps R1 reinforcing and still matches fixes that fail. What stays the same is a balancing loop of relief and a reinforcing loop, through the side effect and a delay, that returns to the brown lawn.

AR 02 Electric cars and public chargers

Archetype: limits to growth



This is one defensible answer, not the only one. Yours can differ and still hold up: the lab's checks show whether it has the brief's structure.

The more electric cars on the road, the more owners' recommendations (+), and the more recommendations, the more electric cars on the road (+): no – effect, so R1 is reinforcing. The more electric cars, the longer the queues at public chargers (+), and the longer the queues, the fewer electric cars join the road (–, with a delay): one – effect, so B1 is balancing. The two loops share only the electric cars on the road, so they match limits to growth: R1 grows the number of cars, and B1 holds it back. The public chargers shorten the queues (–) from outside both loops: the constraint.

Why it works

- R1 and B1 meet at one variable, the electric cars on the road, and share no effect
- No – effect makes the recommendations' loop reinforcing
- One – effect makes the queues' loop balancing
- The delay sits on queues at public chargers → electric cars on the road, where months pass before buyers hear
- The public chargers lie outside both loops and act on the balancing loop through the queues

Step by step

1. Electric cars on the road, drawn first: the number the situation begins and ends with.
2. Owners' recommendations, with a + effect each way to the cars, closing R1, word of mouth: the growth, drawn before anything holds it back.
3. Queues at public chargers, with a + effect from the cars and a – effect back, delayed by the months before word of hour-long waits reaches buyers, closing B1, put off by queues.

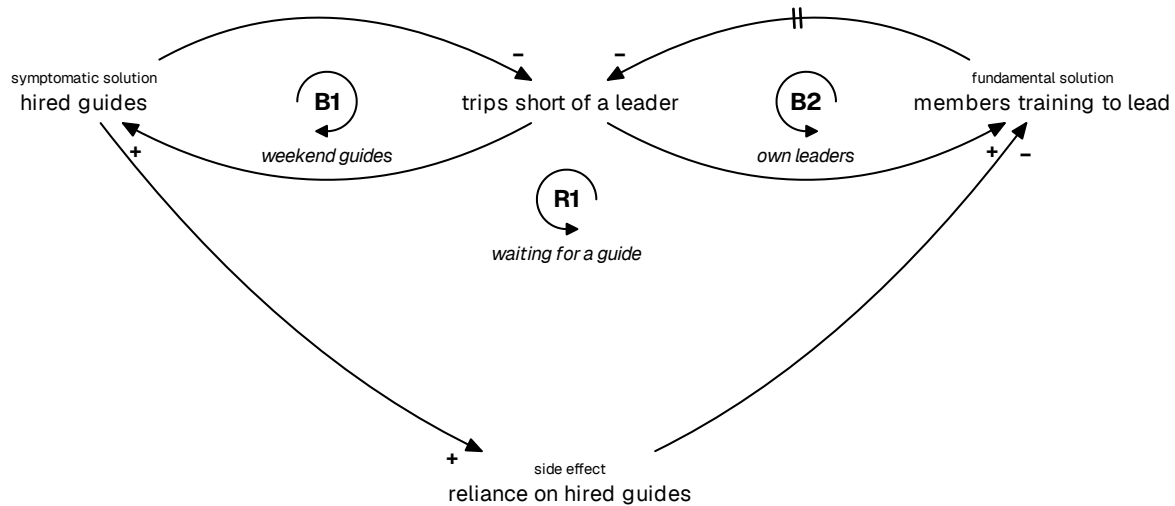
4. Public chargers, with a – effect on the queues, drawn last of the variables: no effect in either loop changes how many there are.
5. Limits to growth, declared once B1 is drawn: with R1 alone, the growth has nothing to limit it, and the drawing matches no archetype.

What another defensible answer might vary

Another defensible answer might name the queues as their opposite, a free charger when one is wanted, with the polarity of each effect into and out of it reversed: B1 stays balancing, and the match holds. Drawing the purchases as a variable both loops pass through would make them share an effect, and the structure would no longer match limits to growth. What stays the same is a reinforcing loop and a balancing loop that meet at one variable, with the chargers outside both.

AR 03 A climbing club that hires guides for its trips

Archetype: shifting the burden



This is one defensible answer, not the only one. Yours can differ and still hold up: the lab's checks show whether it has the brief's structure.

The more trips short of a leader, the more hired guides (+), and the more hired guides, the fewer trips short of a leader (-): one – effect, so B1 is balancing. The more trips short of a leader, the more members training to lead (+), and a season later, the more members training, the fewer trips short of a leader (-, with a delay): B2 is balancing too. The more hired guides, the more the club relies on them (+), and the more it relies on them, the fewer members train (-): R1 runs from the shortage through the hired guides, the reliance and the training back to the shortage, with two – effects, so it is reinforcing. Hired guides are the symptomatic solution, members training to lead the fundamental solution and the reliance on hired guides the side effect; the declared archetype is shifting the burden, which the structure matches with its delay, and fixes that fail within it.

Why it works

- Both balancing loops pass through the trips short of a leader, the shortage the hired guides and the training each relieve
- The delay sits on members training to lead → trips short of a leader, where a season passes
- Two – effects make R1, through the reliance, reinforcing
- The reliance on hired guides reaches the shortage only through the training, so the training's loop is the one it weakens
- Each role is written above its variable

Step by step

1. Trips short of a leader, drawn first: the club meets the shortage before it hires a guide or trains anyone.

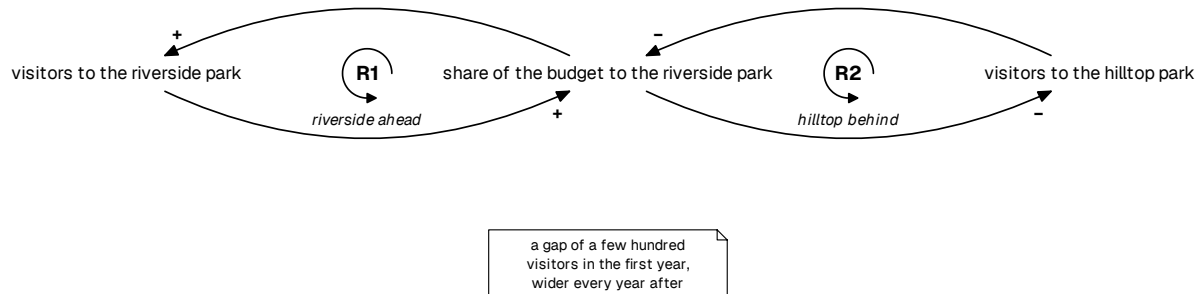
2. Hired guides, the symptomatic solution, with a + effect from the shortage and a – effect back, closing B1, weekend guides: a guide hired for the weekend lets that trip go ahead.
3. Members training to lead, the fundamental solution, with a + effect from the shortage and a – effect back, delayed by the season of courses and logged climbs, closing B2, own leaders.
4. Reliance on hired guides, the side effect, with a + effect from the guides and a – effect into the training, closing R1, waiting for a guide, which runs through B2's delayed effect and so comes after it.
5. Shifting the burden, declared last, once R1 is drawn: without it, the club has two ways to close the shortage, and nothing shifts the burden to the guides.

What another defensible answer might vary

Another defensible answer might draw the training as a chain, members training to lead → qualified leaders → trips short of a leader, with the delay on either effect, or name the side effect the club's self-reliance, with – effects into and out of it: a variable named as its opposite, which keeps R1 reinforcing and still matches shifting the burden. What stays the same is two balancing loops through the shortage, the slower one with its delay, and a reinforcing loop from the hired guides through the training.

AR 04 Two parks and one maintenance budget

Archetype: success to the successful



This is one defensible answer, not the only one. Yours can differ and still hold up: the lab's checks show whether it has the brief's structure.

The more visitors to the riverside park, the larger its share of the budget (+), and the larger that share, the more visitors to the riverside park (+): no – effect, so R1 is reinforcing. The more visitors to the hilltop park, the smaller the riverside park's share (–), and the larger that share, the fewer visitors to the hilltop park (–): two – effects, so R2 is reinforcing too. Two reinforcing loops sharing one variable match success to the successful: the park ahead draws the larger share, and the gap of a few hundred visitors in the first year widens every year after.

Why it works

- The split of the budget is one variable, so both loops pass through it
- R2 has two – effects, an even number, so it is reinforcing as drawn
- The two loops mirror each other across the share, one for each park
- The note names the first year's small gap and its widening

