

Part III — Accumulation

Stocks Inside Feedback

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

Stock & flow diagrams

Part III · Accumulation · Chapter 7 of 12 · the second of two chapters on stock & flow diagrams

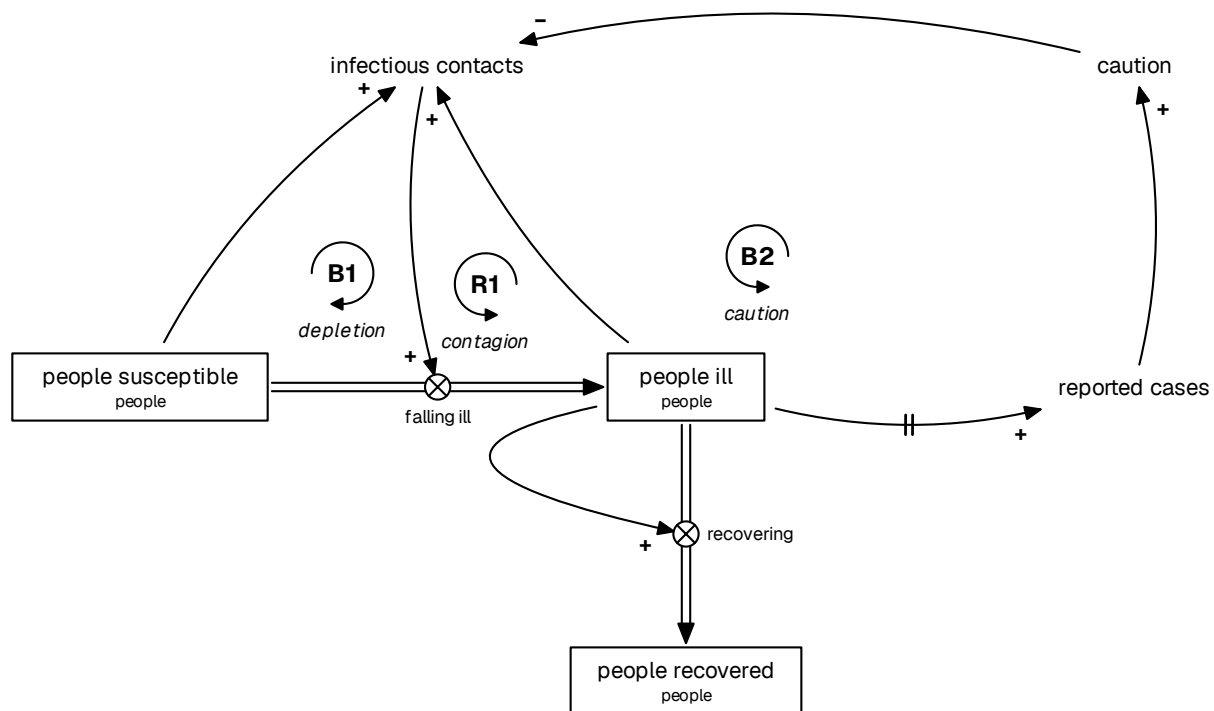
Where do things wait on their way through a system? In stocks, between the flows that fill and drain them. A stock & flow diagram with loops shows which loops pass through each stock, where material waits along a chain of stocks, and which delays hold material and which hold news of it.

A flu season in a region

A new strain of flu reaches a region of a million people, none of whom has had it. Each day people who are ill meet people who have never had it, and some of those catch it. Each person who falls ill is ill for about a week, then recovers and doesn't catch this strain again that season.

Reported cases reach the news a week after people fall ill. As the reports rise, people stay home and keep apart, and fewer fall ill.

The number of people ill rises for weeks, peaks and falls away. When the season ends, some people have never caught it.



What the notation expresses

Loops through stocks

A loop through a stock is a loop

thinking-in-diagrams.aryehnielsen.com/feedback/loops-that-amplify-loops-that-correct/#loops whose path runs along one of the stock's flows: a signal from the stock reaches the flow's valve, directly or through auxiliaries, and the flow changes the stock. The parity rule

thinking-in-diagrams.aryehnielsen.com/feedback/loops-that-amplify-loops-that-correct/#the-parity-rule counts the flow as one step: + from the flow into the stock it fills, – from the flow out of the stock it drains.

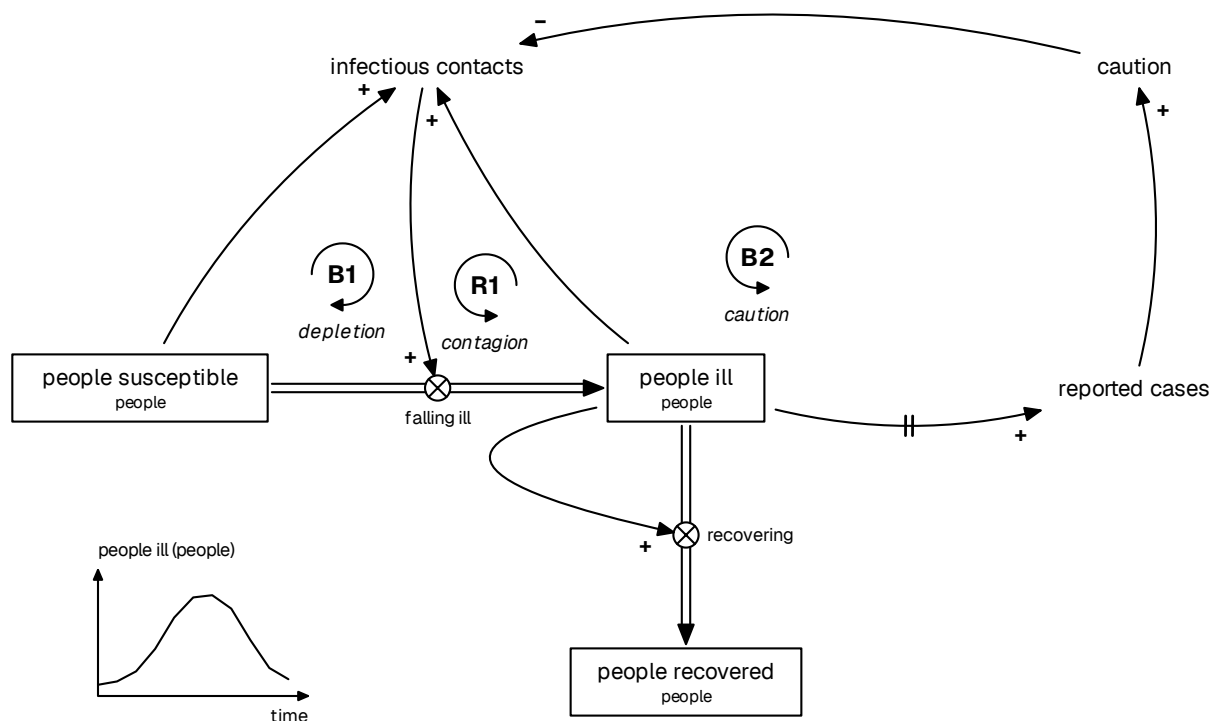
Infectious contacts are meetings between someone ill and someone susceptible, so they rise with both stocks.

Three loops run through *falling ill*:

- **R1, contagion:** people ill → infectious contacts → falling ill, which fills people ill. No – step: reinforcing.
- **B1, depletion:** people susceptible → infectious contacts → falling ill, which drains people susceptible. One – step: balancing.
- **B2, caution:** people ill → reported cases → caution → infectious contacts (–) → falling ill, which fills people ill. One – step: balancing.

