Module 4 : Modelling Whole Systems

Session 4B : System Dynamics

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"Chicken Stock"

HSMA 4

System Dynamics

- A modelling method in which system structures (components and the way in which they relate) are captured.

Fundamental principle of SD :

Structure determines behaviour

Qualitative System Dynamics

- Create map of influences and their directionality
- Identify feedback loops within the map (the “causal loop diagram”)
- Draw insight from the map and its associated feedback loops to better understand system behaviour

Example influences

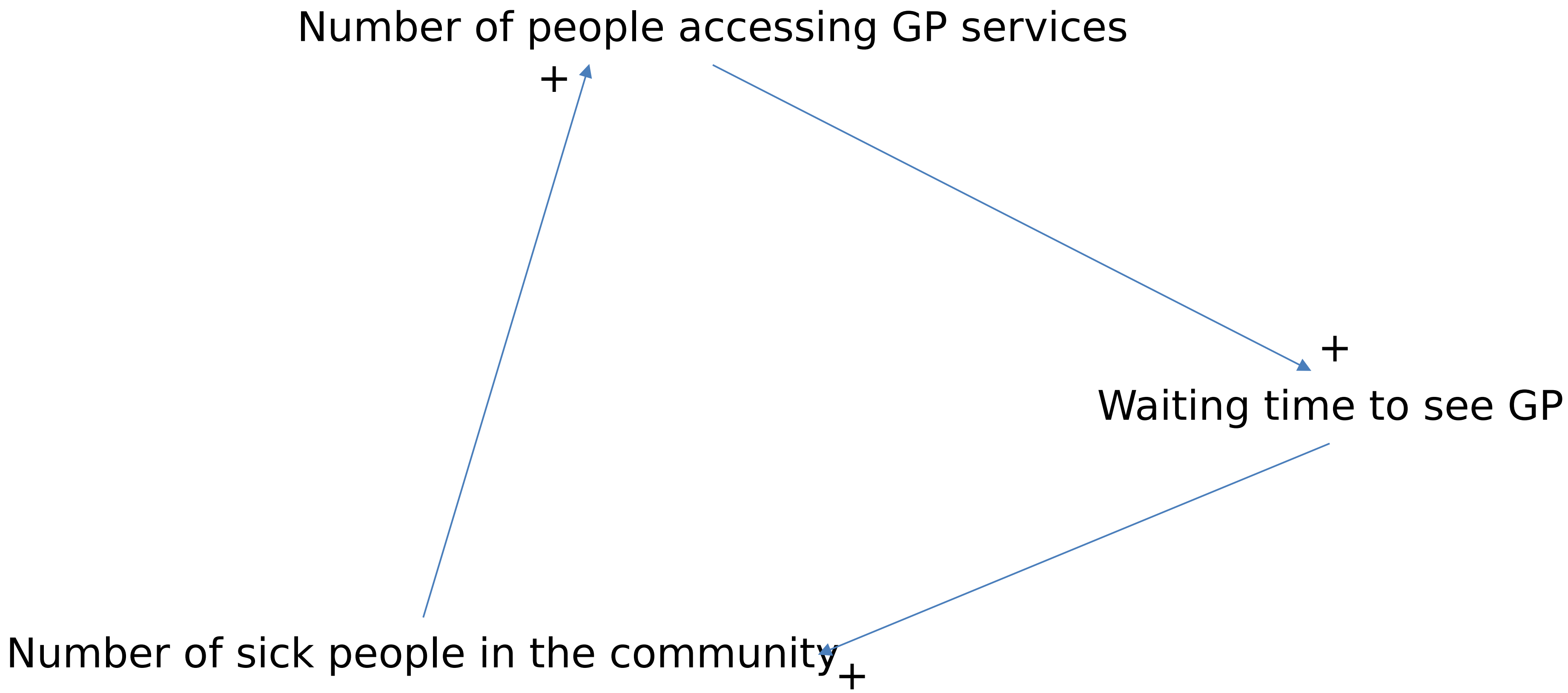
Number of people accessing GP services $\xrightarrow{+}$ Waiting time to see GP