Step by step

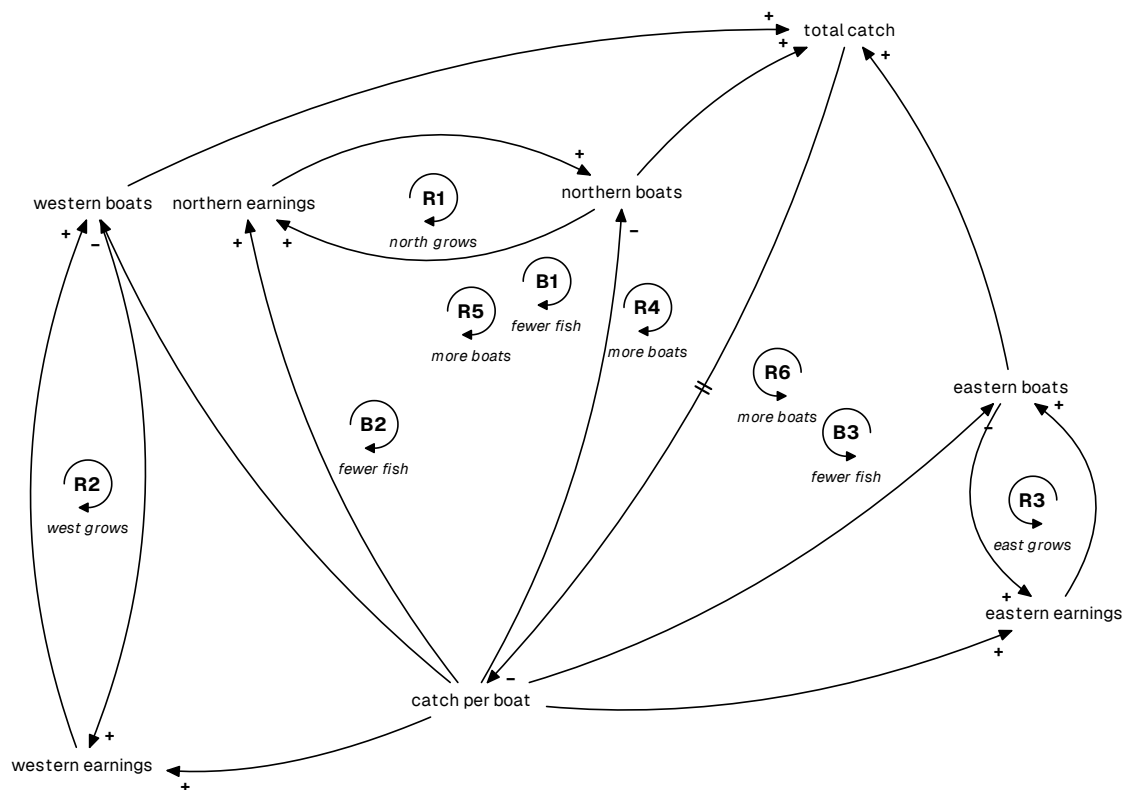
1. Share of the budget to the riverside park, drawn first: the council sets it each spring, and both parks' visitors depend on it.
2. Visitors to the riverside park, with a + effect each way to the share, closing R1, riverside ahead: the park ahead in the first year, so its loop comes first.
3. Visitors to the hilltop park, with a – effect each way to the share, closing R2, hilltop behind: the larger the riverside park's share, the less the hilltop park is mowed, cleaned and repaired.
4. The behavior note under the share, written once both loops are drawn: the gap it names is between the visitors R1 adds and those R2 takes away.
5. Success to the successful, declared last, once R2 holds the hilltop park back by the same split: R1 alone is one park's growth.

What another defensible answer might vary

Another defensible answer might draw the share as the hilltop park's share of the budget, with the polarity of each effect reversed: both loops stay reinforcing, and the match holds. Or it might draw each park's upkeep between the share and its visitors, as a chain of two effects. What stays the same is one variable for the split and two reinforcing loops through it.

AR 05 Three countries' fleets on one fishing ground

Archetype: tragedy of the commons



This is one defensible answer, not the only one. Yours can differ and still hold up: the lab's checks show whether it has the brief's structure.

The more northern boats, the more northern earnings (+), and the more northern earnings, the more northern boats (+): no – effect, so R1 is reinforcing, and R2 and R3 are the western and eastern fleets' loops. Each fleet's boats add to the total catch (+); the larger the total catch, the smaller the catch per boat, years later (–, with a delay); and the larger the catch per boat, the more each fleet earns (+): B1, B2 and B3 run through one fleet's boats and earnings each, with one – effect, so each is balancing. The smaller the catch per boat, the more boats each fleet sends (–): R4, R5 and R6 run from one fleet's boats through the total catch and the catch per boat, with two – effects, so each is reinforcing. Each pair of fleets matches tragedy of the commons, so the structure matches it three times, once for each pair, each with its delay.

Why it works

- One total catch and one catch per boat are shared by every fleet's balancing loop
- Each balancing loop's one – effect is the total catch's on the catch per boat; each loop back to a fleet's boats from the catch per boat adds a second, so it is reinforcing
- The delay sits on total catch → catch per boat, where the missing young fish take years to show
- Three fleets make three pairs, and each pair is one match of tragedy of the commons
- The fleets sit around the shared pair of variables, so no effect crosses another

Step by step

1. Northern boats and earnings, with a + effect each way, closing R1, north grows: the owners spend what they earn on more boats.

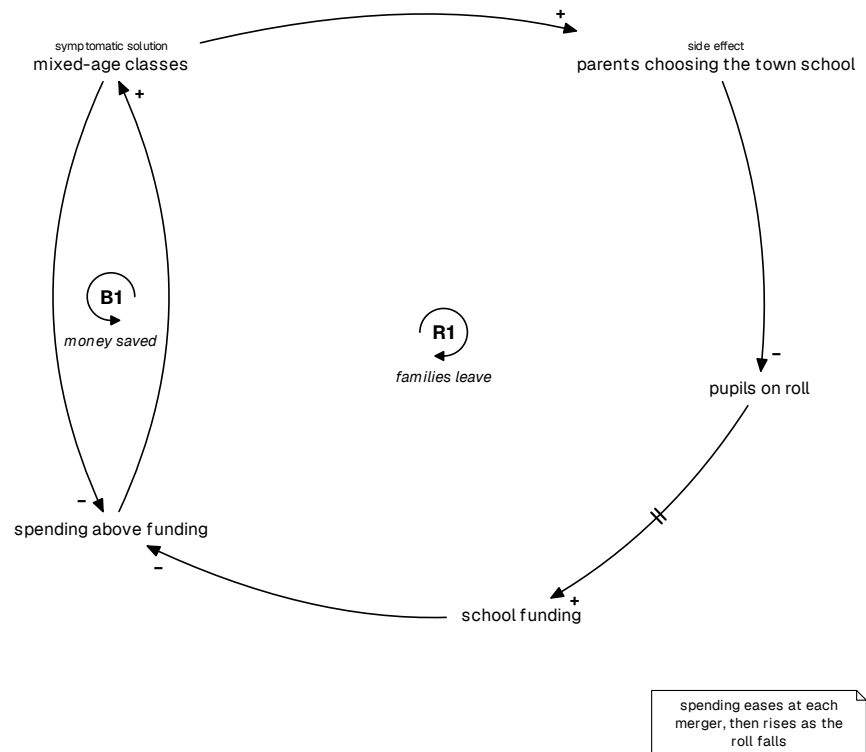
2. The western and eastern boats and earnings, closing R2, west grows, and R3, east grows: each fleet growing on its own until something the three share holds them back.
3. Total catch, with a + effect from each fleet's boats: the one place the three fleets' growth meets, drawn once.
4. Catch per boat, with a – effect from the total catch, delayed by years, and a + effect to each fleet's earnings, closing B1, B2 and B3, fewer fish.
5. A – effect from the catch per boat to each fleet's boats, closing R4, R5 and R6, more boats: drawn after the balancing loops, as a fleet sends more boats only once its catch per boat has fallen.
6. Tragedy of the commons, declared last: no one fleet's loops match it; two fleets' loops drawing on the one catch per boat do.

What another defensible answer might vary

Another defensible answer might draw the fish left to breed between the total catch and the catch per boat, as a chain of two effects with the delay on either, or name each fleet's earnings as its losses, with the polarity of each effect into and out of them reversed: every loop keeps its kind, and the three matches hold. What stays the same is one total catch fed by all three fleets, one catch per boat falling from it after a delay, and two reinforcing loops for each fleet.

CS 10 Kelsham Primary School: merging classes to balance the budget

Archetype: fixes that fail



This is one defensible answer, not the only one. Yours can differ and still hold up: the lab's checks show whether it has the brief's structure.

The more spending above funding, the more mixed-age classes (+), and the more mixed-age classes, the less spending above funding (-): one - effect, so B1 is balancing, and the saving comes at once. The more mixed-age classes, the more parents choosing the town school (+), the fewer pupils on roll (-), the less school funding a year later (+, with a delay), and the more spending above funding (-): R1 has two - effects, so it is reinforcing. Mixed-age classes are the symptomatic solution and parents choosing the town school the side effect; the declared archetype is fixes that fail, which the structure matches with its delay.

Why it works

- Both loops pass through spending above funding, the change the governors merge classes to undo
- One - effect makes the saving balancing; two make the families' leaving reinforcing
- The delay sits on pupils on roll → school funding: each October's count sets the next school year's funding
- Each role is written above its variable: the merged classes' and the parents' choice
- The note names the saving at each merger and the spending that comes back

Step by step

1. Spending above funding, drawn first: it is what the governors act on when they merge classes.
2. Mixed-age classes, the symptomatic solution, with a + effect from spending above funding and a - effect back, closing B1, money saved: merging Years 3 and 4 in 2023 saved £52,000 a year at once.
3. Parents choosing the town school, the side effect, then pupils on roll and school funding, with a + effect, a - effect, a + effect delayed by the October count and a - effect back to spending above funding, closing R1, families leave: drawn after B1, since the funding falls a year after the pupils leave.

4. The behavior note, written once both loops are drawn, since each half of it comes from one: spending eases at each merger, from B1, and rises as the roll falls, from R1.
5. Fixes that fail, declared last: until R1 is drawn, merging classes only saves money, and nothing fails.

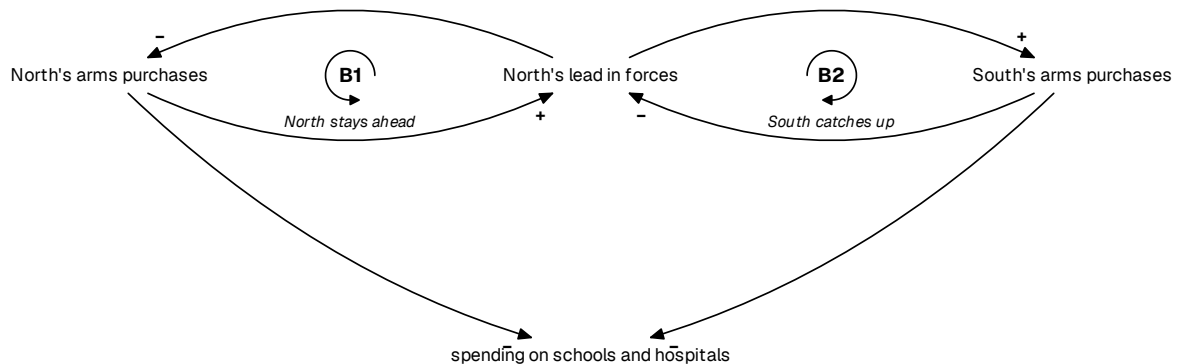
What another defensible answer might vary

Another defensible answer might draw the school's reserve in place of spending above funding, with the polarity of each effect into and out of it reversed: a variable named as its opposite, which keeps both loops' kinds and still matches fixes that fail. Or it might draw teachers between spending above funding and mixed-age classes, or put a second delay on parents choosing the town school → pupils on roll, since families move at the end of a school year. What stays the same is a balancing loop of saving and a reinforcing loop, through the side effect and a delay, that returns to spending above funding.