Falling ill counts + in R1 and – in B1, since it fills one stock and drains the other.

Loop dominance thinking-in-diagrams.aryehnielsen.com/feedback/delays-drivers-and-competing-loops/#loop-dominance shifts as stocks fill and empty. Early in the season nearly everyone is susceptible, R1 dominates, and people ill grows exponentially. As people susceptible empties, each person ill meets fewer people who can catch flu; B1 dominates, falling ill drops below recovering, and people ill falls.



Conservation

Falling ill and *recovering* are transfers thinking-in-diagrams.aryehnielsen.com/accumulation/what-accumulates/#transfers, and the diagram has no cloud, so everyone who leaves one stock arrives in the next. The three stock equations,

change in people susceptible = - falling ill

change in people ill = falling ill - recovering

change in people recovered = recovering

add up to zero: the three stocks always total the region's million people.

Births, deaths and moves are left out. Drawn in, each would run from a source or to a sink, and people would cross the region's boundary thinking-in-diagrams.aryehnielsen.com/feedback/delays-drivers-and-competing-loops/#boundaries only along those flows. An external driver

thinking-in-diagrams.aryehnielsen.com/feedback/delays-drivers-and-competing-loops/#external-drivers reaches a stock through a signal to an auxiliary or a valve, never to the stock: if school holidays cut contacts, *school holidays* → *infectious contacts* is -.

Evidence coding thinking-in-diagrams.aryehnielsen.com/feedback/delays-drivers-and-competing-loops/#evidence-coding marks signals only. A flow is never dashed: that people move from susceptible to ill isn't in question, only how fast, which the signals into its valve set.

Aging chains

An **aging chain** is a row of stocks joined by transfers, through which material passes in order: people susceptible, then ill, then recovered.

The time material spends in a stock is a delay. Someone who falls ill on a Monday is counted in people ill until about the next Monday, so a rise in falling ill shows in recovering about a week later, on average. *People ill* → *recovering* is +: with each person ill for about a week, about a seventh of those ill recover each day. *Recovering* carries no delay: the stock holds the week, and a delay on the flow would count it twice.

Material and signal delays

A delay in a stock & flow diagram, the two strokes of chapter 4's delays

thinking-in-diagrams.aryehnielsen.com/feedback/loops-that-amplify-loops-that-correct/#delays, sits on a flow or on a signal.

A **material delay**, on a flow, holds material in transit, in neither stock: grain at sea between a port and a mill. A **signal delay**, on a signal, holds news: the people are already ill, and the reading of how many arrives late. *People ill* → *reported cases* carries a signal delay of a week.

Caution is set by reported cases, a reading of people ill a week old, so after people ill peaks, reported cases and caution go on rising for about a week, and caution is highest once *fewer* people are ill.

CHECK YOUR UNDERSTANDING

An office orders printer paper by the box. A box arrives five days after it is ordered, and the office manager counts the boxes in the cupboard only on Fridays, then orders from that count. Which of these is a signal delay?

- a** the five days between ordering a box and its arrival
- b** the days between a box leaving the cupboard and the Friday count
- c** the time a box spends in the cupboard before it is used

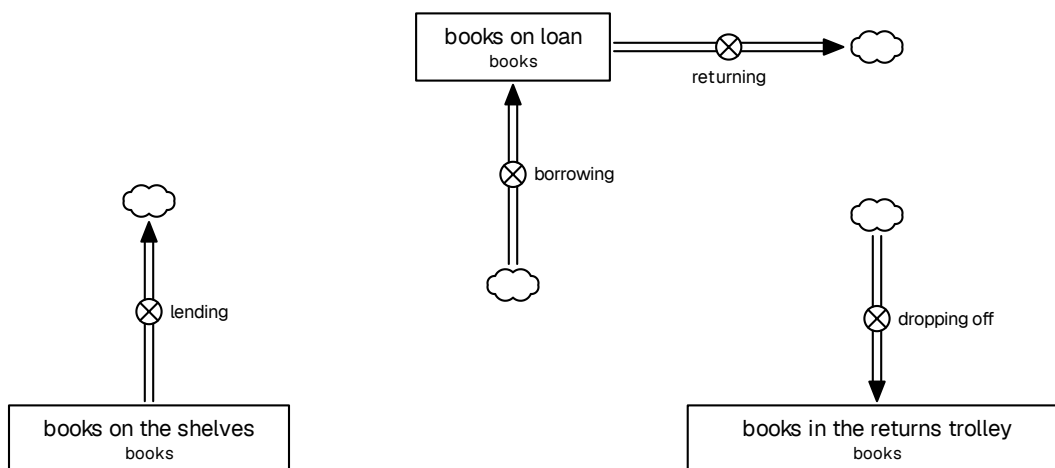
Feedback: Answers, chapter 7

Capacity limits

A stock's capacity is the most it can hold. As the stock nears it, the flow into it slows sharply: a nonlinear effect thinking-in-diagrams.aryehnielsen.com/feedback/delays-drivers-and-competing-loops/#nonlinear-effects on a signal from the stock to its own inflow, its threshold an amount the stock holds. If the flu filled the region's hospital beds, *people in hospital* → *admissions* would be – and nonlinear: weak while beds are free, strong as the last ones fill.

The bad diagram

What's wrong with this diagram of a town library's books, lent from the shelves, returned to a trolley and reshelfed?

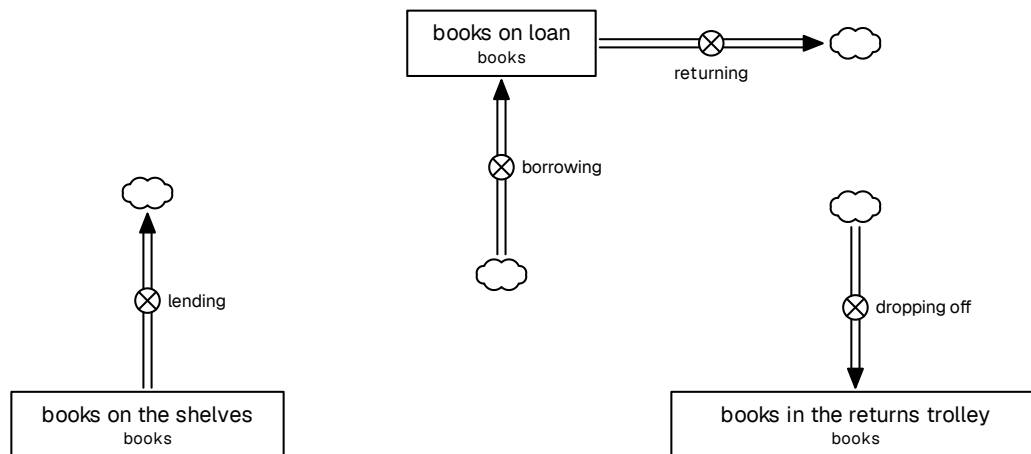
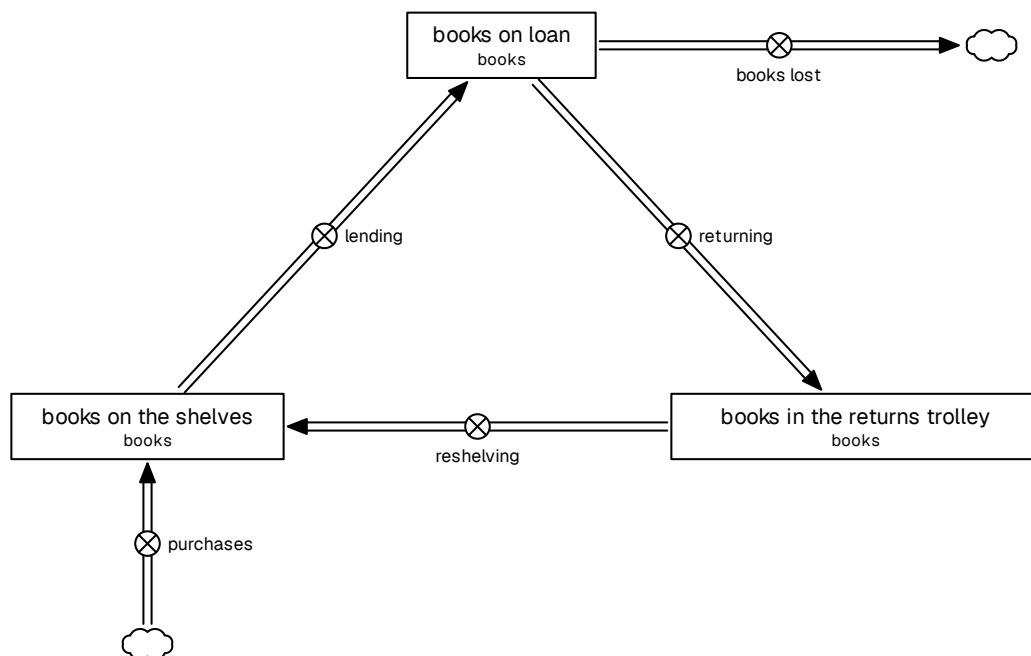


The books on the shelves, on loan and in the returns trolley are three stocks, but lending runs from the shelves to a cloud, borrowing from a cloud into the books on loan, returning to a cloud and dropping off from a cloud. Between each stage and the next the same books leave the model and come back into it, so the three stocks' total can rise or fall with no book bought or lost. The lab's check for at least three transfers reports:

| No transfers. Brief: at least 3. A transfer runs from one stock straight into another, with no cloud between them.

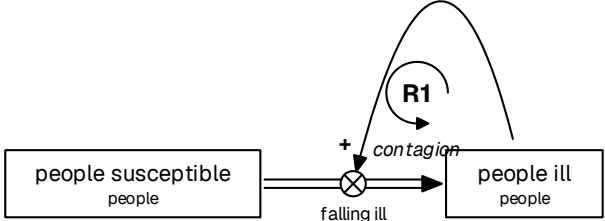
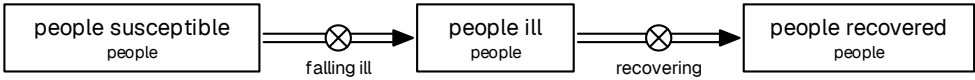
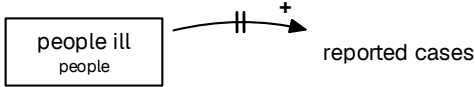
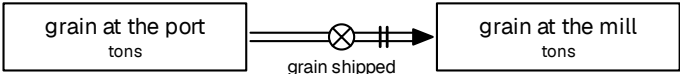
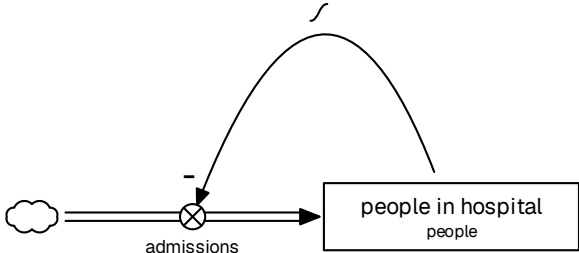
The corrected diagram

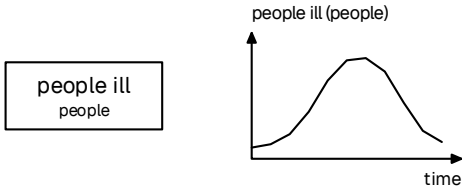
Corrected, lending, returning and reshelving are transfers around the three stocks; purchases arrive from a source and lost books leave to a sink, so each book is counted in one stock from the day it is bought until it is lost.

Bad diagram**Corrected diagram**

Labels unchanged. Flows: 3 added, 2 removed, lending now ends at books on loan instead of a cloud, returning now ends at books in the returns trolley instead of a cloud.

Notation moves

Notation move	When	What it shows	Example
Declare a loop through a flow	A signal from a stock reaches the valve of one of its own flows	Which loops change the stock, and through which flow	R1 <i>contagion</i> , through <i>falling ill</i>
			
Chain stocks with transfers	Material passes through stages in order	Where it waits, with none lost between stages	<i>people susceptible</i> → <i>people ill</i> → <i>people recovered</i>
			
Mark a signal delay	A reading arrives well after what it reads	News running behind a stock	<i>people ill</i> → <i>reported cases</i>
			
Mark a material delay	Material is in transit between stocks	Material in neither stock	grain shipped to a mill
			
Mark a nonlinear signal from a stock to its inflow	A stock nears the most it can hold	Where the capacity lies	<i>people in hospital</i> → <i>admissions</i>
			

Notation move	When	What it shows	Example
Graph a stock in a loop		The shape the shifts in dominance produce	<i>people ill</i> , overshoot and collapse
			

Common misreading

Reading a stock's graph as the shape of its inflow, the stock highest when the inflow is fastest, is the correlation heuristic (Cronin, Gonzalez and Sterman, 2009). Falling ill peaks first. At its peak more people still fall ill each day than recover, so people ill goes on rising; it peaks later, on the day falling ill has dropped to equal recovering.

Shown graphs of people entering and leaving a department store each minute, 96 percent of 173 graduate students in a business simulation course at MIT found the minute the most people entered, and 44 percent the minute the most people were *in* the store; 29 percent chose the minute of the largest net flow into the store.

The strongest objection

Without equations and simulation, a stock & flow diagram is a causal loop diagram with boxes: when loops trade dominance, and how far a stock overshoots, depend on numbers the diagram doesn't hold. Homer and Oliva (2001), answering Coyle (2000), argue that simulation lets a modeler draw behavioral inferences reliably "in a way that is rarely possible with maps alone".

A behavior-over-time graph drawn from the structure is a hypothesis until the model is simulated or the system measured: the graph of people ill shows an overshoot and collapse, not how high it peaks or in which week.

Units and conservation are checked on the drawing, before any number. The lab's checks catch a transfer between stocks in different units, books that vanish between the shelves and the loans, and a signal drawn into a stock; a causal loop diagram has no mark they could catch.