Chapter 11 · Diagnosing Tangled Situations

AR 06 An arms race between two neighboring countries

Archetype: escalation



This is one defensible answer, not the only one. Yours can differ and still hold up: the lab's checks show whether it has the brief's structure.

The more arms North buys, the larger North's lead in forces (+), and the larger that lead, the fewer arms North buys (-): one – effect, so B1 is balancing. The more arms South buys, the smaller North's lead (-), and the larger North's lead, the more arms South buys (+): B2 is balancing too. Traced as a figure 8 through both loops, each country's purchases lead to the other's: the spiral of escalation. Both countries' purchases lower the spending on schools and hospitals (-), which acts on neither loop. The declared archetype is escalation, which the structure matches; the same two loops also match eroding goals, since both archetypes are two balancing loops sharing one variable. What tells the two stories apart is what each loop changes: here each changes one country's arms, pushing the shared lead its own way; in eroding goals one loop changes what is achieved and the other lowers the target.

Why it works

- One variable, North's lead in forces, is read by both countries, so both loops pass through it
- Each loop has one – effect, so both are balancing
- The spending on schools and hospitals is reached from both countries' purchases and returns to neither loop
- The declaration names escalation, since both loops change arms and neither lowers a target

Step by step

1. North's lead in forces, drawn first: each country judges its safety by it before buying anything.
2. North's arms purchases, with a + effect to the lead and a – effect back, closing B1, North stays ahead: North buys until it is well ahead.
3. South's arms purchases, with a – effect to the lead and a + effect back, closing B2, South catches up: each of South's purchases shrinks the lead that North's loop restores.
4. Spending on schools and hospitals, with a – effect from each country's purchases, drawn after both loops: it comes out of the same budgets and changes no purchase.

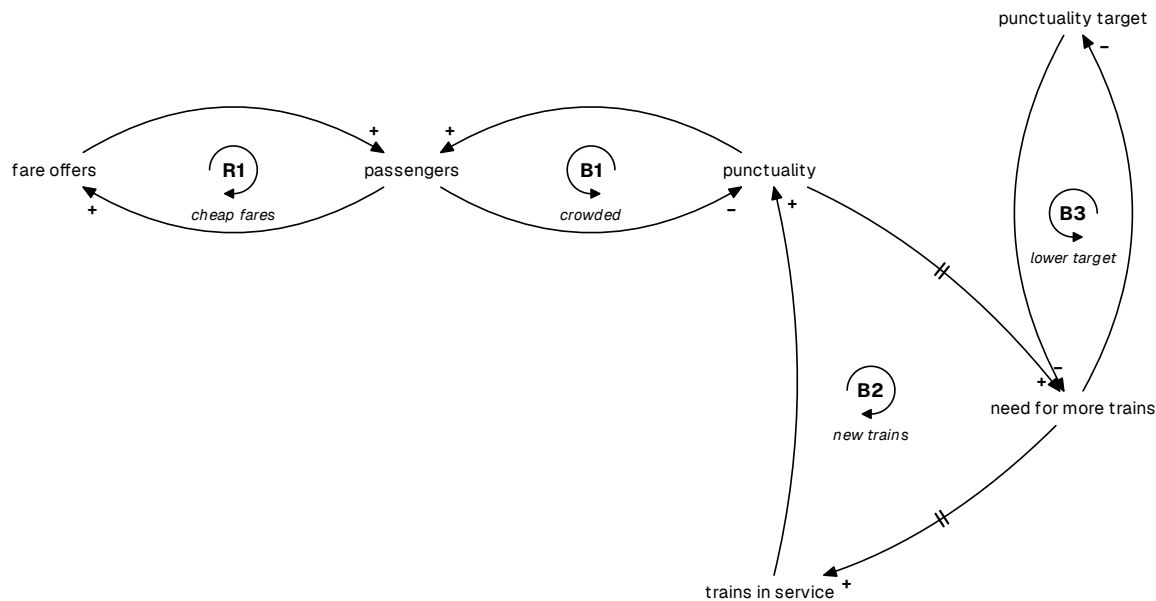
5. Escalation, declared last, once both countries' loops are drawn: with North's alone, there is no one to escalate against.

What another defensible answer might vary

Another defensible answer might name the comparison South's lead in forces, with the polarity of each effect into and out of it reversed: both loops stay balancing, and the match holds. Or it might draw a delay on each country's purchases, since arms take years to arrive. What stays the same is one comparison read by both countries, two balancing loops through it, and the spending on schools and hospitals outside both.

AR 07 A country's railways

Archetype: growth and underinvestment



This is one defensible answer, not the only one. Yours can differ and still hold up: the lab's checks show whether it has the brief's structure.

The more passengers, the more fare offers (+), and the more fare offers, the more passengers (+): no – effect, so R1 is reinforcing. The more passengers, the lower the punctuality (–), and the higher the punctuality, the more passengers (+): one – effect, so B1 is balancing. The lower the punctuality, the greater the need for more trains (–, with a delay); the greater the need, the more trains in service (+, with a delay); and the more trains in service, the higher the punctuality (+): B2 is balancing. The higher the target, the greater the need (+), and the greater the need, the lower the target (–): B3 is balancing. The declared archetype is growth and underinvestment, which the structure matches with its delay, and limits to growth sits within it: R1 held back by B1. B3 and B2 also match eroding goals, with the need for more trains as the gap: each time the target is lowered, the need it reads is smaller, and fewer trains are ordered.

Why it works

- R1, B1 and B2 meet at the passengers and the punctuality, as growth and underinvestment's three loops do
- One delay sits where the operator reads the need, the other where new trains arrive
- The punctuality target acts on the need for more trains, and B3 lowers it as the need grows
- Each loop's kind follows its count of – effects

Step by step

1. Passengers and fare offers, with a + effect each way, closing R1, cheap fares: the growth the operator starts from.
2. Punctuality, with a – effect from the passengers and a + effect back, closing B1, crowded: crowding holds the growth back before any train is ordered.
3. Need for more trains and trains in service, with a delay where the year's figures come in and another for the four years a train takes to build, closing B2, new trains.

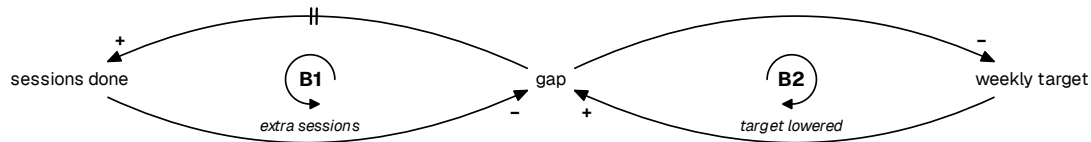
4. Punctuality target, with a + effect on the need and a – effect back, closing B3, lower target: drawn after B2, as the operator lowers the target only when the need is already large.
5. Growth and underinvestment, declared last: its template's three loops are R1, B1 and B2, and its delay is the four years of building, not the year of figures.

What another defensible answer might vary

Another defensible answer might draw the target's effect on the need through a gap, punctuality target → punctuality below the target → need for more trains, or name the punctuality as the lateness of trains, with the polarity of each effect into and out of it reversed: every loop keeps its kind, and the match holds. What stays the same is a reinforcing loop of passengers, two balancing loops meeting at the punctuality, two delays, and the target acting on the need.

AR 08 Knee exercises after an operation

Archetype: eroding goals



This is one defensible answer, not the only one. Yours can differ and still hold up: the lab's checks show whether it has the brief's structure.

The larger the gap, the more sessions done a week later (+, with a delay), and the more sessions done, the smaller the gap (–): one – effect, so B1 is balancing. The larger the gap, the lower the weekly target (–), and the higher the target, the larger the gap (+): B2 is balancing too. Both close the gap: B1 by raising the sessions done a week later, B2 by lowering the target as soon as it is reset. The declared archetype is eroding goals, which the structure matches with its delay. In the match, the weekly target and the sessions done are interchangeable: swapped, every loop keeps its kind, so the loops alone don't settle which is the target; only the target is set by Priya each Sunday.

Why it works

- The gap is a variable of its own, between the weekly target and the sessions done
- Each loop has one – effect, so both are balancing
- The delay sits on the gap's effect on the sessions done, where extra sessions wait for the next week
- B2 is named target lowered: the gap closes without more sessions