Check your understanding

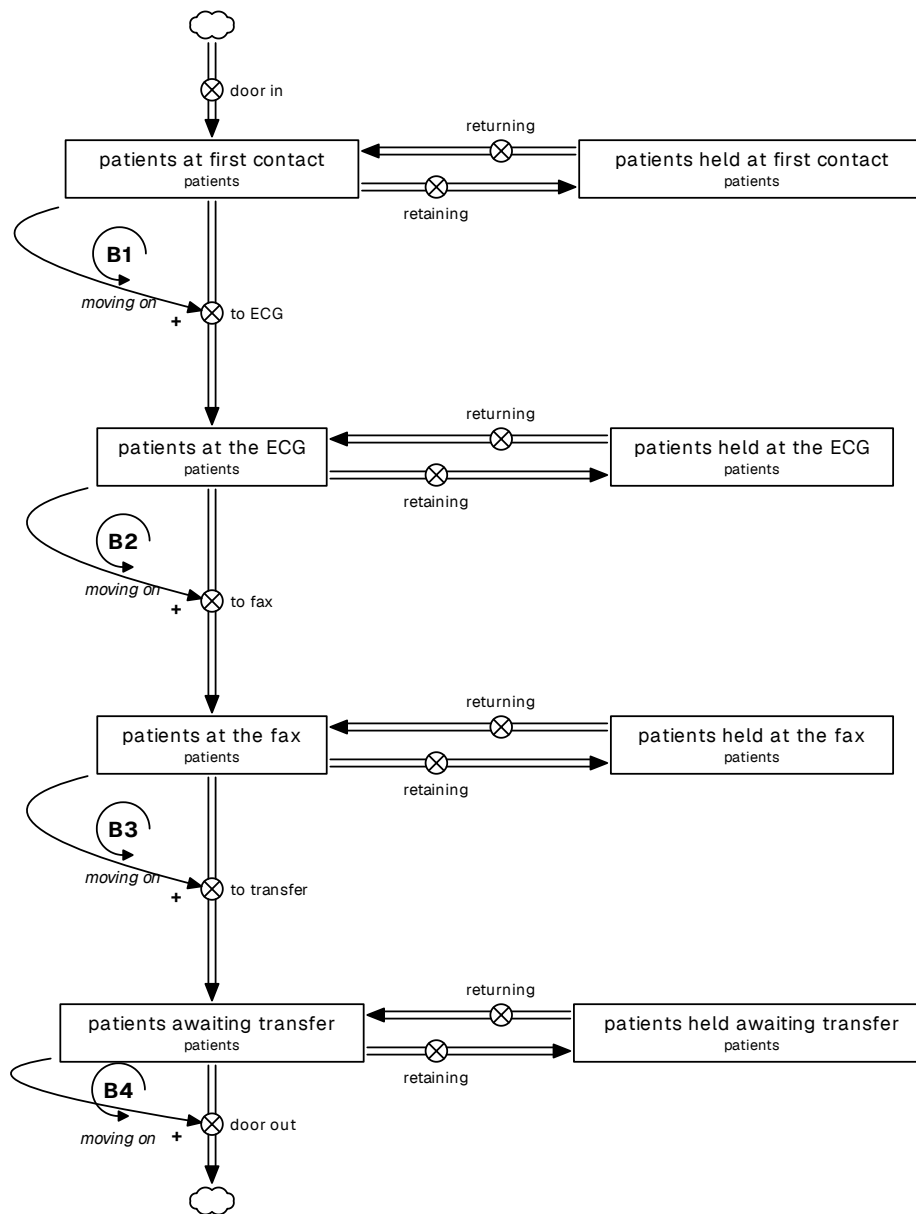
CHECK YOUR UNDERSTANDING

Skiers join the queue for a chairlift at 10 a minute at 8:30, at 60 a minute at 9:30, and at 10 a minute again by 11:00. The lift carries 30 skiers a minute all morning. When is the queue longest?

- a** at 9:30, when skiers join fastest
- b** after 9:30, when joining has fallen back to 30 a minute
- c** at 11:00, when joining is slowest

Feedback: Answers, chapter 7

Waits for heart attack care, redrawn



Redrawn from Luciano de Andrade, Catherine Lynch, Elias Carvalho, Clarissa Garcia Rodrigues, João Ricardo Nickenig Vissoci, Guttenberg Ferreira Passos, Ricardo Pietrobon, Oscar Kenji Nihei and Maria Dalva de Barros Carvalho, "System Dynamics Modeling in the Evaluation of Delays of Care in ST-Segment Elevation Myocardial Infarction Patients within a Tiered Health System", PLOS ONE 9(7): e103577 (2014) doi.org/10.1371/journal.pone.0103577, Figure 4. CC BY 4.0 creativecommons.org/licenses/by/4.0/.

Its four stages, first medical contact (FMC), ECG and diagnosis (ECG), the ECG sent by fax to the PCI center, where the blocked artery is opened, and its reply (TXF), and the wait for transfer there (TWT), named for the patients at each; each Retained stock named for the patients held there, and its retain and back flows renamed retaining and returning; each output named for where its patients go, the last door out; its auxiliaries and their signals left out; its B1 to B4, each labeled inside a stage's path of retaining and returning, which carries no signal, each drawn as the loop through the signal from its stage's patients to their outflow, which it draws, and named moving on; the chain drawn downward.

QUESTION 1 OF 3

A patient reaches the first hospital at two o'clock and leaves for the PCI center at four. Where in the diagram are those two hours spent?

- a In the flows, since a flow is the patient moving from one stage to the next.
- b In the loops B1 to B4, since each loop keeps patients until they move on.
- c In the stocks: at each stage in turn, and in a held stock wherever the patient is held.

QUESTION 2 OF 3

B2 runs from patients at the ECG to the valve of to fax, the flow that drains them. What does B2 do to patients at the ECG?

- a The more patients at the ECG, the faster they leave for the fax, so a rise in that stock comes back against itself.
- b It holds the patients' wait at the guidelines' optimal time, the value the authors compare each wait with.
- c It makes patients at the ECG grow, since more of them send more on to the fax.

QUESTION 3 OF 3

At the fax stage, 76% of the patients the authors followed waited longer than the optimal time. Where does a patient's wait at that stage appear in the diagram?

- a As a material delay on to transfer, for patients between the two stages.
- b As the time a patient spends in patients at the fax and in patients held at the fax, with no delay drawn.
- c As a signal delay on patients at the fax → to transfer, since the reply from the PCI center arrives late.

Feedback: Answers, chapter 7

Exercises

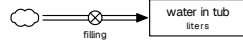
Passing the checks means meeting the brief, not being right.

SF 06 Players of an online game

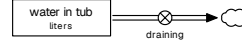
Your palette



stock



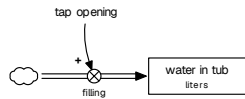
flow



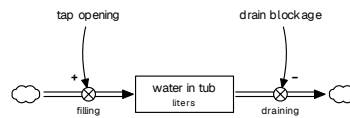
cloud

tap opening

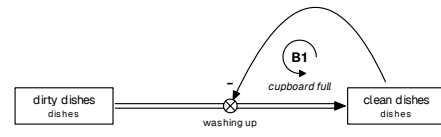
auxiliary



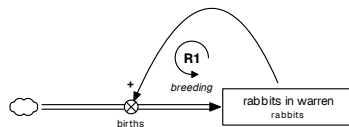
signal



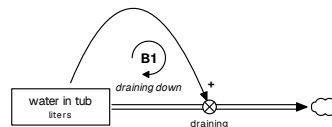
polarity



loop



reinforcing loop



balancing loop

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.

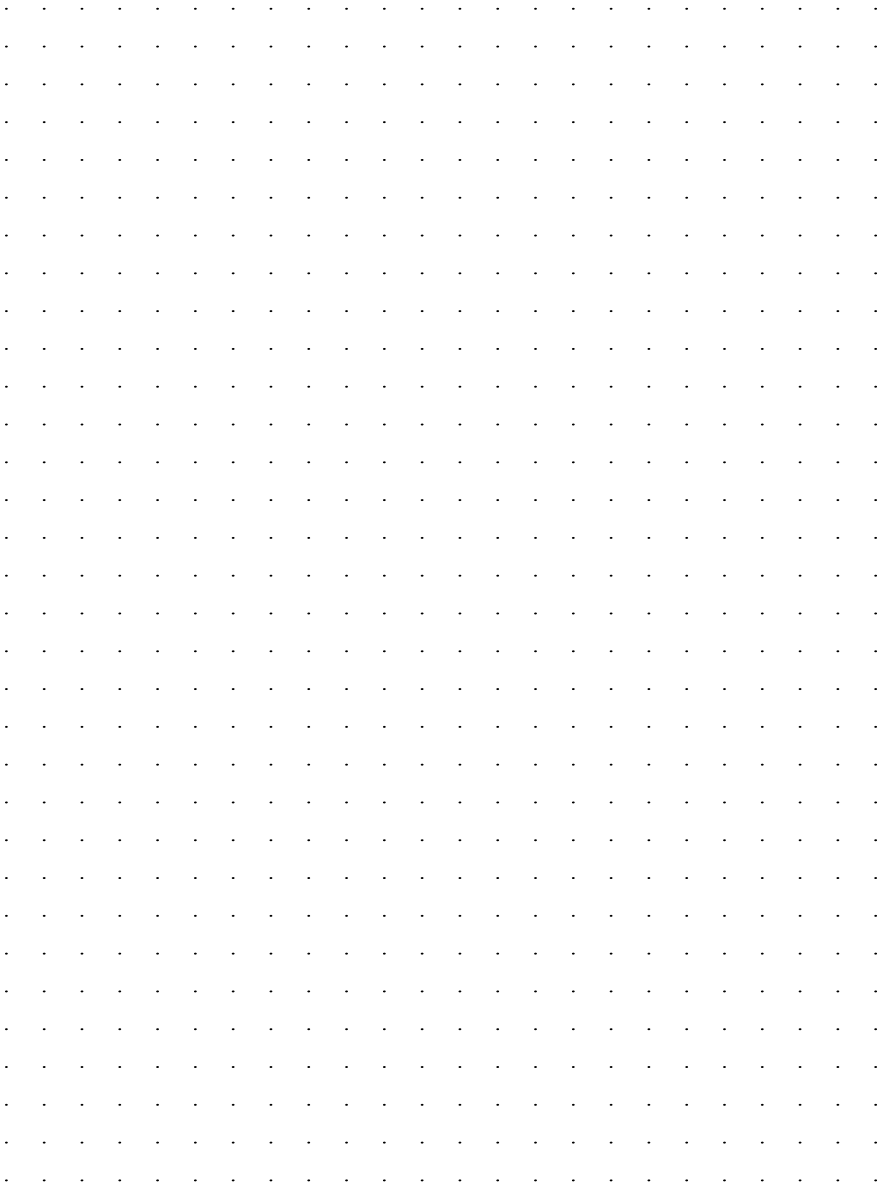
The brief

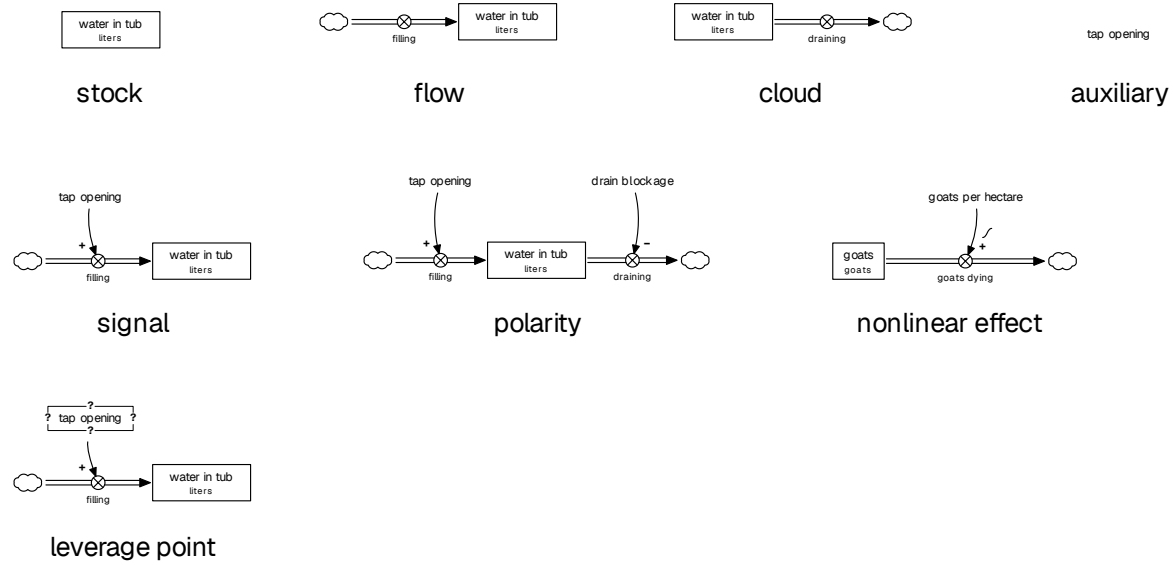
- ☐ Draw two flows: players joining, and players quitting.
- ☐ Declare one reinforcing loop.
- ☐ Declare one balancing loop.
- ☐ Run each loop through a flow, so that it passes through the stock.
- ☐ Each loop is named for what goes around it, such as word of mouth or queue frustration.

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.

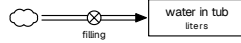
The brief

- ☐ 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.

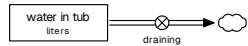
Your palette



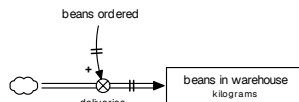
stock



flow



cloud



delay



behavior note

full in about ten minutes

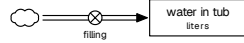
Draw here

SF 09 A city's bike-share fleet

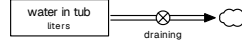
Your palette



stock



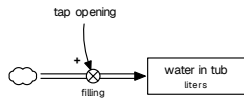
flow



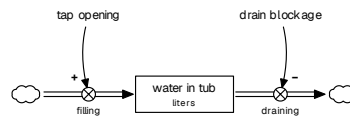
cloud

tap opening

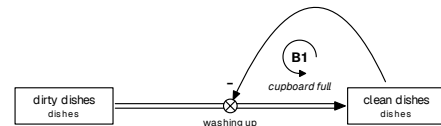
auxiliary



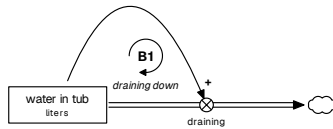
signal



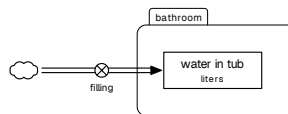
polarity



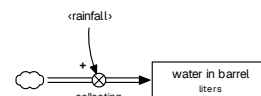
loop



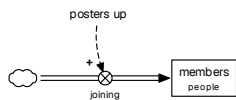
balancing loop



boundary



external driver



evidence coding

Multiple stocks, a boundary and evidence

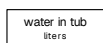
A city's bike-share scheme has docks on a hilltop and by the river. Riders seldom pedal uphill, so rides between the two run downhill and bikes collect at the riverside docks; on rainy days about a third fewer bikes are ridden. Vans collect bikes from the riverside docks and bring them to the scheme's 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.

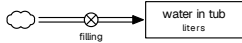
On the page before this sheet.