Step by step

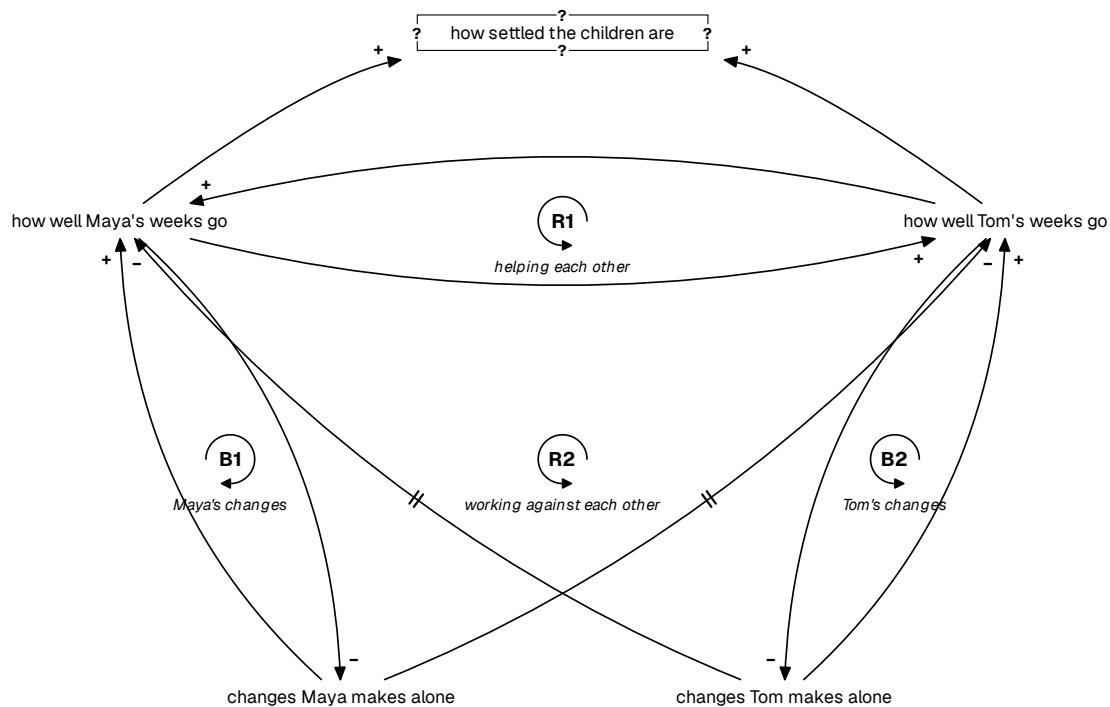
1. Weekly target, sessions done and the gap, with a + effect from the target and a – effect from the sessions: Priya's count each Sunday, before she acts on it.
2. A + effect from the gap to the sessions done, delayed by the week before extra sessions fit in, closing B1, extra sessions.
3. A – effect from the gap to the weekly target, closing B2, target lowered: drawn after B1, as Priya lowers her target only after a busy week when she falls short.
4. Eroding goals, declared last: B1 alone is a target worked toward, and B2's lowered target is what makes it erode.

What another defensible answer might vary

Another defensible answer might name the sessions done as the sessions skipped, with the polarity of each effect into and out of it reversed: both loops stay balancing, and the match holds. Or it might draw extra sessions planned between the gap and the sessions done, as a chain of two effects with the delay on either. What stays the same is one gap between the target and the sessions done, two balancing loops through it, and the delay on the loop through the sessions done.

AR 09 Two parents sharing care after a separation

Archetype: accidental adversaries



This is one defensible answer, not the only one. Yours can differ and still hold up: the lab's checks show whether it has the brief's structure.

The better Maya's weeks go, the better Tom's (+), and the better Tom's, the better Maya's (+): R1 is reinforcing. The worse Maya's weeks go, the more changes she makes alone (-), and the more changes, the better her weeks go (+): one - effect, so B1 is balancing, and B2 is Tom's. Each parent's changes make the other's weeks worse, after a delay (-): R2 runs from Maya's weeks through her changes, Tom's weeks and his changes back to Maya's weeks, with four - effects, so it is reinforcing. The declared archetype is accidental adversaries, which the structure matches: each parent's changes ease their own weeks at once and, weeks later, the other's get worse, which brings on the other's changes. How settled the children are, reached from both parents' weeks, is the leverage point: it is the one measure both parents see, and a change that eases one home and unsettles the other shows in it.

Why it works

- R1, the help each parent gives the other, and R2, their changes working against each other, both pass through both parents' weeks
- B1 and B2 are each parent's changes, easing their own weeks
- The delays sit on the effects from each parent's changes to the other's weeks, where the children carry them between homes
- The leverage point is how settled the children are, a measure both parents see

Step by step

1. How well Maya's and Tom's weeks go, with a + effect each way, closing R1, helping each other: the lifts to football and the shared homework rules the situation starts with.

2. Changes Maya makes alone, with a – effect from her weeks and a + effect back, closing B1, Maya's changes: a new bedtime that eases her own week.
3. Changes Tom makes alone, with the same two effects on his side, closing B2, Tom's changes: a swapped weekend that eases his.
4. A – effect from each parent's changes to the other's weeks, each delayed by the week or two before the children bring them over, closing R2, working against each other.
5. How settled the children are, the leverage point, with a + effect from each parent's weeks: drawn last of the variables, as it is reached from both homes and acts on neither loop.
6. Accidental adversaries, declared last, once R2, the loop the delayed effects close, is drawn.

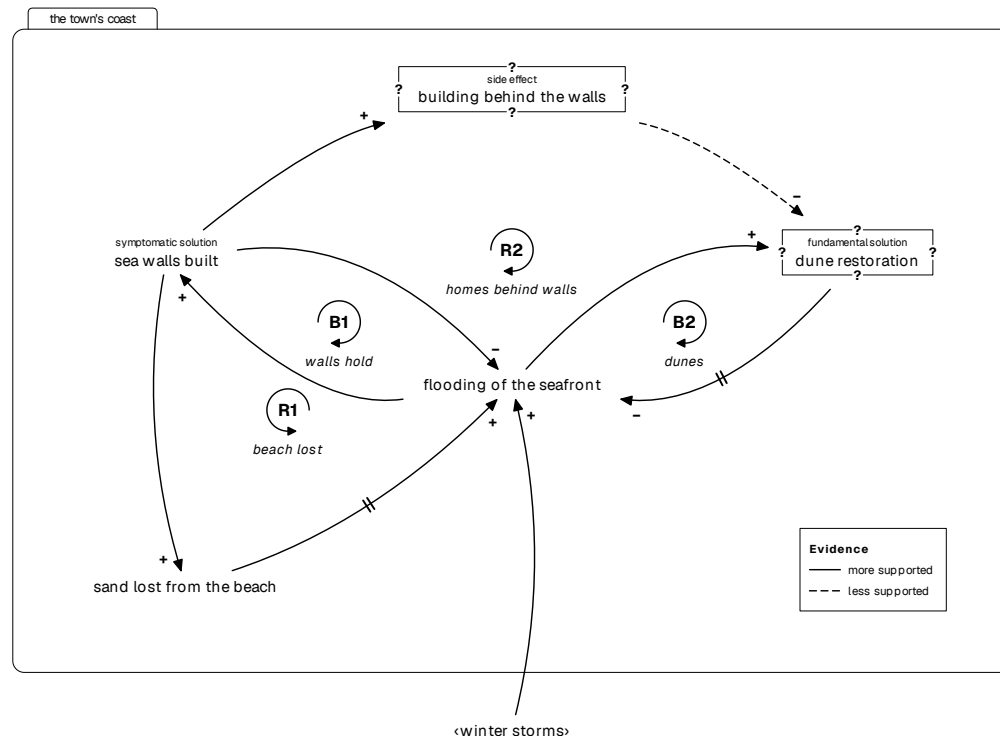
What another defensible answer might vary

Another defensible answer might draw the two further loops the structure holds, Maya's changes worsening Tom's weeks and so the help he gives her (and Tom's likewise), each reinforcing, or name each parent's weeks as how hard they go, with the polarity of each effect into and out of them reversed: every loop keeps its kind, and the match holds. It might also mark the leverage point on a shared calendar of both homes' rules, drawn as a variable acting on both parents' changes. What stays the same is the help between the two parents' weeks, each parent's changes easing their own weeks, those changes reaching the other's weeks after a delay, and one leverage point.

AR 10 A coastal town and its sea walls

Archetype: fixes that fail

Archetype: shifting the burden



This is one defensible answer, not the only one. Yours can differ and still hold up: the lab's checks show whether it has the brief's structure.

Winter storms, outside the town's coast, raise the flooding of the seafront (+). The more flooding, the more sea walls built (+), and the more walls, the less flooding (-): one - effect, so B1 is balancing. The more walls, the more sand lost from the beach (+), and the more sand lost, the more flooding, years later (+, with a delay): R1 runs from the flooding through the walls and the sand back to the flooding with no - effect, so it is reinforcing. The more flooding, the more dune restoration (+), and the more restoration, the less flooding, after a delay (-): B2 is balancing. The more walls, the more building behind them (+), and the more building, the less dune restoration (-, coded as a hypothesis): R2 runs from the flooding through the walls, the building and the restoration back to the flooding, with two - effects, so it is reinforcing. B1 and R1 match fixes that fail, with its delay; B1, B2 and R2 match shifting the burden, with its delay. The two archetypes are coupled through the sea walls built and the flooding of the seafront: each wall relieves the flooding at once, loses sand from the beach, and makes the restoration that would last for decades costlier.

Why it works

- The sea walls built are one variable, the symptomatic solution in both archetypes, which share it and the flooding
- The delays sit where the lost sand brings flooding back and where restored dunes lower it, years after each change
- The building's effect on dune restoration is dashed, and the legend shows the coding
- The winter storms act on the flooding from outside the town's coast, and nothing inside acts on them

- Leverage, ranked first: dune restoration, the fundamental solution, which lowers the flooding without losing sand from the beach; its delay of years means it starts long before the flooding it prevents
- Ranked second: building behind the walls, whose limit keeps dune restoration affordable and weakens R2
- The sea walls built are no leverage point: each wall adds to both R1 and R2

Step by step

1. The town's coast as a boundary, the flooding of the seafront inside it and winter storms outside, with a + effect: the situation opens with the storms that flood the town.
2. Sea walls built, the symptomatic solution, with a + effect from the flooding and a – effect back, closing B1, walls hold: a wall stops the sea at once.
3. Sand lost from the beach, with a + effect from the walls and a + effect to the flooding, delayed by the years before the sea reaches the walls with more force, closing R1, beach lost.
4. Dune restoration, the fundamental solution and a leverage point, with a + effect from the flooding and a – effect back, delayed by the years new dunes take to grow, closing B2, dunes.
5. Building behind the walls, the side effect and the other leverage point, with a + effect from the walls and a dashed – effect, the engineers' hypothesis, to the dune restoration, closing R2, homes behind walls, with the legend for the dashed line.
6. Fixes that fail and shifting the burden, declared last: B1 and R1 matched fixes that fail from step 3, and shifting the burden matched only once B2 and R2 were drawn.