SF 10 Teachers in a country's schools

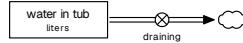
Your palette



stock



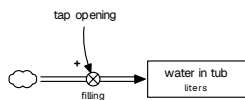
flow



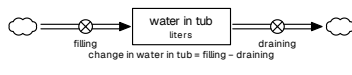
cloud

tap opening

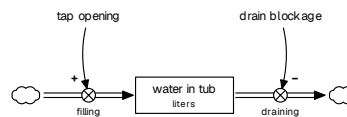
auxiliary



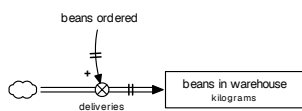
signal



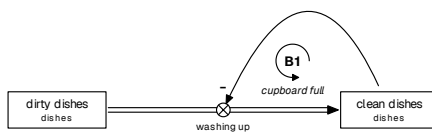
stock equation



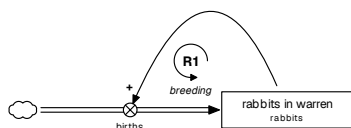
polarity



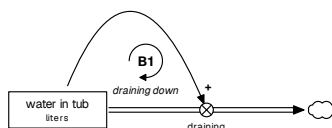
delay



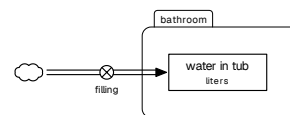
loop



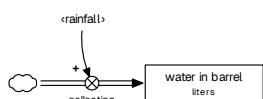
reinforcing loop



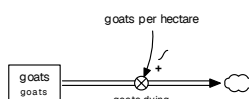
balancing loop



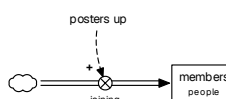
boundary



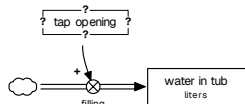
external driver



nonlinear effect



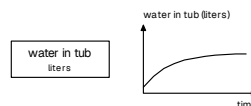
evidence coding



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

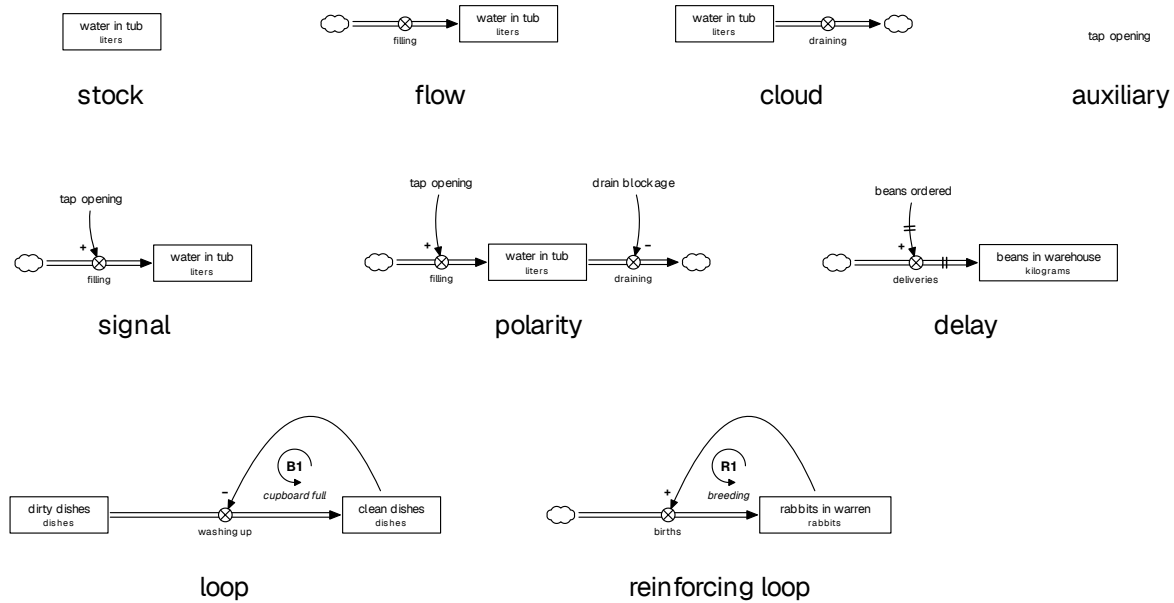
On the page before this sheet.

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

On the page before this sheet.

Draw here

Diagram drawing area with a grid of dots.

Sources

- Matthew A. Cronin, Cleotilde Gonzalez and John D. Sterman, “Why Don’t Well-Educated Adults Understand Accumulation? A Challenge to Researchers, Educators, and Citizens” doi.org/10.1016/j.obhdp.2008.03.003, *Organizational Behavior and Human Decision Processes* 108, no. 1 (2009), on the correlation heuristic and the department store task.
- John D. Sterman, *Business Dynamics: Systems Thinking and Modeling for a Complex World* (Irwin/McGraw-Hill, 2000), chapter 9, *S-Shaped Growth: Epidemics, Innovation Diffusion, and the Growth of New Products*, on epidemics; chapter 11, *Delays*, on delays in material and in information; and chapter 12, *Co-Flows and Aging Chains*.
- Jack B. Homer and Rogelio Oliva, “Maps and Models in System Dynamics: A Response to Coyle” doi.org/10.1002/sdr.224, *System Dynamics Review* 17, no. 4 (2001), on what simulation adds to maps.
- Geoff Coyle, “Qualitative and Quantitative Modelling in System Dynamics: Some Research Questions” doi.org/10.1002/1099-1727%28200023%2916:3%3C225::AID-SDR195%3E3.0.CO;2-D, *System Dynamics Review* 16, no. 3 (2000), the paper Homer and Oliva answer.

Answers

Chapter 7 · Stocks Inside Feedback

An office orders printer paper by the box. A box arrives five days after it is ordered, and the office manager counts the boxes in the cupboard only on Fridays, then orders from that count. Which of these is a signal delay?

- a the five days between ordering a box and its arrival
Not quite. That is a material delay: for those five days the box is in transit, in neither the supplier's stock nor the cupboard. It is marked on the flow of deliveries.
- b the days between a box leaving the cupboard and the Friday count
Yes. The box has already left the cupboard; only the count of it is late. The delay is marked on the signal from the boxes in the cupboard to orders.
- c the time a box spends in the cupboard before it is used
Not quite. That is the time spent in a stock. The cupboard holds the box for that time, so no delay is drawn for it.

Skiers join the queue for a chairlift at 10 a minute at 8:30, at 60 a minute at 9:30, and at 10 a minute again by 11:00. The lift carries 30 skiers a minute all morning. When is the queue longest?

- a at 9:30, when skiers join fastest
Not quite. That reads the queue's graph as the shape of its inflow. At 9:30, 60 skiers join a minute and 30 leave, so the queue is still growing by 30 a minute.
- b after 9:30, when joining has fallen back to 30 a minute
Yes. The queue grows while more skiers join than the lift carries, and shrinks once fewer do, so it is longest when joining equals the lift's 30 a minute.
- c at 11:00, when joining is slowest
Not quite. By 11:00, 10 skiers join a minute and 30 leave, so the queue has been shrinking since joining fell below 30 a minute.

QUESTION 1 OF 3

A patient reaches the first hospital at two o'clock and leaves for the PCI center at four. Where in the diagram are those two hours spent?

- a In the flows, since a flow is the patient moving from one stage to the next.
Not quite. A flow is a rate, patients a minute, and holds no one at an instant. Every patient counted at an instant is in one of the eight stocks.
- b In the loops B1 to B4, since each loop keeps patients until they move on.
Not quite. A loop is a closed path, here a signal and a flow: it sets how fast patients leave a stage, and holds no one. Patients wait only in stocks.
- c In the stocks: at each stage in turn, and in a held stock wherever the patient is held.
Yes. A stock is where material waits between the flows that fill and drain it. The four stages are an aging chain, passed through in order, and a stay in a held stock adds to the time at its stage until returning brings the patient back.