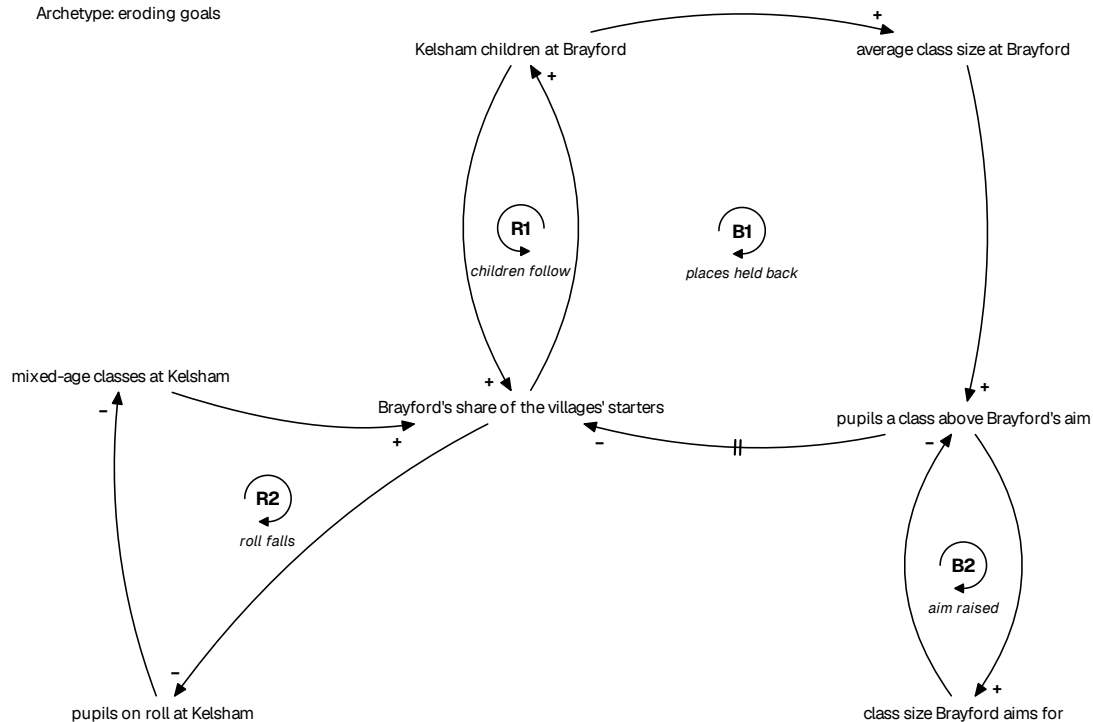
What another defensible answer might vary

Another defensible answer might name the sand lost as the sand on the beach, with the polarity of each effect into and out of it reversed: every loop keeps its kind, and both matches hold. Or it might draw rising sea level beside the winter storms, a second external driver acting on the flooding, or mark the sand lost from the beach as the side effect of fixes that fail. What stays the same is one variable for the sea walls built, shared by both archetypes, the two delays, the building's effect on the restoration coded as a hypothesis, and a ranking written beside the diagram, not drawn.

CS 11 Kelsham Primary School: the town school's pull and its rising class size

Archetype: success to the successful

Archetype: eroding goals



This is one defensible answer, not the only one. Yours can differ and still hold up: the lab's checks show whether it has the brief's structure.

Brayford's share of the villages' starters sits on three of the four loops. The larger the share, the more Kelsham children at Brayford (+), and the more of them, the larger the share (+): R1 is reinforcing. The larger the share, the fewer pupils on roll at Kelsham (-), the more mixed-age classes there (-), and the larger the share (+): two – effects, so R2 is reinforcing too. R1 and R2 match success to the successful, the share as the allocation: Brayford gains what Kelsham loses. The more Kelsham children at Brayford, the larger its average class size (+) and the more pupils a class above its aim (+), which holds places back the next September (-, with a delay): one – effect, so B1 is balancing. The more pupils above the aim, the higher the aim (+), and the higher the aim, the fewer pupils above it (-): B2 is balancing. B1 and B2 match eroding goals with its delay. The two archetypes are coupled through the share and the Kelsham children at Brayford: each rise in the aim closes the gap before B1 holds places back, so the share goes on growing and the pupils on roll at Kelsham go on falling.

Why it works

- Brayford's share of the villages' starters is one variable: the allocation in success to the successful, and on B1's path from the gap to the class size
- R2 has two – effects, an even number, so it is reinforcing
- The gap is a variable of its own, between Brayford's average class size and its aim, named by the pupils above the aim
- The delay sits on the gap's effect on the share: places are held back only from the next September
- B2 is named aim raised: the gap closes without a place held back
- Each rise in the aim lets Brayford take more of the villages' starters, so the pupils on roll at Kelsham fall faster

Step by step

1. Brayford's share of the villages' starters, drawn first: three of the four loops pass through it.
2. Kelsham children at Brayford, with a + effect from the share and a + effect back, closing R1, children follow: brothers, sisters and friends follow the children already there.
3. Pupils on roll at Kelsham and mixed-age classes at Kelsham, with a – effect from the share, a – effect between them and a + effect back to the share, closing R2, roll falls: Brayford's gain seen from Kelsham's side.
4. Average class size at Brayford, with a + effect from the Kelsham children there, then the class size Brayford aims for and the gap, with a + effect from the class size and a – effect from the aim: Brayford compares the two before it acts.
5. A – effect from the gap to the share, delayed until the next September, when places are held back, closing B1, places held back.
6. A + effect from the gap to the aim, closing B2, aim raised: drawn after B1, since the governors raise the aim only after a year above it.
7. Success to the successful and eroding goals, declared last: the first matched from step 3, the second only once B2 was drawn, coupled through the share and the Kelsham children at Brayford.

What another defensible answer might vary

Another defensible answer might name the gap the places left in Brayford's classes, with the polarity of each effect into and out of it reversed: both balancing loops keep their kinds, and the match holds. Or it might draw Kelsham's share of the villages' starters in place of Brayford's, which reverses the polarity of each effect into and out of it and leaves all four loops' kinds as they are. What stays the same is one share on both archetypes, two reinforcing loops through it, two balancing loops through the gap, and the delay on the places held back.

Chapter 12 · Choosing the Diagram

CD 01 Which diagram?

What does Ines draw, or write, to answer her question?

- a** A system context map

Yes. Whom the team deals with is the parties outside one boundary, the team's, and what passes each way is the exchanges, each a named one-way line between a party and the boundary. Callouts from the police and rescue reports to them are two exchanges, one each way.

- b** No diagram: a list

Not quite. A list names the five parties but not what passes each way: the police, on a list, carry neither the callouts they send nor the rescue reports they receive.

- c** A causal loop diagram

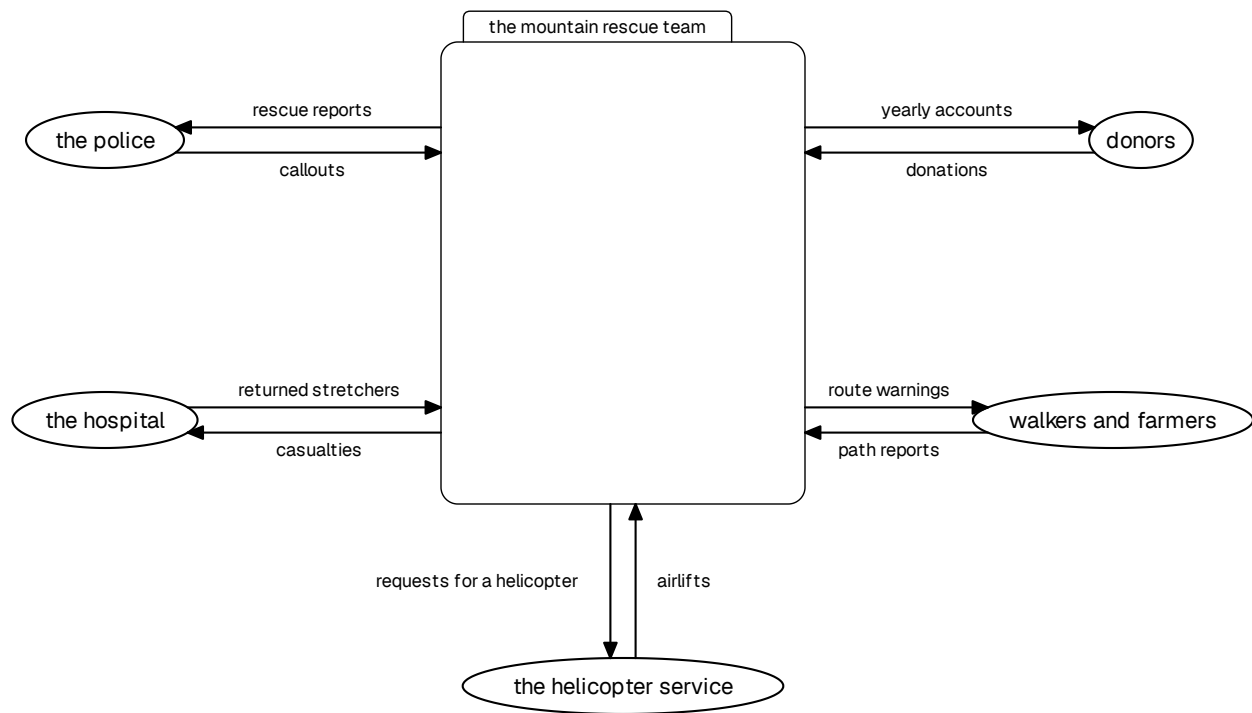
Not quite. A causal loop diagram shows how a change in one variable produces a change in another, and where those changes come back around in loops. Ines is after who sends what to whom, not what changes what.

- d** An influence map

Not quite. An influence map shows what bears on one outcome, ranked. Ines names no outcome: she is after the parties and what passes between them and the team.

- e** A stock & flow diagram

Not quite. A stock & flow diagram shows what accumulates and what fills and drains it: money in the team's account, filled by donations. The police, the hospital and the walkers have no place in it.

CD 01 A mountain rescue team

This is one defensible answer, not the only one. Yours can differ and still hold up: the lab's checks show whether it has the brief's structure.