QUESTION 2 OF 3

B2 runs from patients at the ECG to the valve of to fax, the flow that drains them. What does B2 do to patients at the ECG?

- a** The more patients at the ECG, the faster they leave for the fax, so a rise in that stock comes back against itself.

Yes. The signal is +, and to fax counts – from the flow into the stock it drains: one – step, so B2 is balancing. The stock settles where its outflows run as fast as its inflows.

- b** It holds the patients' wait at the guidelines' optimal time, the value the authors compare each wait with.

Not quite. No target is drawn: no variable holds a chosen time, and nothing compares one with the wait. B2 drains the stock faster the fuller it is, and no more.

- c** It makes patients at the ECG grow, since more of them send more on to the fax.

Not quite. More patients sent on is a faster outflow from patients at the ECG, which lowers it. The rise is in patients at the fax, the next stock along.

QUESTION 3 OF 3

At the fax stage, 76% of the patients the authors followed waited longer than the optimal time. Where does a patient's wait at that stage appear in the diagram?

- a** As a material delay on to transfer, for patients between the two stages.

Not quite. A material delay holds material in neither stock, as grain at sea is. These patients wait at the fax stage, counted in its stocks; moving on to transfer takes no time of its own.

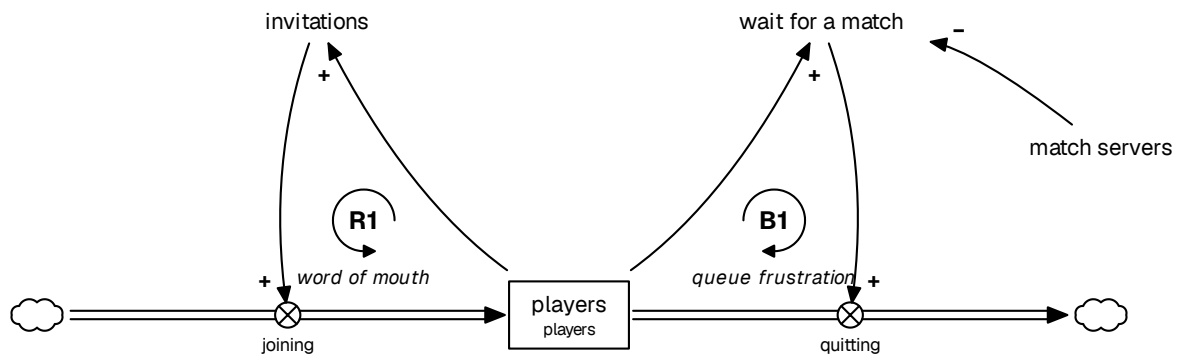
- b** As the time a patient spends in patients at the fax and in patients held at the fax, with no delay drawn.

Yes. The time material spends in a stock is a delay already, so a delay drawn on to transfer would count the wait twice. A patient held adds the time in the held stock.

- c** As a signal delay on patients at the fax → to transfer, since the reply from the PCI center arrives late.

Not quite. A signal delay holds news of a quantity. The reply is what the patients wait for, and the patients themselves sit in the stock, counted there until they move on.