One boundary, the mountain rescue team, with five parties outside it: the police, the hospital, the helicopter service, donors, and walkers and farmers. Ten named exchanges cross it, one each way with every party: callouts in and rescue reports out; casualties out and returned stretchers in; requests for a helicopter out and airlifts in; donations in and yearly accounts out; path reports in and route warnings out.

Why it works

- One boundary, named for the team, so the volunteers are the system and none of them is drawn as a party
- The helicopter service outside the boundary: the team requests its helicopter and doesn't run it
- Walkers and farmers drawn as one party, since they send the same reports and read the same warnings
- Each exchange names one thing, so callouts and rescue reports are two lines, not one with two arrowheads
- Every party both gives and receives, which a list of the five leaves out

Step by step

1. The mountain rescue team as the boundary, drawn alone: every exchange Ines asks about crosses it.
2. The police, with callouts in and rescue reports out: every rescue starts with their callout.
3. The hospital, with casualties out and returned stretchers in: where each carry down the hill ends.
4. The helicopter service, with requests for a helicopter out and airlifts in: called only for a serious injury or a long carry.
5. Donors, with donations in and yearly accounts out: the money behind the rescues, which reaches the team apart from any callout.
6. Walkers and farmers, with path reports in and route warnings out: exchanges that run between rescues, before any call.

What another defensible answer might vary

Another defensible answer might draw walkers and farmers as two parties, or leave out the returned stretchers. The casualties the helicopter service flies to the hospital pass between two parties outside the team, so no exchange of the team's carries them. What stays the same is one named boundary, the parties outside it, and one thing per exchange.

CD 02 Which diagram?**What does Mateus draw, or write, to answer his question?**

- a** A causal loop diagram

Not quite. A causal loop diagram gives every effect a + or – and shows the loops they close. Mateus can give a + or – only to the salary's effect: drawn there, the other effects would carry guesses as findings, and no loop runs through his wish to move.

- b** No diagram: a list

Not quite. A list names the salary, Ilse's chances, the hours with his parents and the team he would lead, but not that the music schools reach his wish to move only through Ilse's chances, or his father's health only through the hours he helps.

- c** An influence map

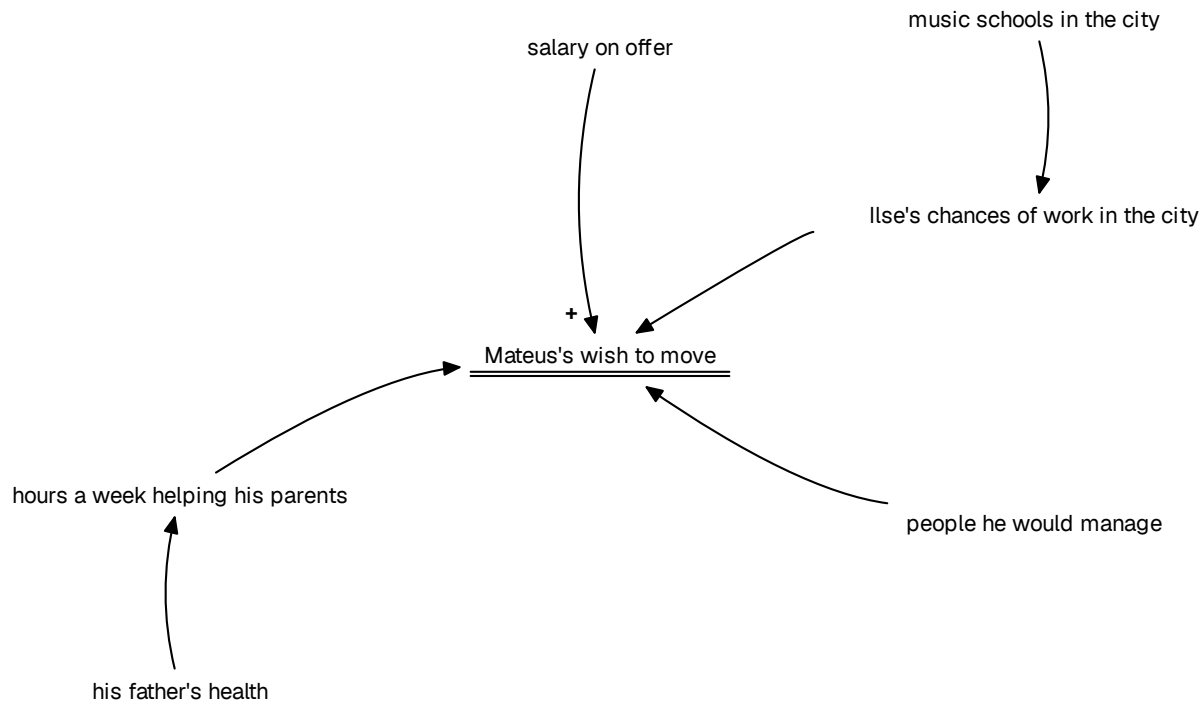
Yes. What bears on his wish to move is one central outcome and the variables that act on it. That he can't yet say which way most of them push makes each an influence claim, with no + or –; the salary's claim alone is upgraded, with a +.

- d** A system context map

Not quite. A system context map shows the parties outside a boundary and what passes each way: Mateus's household, his parents, the new employer. Who sends what to whom leaves out what draws him to the city and what holds him at home.

- e** A stock & flow diagram

Not quite. A stock & flow diagram shows what accumulates and what fills and drains it: Mateus's savings, filled faster by the higher salary. His question is what bears on one wish, and a wish fills from no flow.

CD 02 Moving to another city for a job

This is one defensible answer, not the only one. Yours can differ and still hold up: the lab's checks show whether it has the brief's structure.

Mateus's wish to move as the central outcome, with four direct influences: the salary on offer, Ilse's chances of work in the city, the hours a week he spends helping his parents, and the people he would manage. The salary's claim is a causal claim with a +; the other three are influence claims, since he can't yet say which way they push. Music schools in the city reach his wish through Ilse's chances, and his father's health through the hours he helps, each an influence claim too.

Why it works

- One central outcome, a quantity: how strong his wish to move is
- One causal claim, the salary's, the only direction Mateus can say
- The hours with his parents and the team he would lead left as influence claims: each could push either way
- Music schools and his father's health drawn to the variables they act on, not to his wish

Step by step

1. Mateus's wish to move, the central outcome, drawn alone: his question names it, and every claim drawn after ends at it or reaches it.
2. Ilse's chances of work in the city, the hours a week helping his parents and the people he would manage, each with an influence claim on his wish: plain lines, since an influence claim is where every claim starts.
3. Music schools in the city and his father's health, each with an influence claim on the direct influence it acts through, drawn once those are there.
4. The salary on offer, its claim upgraded to a causal claim with a +, drawn last of the claims: a third above what he earns now, it is the pull Mateus is sure of.

What another defensible answer might vary

Another defensible answer might add rent in the city, or draw Ilse's wish to move as a variable of its own between her chances and his wish. What stays the same is one central outcome, Mateus's wish to move, one causal claim, the salary's, and every other claim an influence claim.

CD 03 Which diagram?**What does Halima draw, or write, to answer her question?**

- a** A causal loop diagram

Not quite. A causal loop diagram shows that more emissions bring more carbon dioxide in the air, a + effect, but not that the carbon dioxide accumulates. Read as an effect, steady emissions give steady carbon dioxide, which is wrong here.

- b** A stock & flow diagram

Yes. Whether the carbon dioxide in the air stops rising is a question about how an amount changes over time: it is a stock, filled by emissions and drained by what the oceans and vegetation on land absorb. Holding emissions steady fixes the inflow, not the stock: with about 11 in and about 5 out each year, the stock goes on rising.

- c** No diagram: a sentence

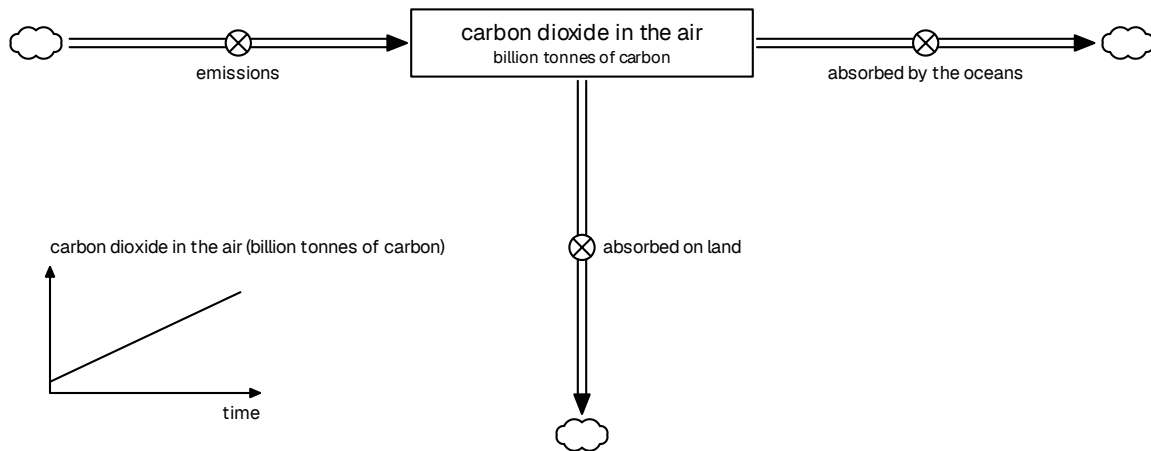
Not quite. The sentence is what Halima writes once the stock is drawn: while emissions exceed what the oceans and vegetation on land absorb, the carbon dioxide in the air rises. Without the stock, most adults Sterman and Booth Sweeney tested expected it to hold steady once emissions did.

- d** An influence map

Not quite. An influence map shows what bears on one outcome, ranked. What bears on the carbon dioxide in the air is known here: emissions and what is absorbed. Halima's question is how much of it there is as the years pass.

- e** A feedback control diagram

Not quite. A feedback control diagram shows a target, a measured value and a correction that closes the gap between them. Nothing here holds the carbon dioxide in the air to a target; Halima's question is what steady emissions do to it.

CD 03 Carbon dioxide in the atmosphere

This is one defensible answer, not the only one. Yours can differ and still hold up: the lab's checks show whether it has the brief's structure.

One stock, carbon dioxide in the air, counted in billion tonnes of carbon, filled from a cloud by emissions and drained to two clouds by what the oceans and vegetation on land absorb. The time unit is a year, so each flow is counted in billion tonnes of carbon a year. Held steady, emissions of about 11 still exceed the about 5 absorbed, so the stock gains about 6 a year: it goes on rising, and stops rising only when emissions fall to what is absorbed.

Why it works

- The carbon dioxide in the air is the stock: an amount there at any moment, changed only by its flows
- Emissions held steady fix the inflow, not the stock, which rises while the inflow exceeds the outflows
- One outflow for the oceans and one for vegetation on land, each to a cloud outside what the model holds
- The graph rises: Halima's answer is no

Step by step

1. Carbon dioxide in the air, the stock, counted in billion tonnes of carbon, drawn first: Halima asks how much of it there will be as the years pass.
2. Emissions, the inflow, from a cloud: about 11 billion tonnes of carbon a year, which Halima supposes will hold steady.
3. Absorbed by the oceans and absorbed on land, two outflows to clouds, about 3 and 2 billion tonnes a year: drawn after the inflow, to be set against it.
4. The behavior-over-time graph of the stock, drawn last, since its shape follows from the flows: a straight line rising while they hold as they are.

What another defensible answer might vary

Another defensible answer might draw one outflow for what the oceans and vegetation on land absorb together, or a graph that rises and flattens, taking the oceans and vegetation to absorb more as the carbon dioxide in the air rises. What stays the same is one stock, emissions flowing in, at least one outflow, the time unit a year, and a graph that rises.

CD 04 Which diagram?

What does their father draw, or write, to answer his question?

- a** A causal loop diagram

Not quite. A causal loop diagram shows the two reinforcing loops through Noor's share of the turns, and no archetype. The same loops drawn there and opened in an archetype lab, with the archetype they match declared, are the diagram that answers whether others have seen this story.

- b** An influence map

Not quite. An influence map shows what bears on one outcome, its directions left open until measured. The father's rule fixes every direction here, and the effects close two loops, which no one declares on an influence map.

- c** A system archetype

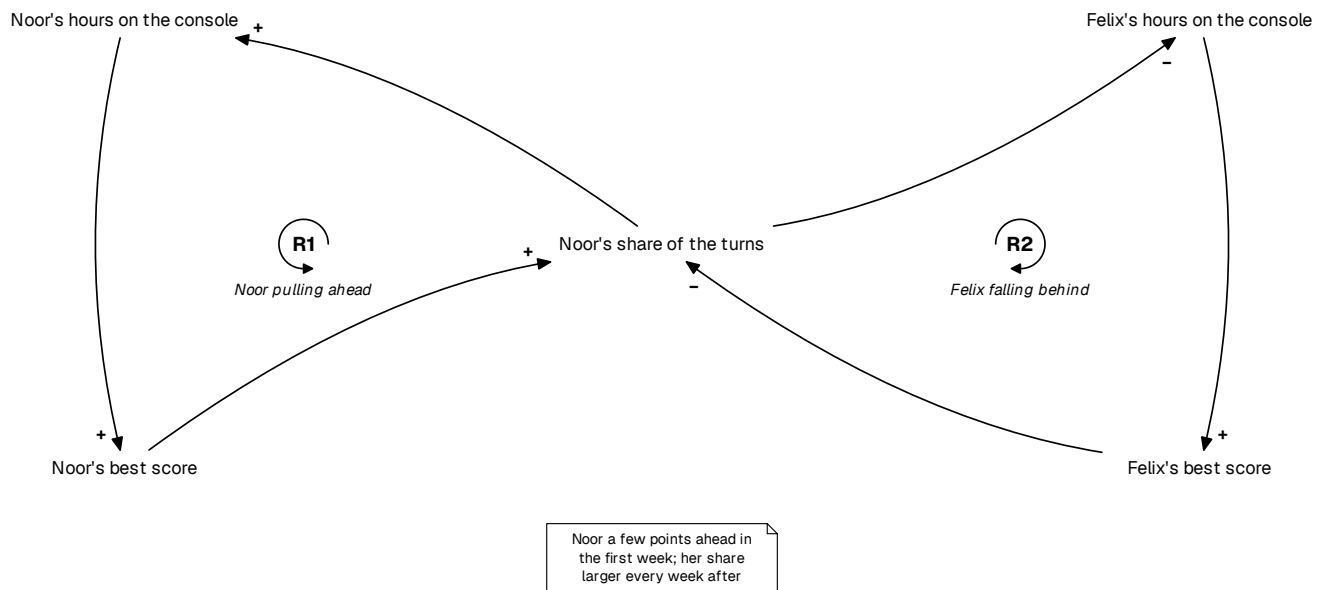
Yes. The father asks after a recurring loop structure with a name: a story others have seen, and how it usually runs. The two reinforcing loops, one through each child's hours, share Noor's share of the turns, and that structure matches an archetype, declared in one line; how the split usually runs is that archetype's known course.

- d** A stock & flow diagram

Not quite. A stock & flow diagram shows what accumulates and what fills it, such as each child's hours played. The father's question is whether the two loops through the split are a story with a name, which no stock or flow carries.

- e** No diagram: a sentence

Not quite. A sentence states the father's rule and Noor's lead in the first week. Whether the story recurs elsewhere is read from its loops: two reinforcing loops through one split, matched to an archetype.

CD 04 Two siblings and one games console

Archetype: success to the successful

This is one defensible answer, not the only one. Yours can differ and still hold up: the lab's checks show whether it has the brief's structure.

Noor's share of the turns sits on both loops. In R1, a larger share gives Noor more hours on the console (+), more hours a higher best score (+), and a higher score a larger share (+). In R2, a larger share for Noor gives Felix fewer hours (-), fewer hours a lower best score (+), and a higher score for Felix a smaller share for Noor (-): two - effects, so R2 is reinforcing too. The father declares success to the successful, which the structure matches with the share as the allocation: which child ends ahead depends on who started ahead as much as on what each could do with an equal share, so Noor's lead of a few points grows every week.

Why it works

- The father's rule is one variable, Noor's share of the turns, so both loops pass through it
- Each child's hours on the console sit between the share and that child's score, a chain the archetype's match allows
- R2 has two - effects, an even number, so it is reinforcing
- The declaration names the archetype in one line, which a causal loop diagram of the same loops lacks
- The note names Noor's first-week lead and its growth

Step by step

1. Noor's share of the turns, drawn first: it is the father's rule, set each Sunday, that both children's play depends on.
2. Noor's hours on the console and her best score, with three + effects from the share through both and back to it, closing R1, Noor pulling ahead: the child the rule favors from the first week.
3. Felix's hours and best score, with a - effect from the share, a + effect to his score and a - effect back, closing R2, Felix falling behind: the father's rule seen from Felix's side.
4. The behavior note under the share, written once both loops are drawn: the week-by-week course the father asks about.

5. Success to the successful, declared last in one line: the name of the story the father asks after, given once the loops it names are drawn.

What another defensible answer might vary

Another defensible answer might draw Felix's share of the turns instead, which changes the polarity of every effect into and out of it and leaves both loops reinforcing, or draw each score straight to and from the share, leaving out the hours. What stays the same is one variable for the split, two reinforcing loops through it, and success to the successful declared.

CD 05 Which diagram?

What does Ruth draw, or write, to answer her question?

a A stock & flow diagram

Not quite. A stock & flow diagram shows the water in the stretch, the water from the hill lake and the water drawn by the locks: the same stock and flows a feedback control diagram of the stretch holds, without its roles. With no target, gap or corrective action written, it shows neither the depth Ruth holds the stretch to nor that her morning reading arrives late.

b A causal loop diagram

Not quite. A causal loop diagram shows the balancing loop through the depth and the water let in, but not what accumulates, nor which variable is the target and which the reading. Ruth's question turns on both.

c A system context map

Not quite. A system context map shows the parties outside the canal, such as boaters and the lake's owners, and what passes each way. It leaves out how the depth is held, and where that falls short.

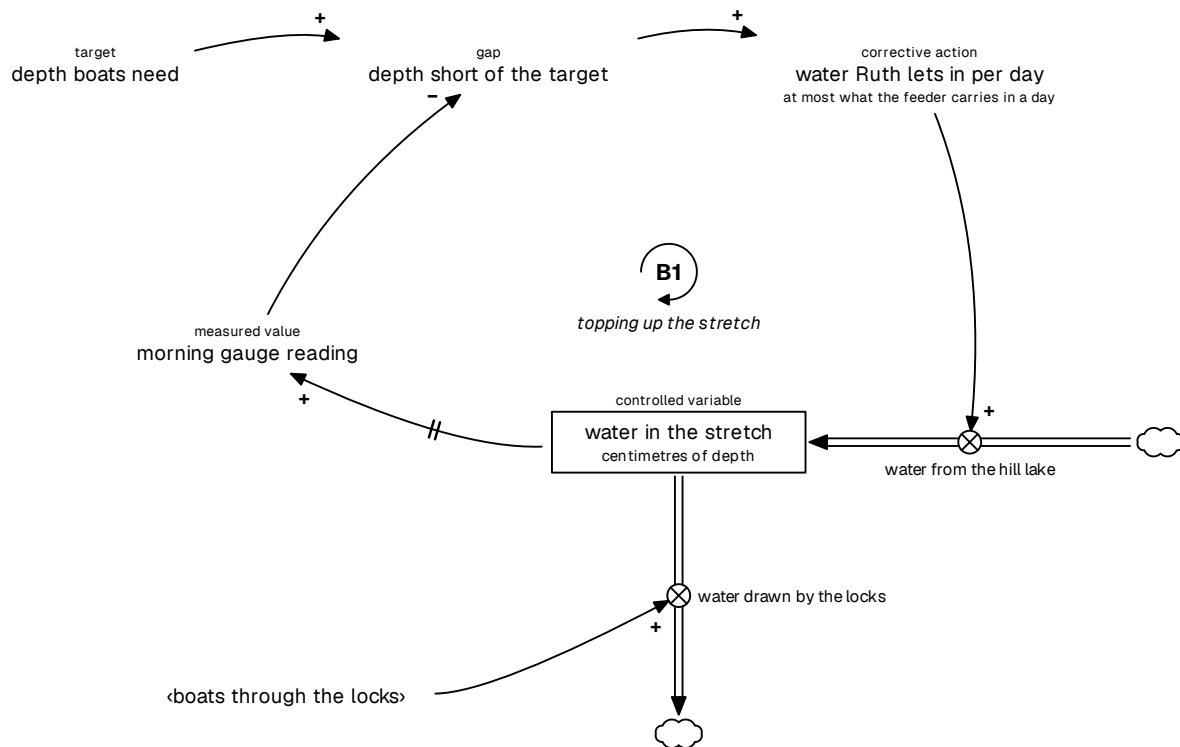
d A feedback control diagram

Yes. Ruth holds the stretch at the depth boats need: that depth is a target, and her morning reading a measured value, up to a day behind the water in the stretch. The gap between them sets the water she lets in, which the feeder limits: one control loop, its roles written over the stretch's stock and flows.

e No diagram: a sentence

Not quite. A sentence states Ruth's rule: the further the depth reads below what boats need, the more water she lets in. Where that falls short, between one morning's reading and the next and at the feeder's limit, shows on the loop drawn with its delay and its limit.