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

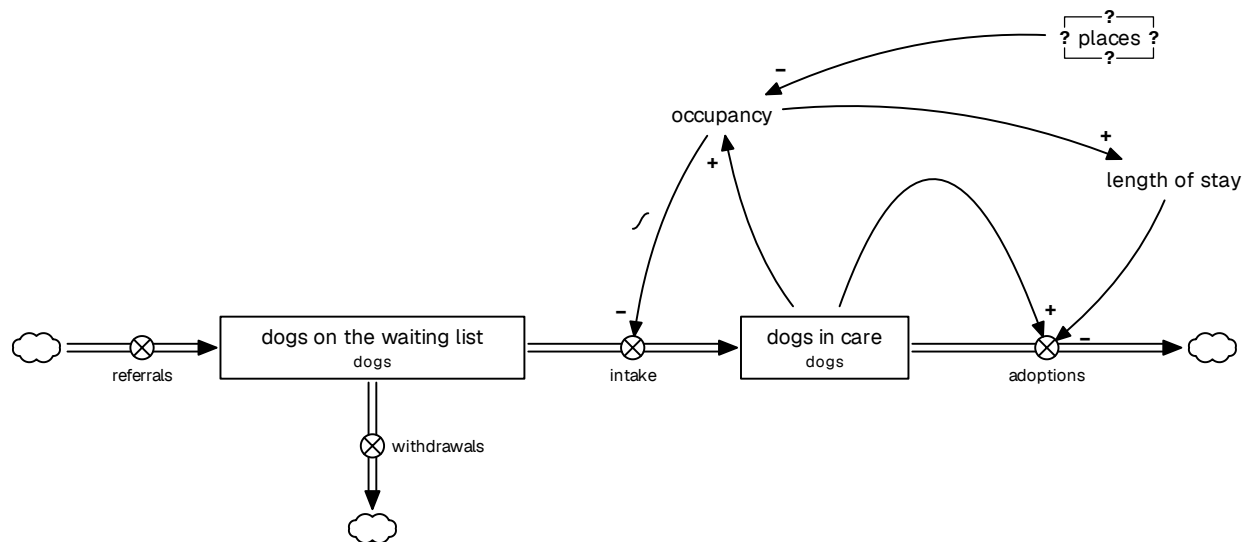
Step by step

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

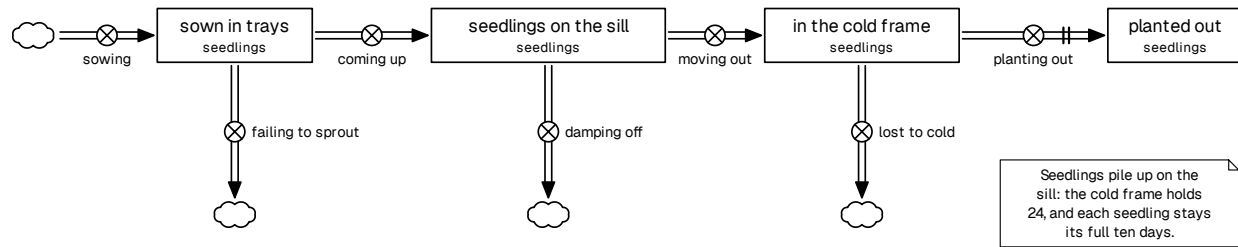
Step by step

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

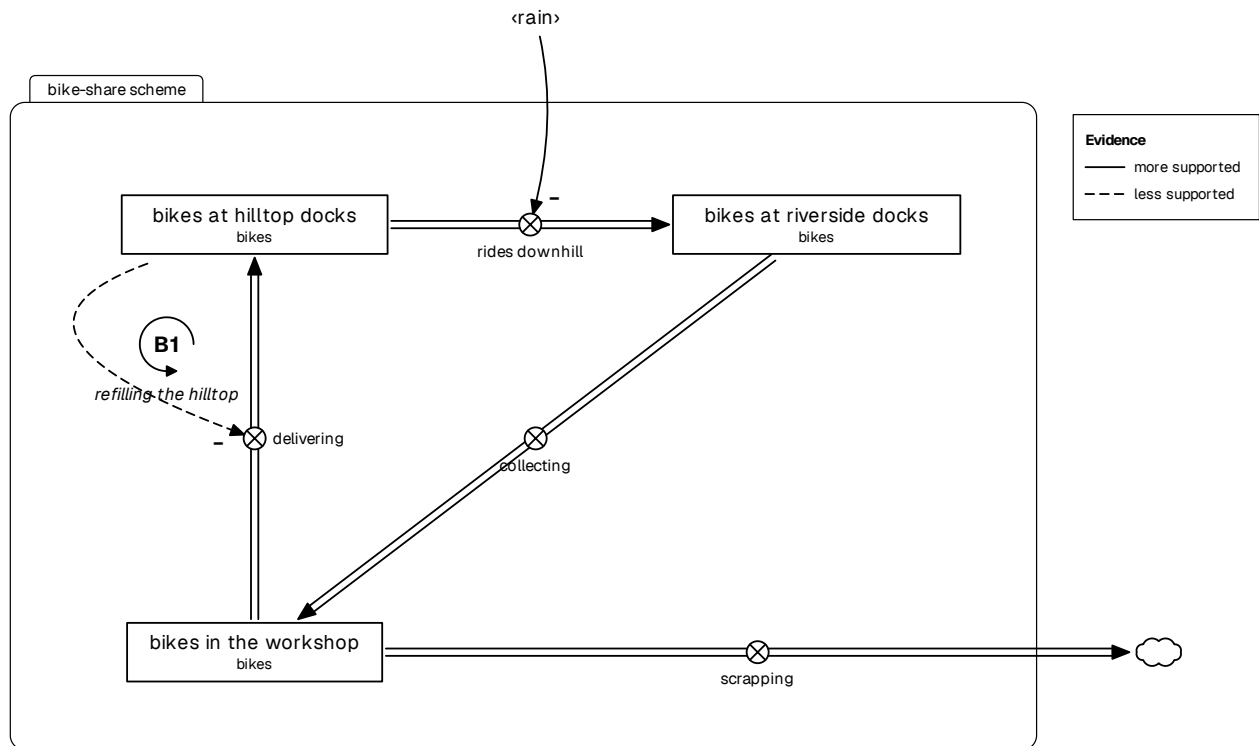
Step by step

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

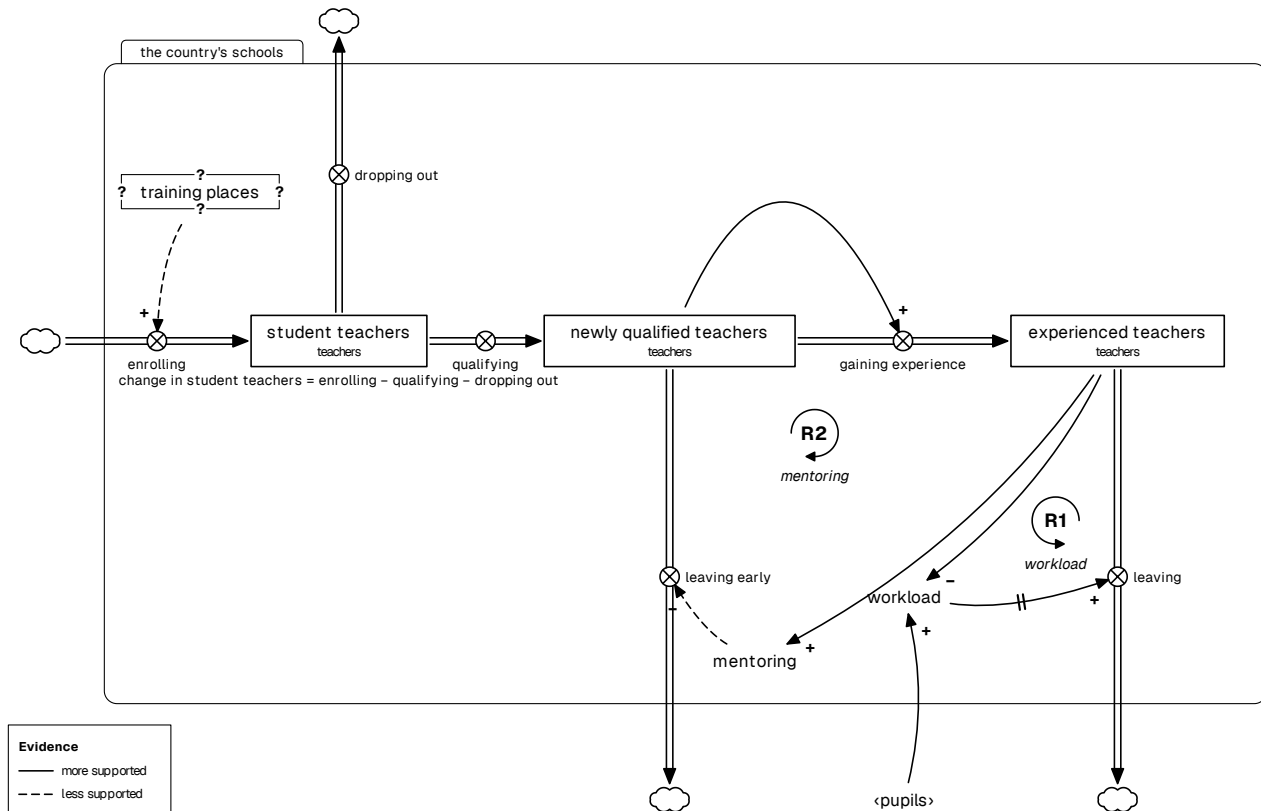
1. Three stocks, each counted in bikes, with the time unit a day: bikes at hilltop docks, at riverside docks and in the workshop, each a count staff could take on any day.
2. Rides downhill, collecting and delivering, three transfers around the stocks: a bike rides from the hilltop to the river, goes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

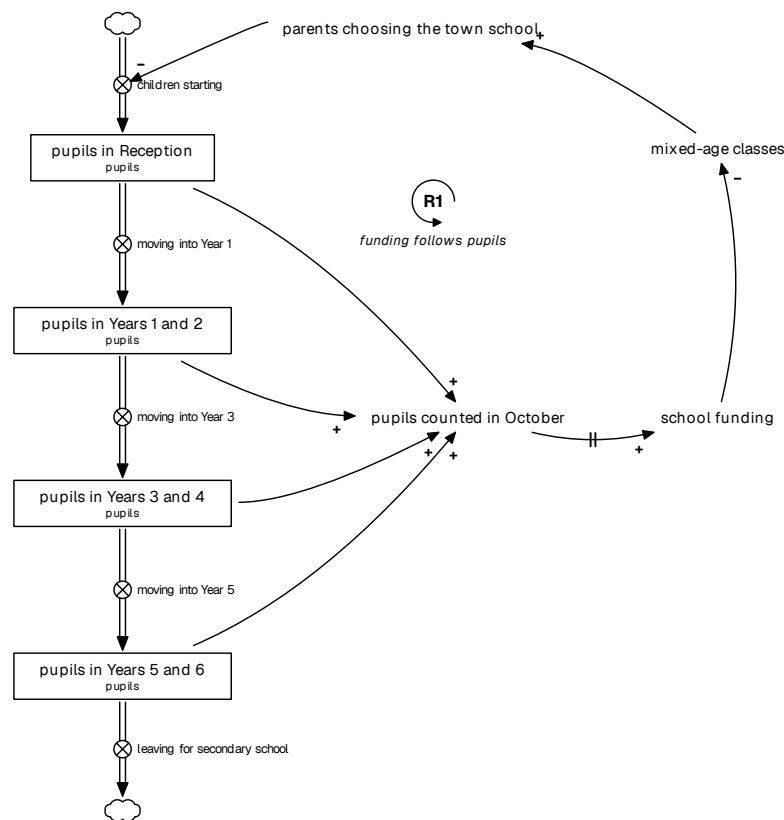
Step by step

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.