CD 05 A canal through a dry summer



This is one defensible answer, not the only one. Yours can differ and still hold up: the lab's checks show whether it has the brief's structure.

One stock, water in the stretch, counted in centimetres of depth: the controlled variable. Water from the hill lake fills it from a cloud and water drawn by the locks drains it to a cloud, both in centimetres a day. Depth short of the target is the gap, read from the depth boats need (+) and the morning gauge reading (-); it sets the water Ruth lets in per day (+), at most what the feeder carries in a day, whose signal reaches the valve of water from the hill lake (+). The reading follows the water in the stretch with a delay, one reading a morning. B1 has one - step, so it is balancing. Boats through the locks act at the valve of water drawn by the locks. A busy day of boats lowers the stretch between readings, and when the locks draw more in a day than the feeder carries, the stretch falls however large the gap.

Why it works

- The target, the depth boats need, has no signal into it: Ruth sets it
- The once-a-morning reading is a delay between the water in the stretch and the reading: the return path
- What the feeder carries in a day is written as the limit beneath the water Ruth lets in
- The boats act on the controlled variable at the valve of water drawn by the locks, never on the gap
- The one - step, from the reading to the gap, makes the loop balancing

Step by step

1. Water in the stretch, the controlled variable, a stock counted in centimetres of depth: the amount Ruth keeps deep enough for boats, drawn first.
2. Morning gauge reading, the measured value, with a + signal from the water in the stretch, delayed: water drawn at noon shows on the board only the next morning.

3. Depth boats need, the target, and depth short of the target, the gap, with a + signal from the target and a – signal from the reading: what Ruth works out each morning.
4. Water Ruth lets in per day, the corrective action, limited by what the feeder carries in a day, with a + signal from the gap and a + signal to the valve of water from the hill lake, the inflow, closing B1, topping up the stretch.
5. Boats through the locks, an external driver, with a + signal to the valve of water drawn by the locks, the outflow: drawn last, as what Ruth's loop has to keep up with, dozens of boats on a busy day.

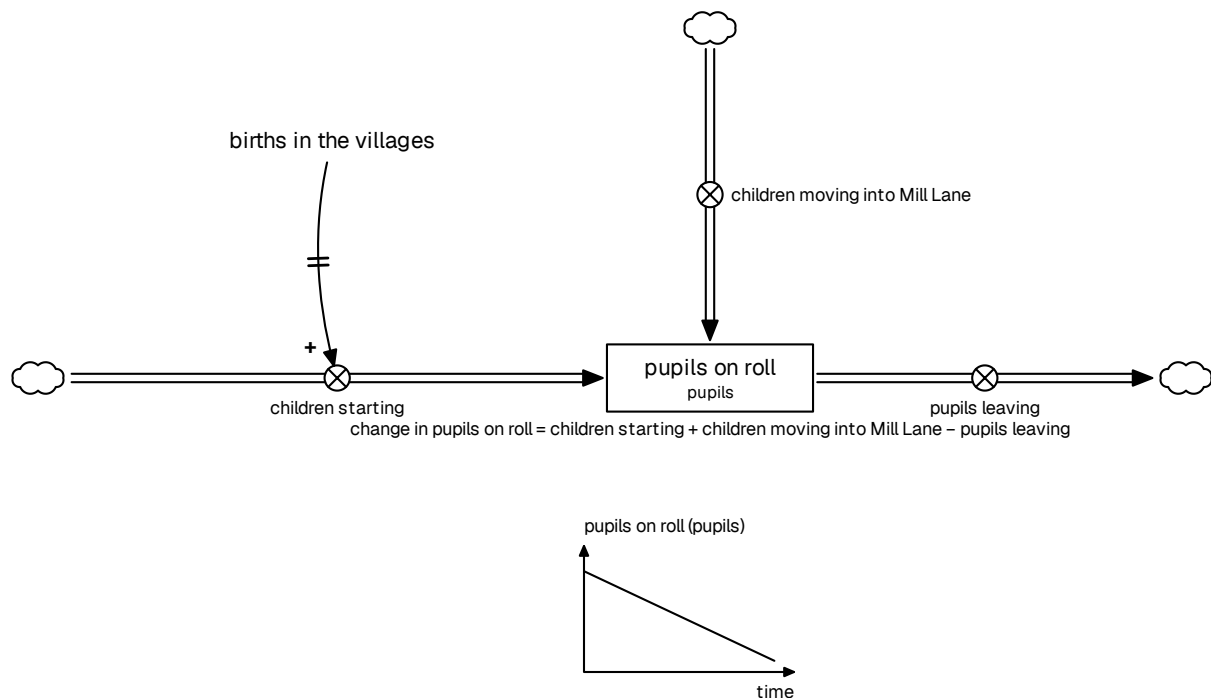
What another defensible answer might vary

Another defensible answer might count the water in cubic metres, with the target and the reading in cubic metres too, or add evaporation as a second outflow in a dry summer. What stays the same is one stock with water from the hill lake flowing in and water drawn by the locks flowing out, one balancing control loop with the target off it, a delay on the morning reading, and the feeder's limit on the water Ruth lets in.

CS 12 Which diagram?

What does David Brennan draw, or write, to answer his question?

- a A causal loop diagram
Not quite. In a causal loop diagram, homes lived in at Mill Lane → pupils on roll is a + effect, which reads as more homes, more pupils for good. The homes bring their 15 children once, as they are first lived in; whether the roll goes on falling afterwards turns on what fills it and what drains it each year.
- b A stock & flow diagram
Yes. Whether the roll goes on falling is a question about how an amount changes over the years: the pupils on roll are a stock, filled by the children starting and the children moving into Mill Lane, and drained by the pupils leaving. The inflow from Mill Lane stops once the last home is lived in, and the children starting, fewer than the births four years before, are fewer each year than the pupils leaving.
- c An influence map
Not quite. An influence map shows what bears on one outcome, ranked, its directions left open. Here every direction is known: the births, the homes and the pupils leaving each fill or drain the roll. David Brennan's question is how many pupils are left as the years pass.
- d A feedback control diagram
Not quite. A feedback control diagram shows a target, a measured value and a correction that closes the gap between them. Nothing here holds the roll to a target; the question is where the roll goes once the homes are lived in.
- e No diagram: a sentence
Not quite. The sentence is what David Brennan writes once the roll is drawn as a stock: after 2029 only the children starting fill it, and fewer start than leave each year, so it goes on falling. Without the stock, Tom Hale's reading, that the homes turn the roll around, goes unchecked.

CS 12 Kelsham Primary School: the council's question

This is one defensible answer, not the only one. Yours can differ and still hold up: the lab's checks show whether it has the brief's structure.

One stock, pupils on roll, counted in pupils, a year at a time. It is filled from clouds by the children starting each September, set by the births in the villages four years before through a delayed signal, and by the children moving into Mill Lane, 15 in all from 2027 to 2029; it is drained to a cloud by the pupils leaving. Once the last home is lived in, the inflow from Mill Lane stops, and the children starting, fewer than the 11 or 12 born each year since 2023, are fewer than the pupils leaving, 16 in the year to October 2026: the stock goes on falling. David Brennan's answer is yes: the homes slow the fall while they fill, and don't turn the roll around.

Why it works

- The pupils on roll are the stock: an amount there each October, changed only by its flows
- The Mill Lane homes fill the roll only while they are first lived in, 15 children in all, and not after
- The births set the children starting four years later through a delayed signal, so the starters to 2029 are known now
- The graph falls: once the homes are lived in, fewer children start than pupils leave

Step by step

1. Pupils on roll, the stock, counted in pupils with its stock equation, drawn first: David Brennan asks how many there will be as the years pass.
2. Children starting, an inflow from a cloud: each September's starters, 9 in the year to October 2026.
3. Births in the villages, with a + signal to the children starting, delayed by the four years before a child starts: the births to 2025 set the starters to 2029.

4. Children moving into Mill Lane, a second inflow from a cloud: 15 in all, as the 60 homes are first lived in from 2027 to 2029.
5. Pupils leaving, the outflow to a cloud, drawn after both inflows to be set against them: 16 in the year to October 2026.
6. The behavior-over-time graph of the stock, drawn last, since its direction follows from the flows: falling once the last home is lived in.

What another defensible answer might vary

Another defensible answer might draw the homes lived in at Mill Lane as an auxiliary with a signal to the children moving into Mill Lane, or the pupils leaving as two outflows, for secondary school and for Brayford Primary School. Or its graph might fall and flatten, as smaller years reach Year 6 and fewer pupils leave. What stays the same is one stock, two inflows, one outflow, the births' delay, and a graph that falls once the homes are lived in.