As the number of people accessing GP services ***increases****,*
the waiting time to see a GP ***increases***
(Both go in the same direction)

Number of people admitted to hospital $\xrightarrow{-}$ Number of beds available in hospital

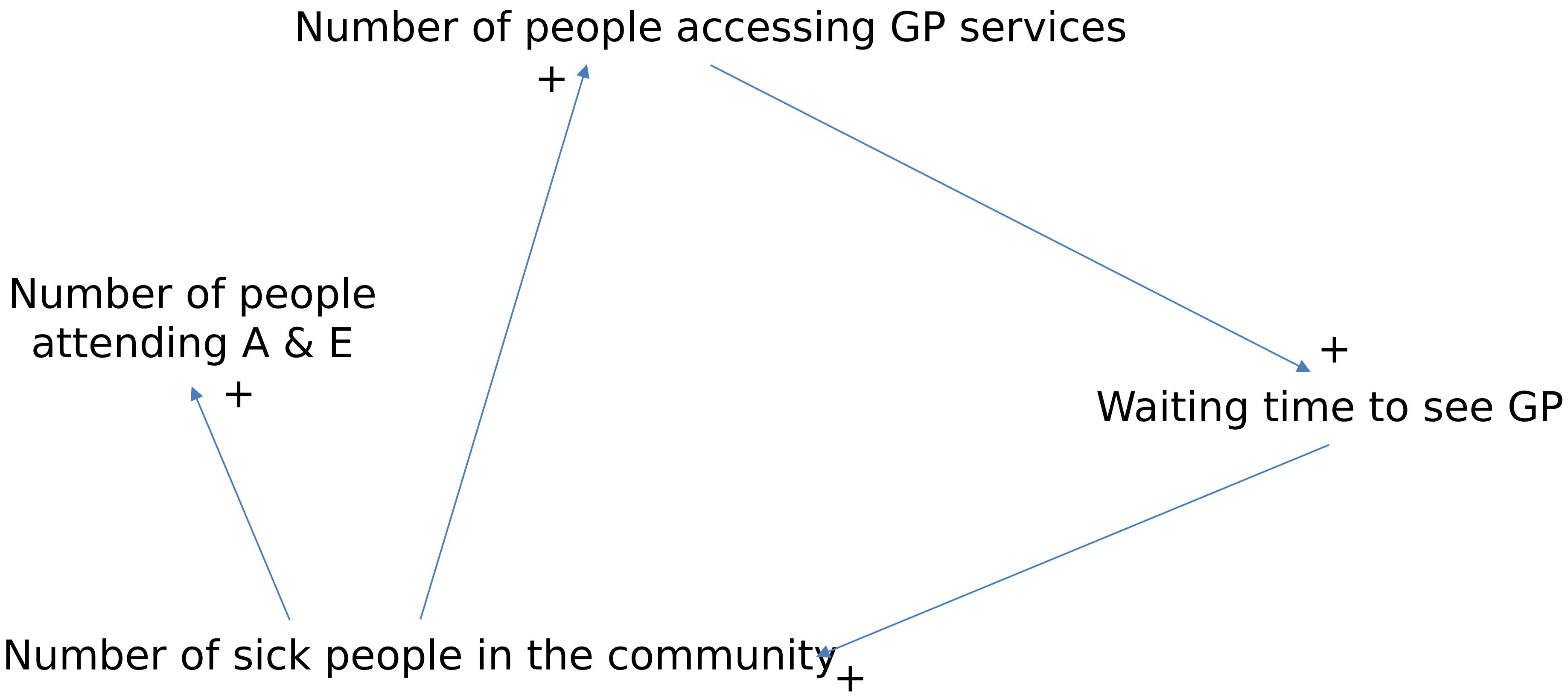
As the number of people admitted to hospital ***increases****,*
the number of beds available in the hospital ***decreases***
(Each goes in opposite directions)

Reinforcing Loops (“Vicious Circles”)



*Reinforcing Loops have an __even__ number of (**or zero**) minus signs.*
*Therefore the **same conclusion is reached each time you loop.***

Reinforcing Loops ("Vicious Circles")



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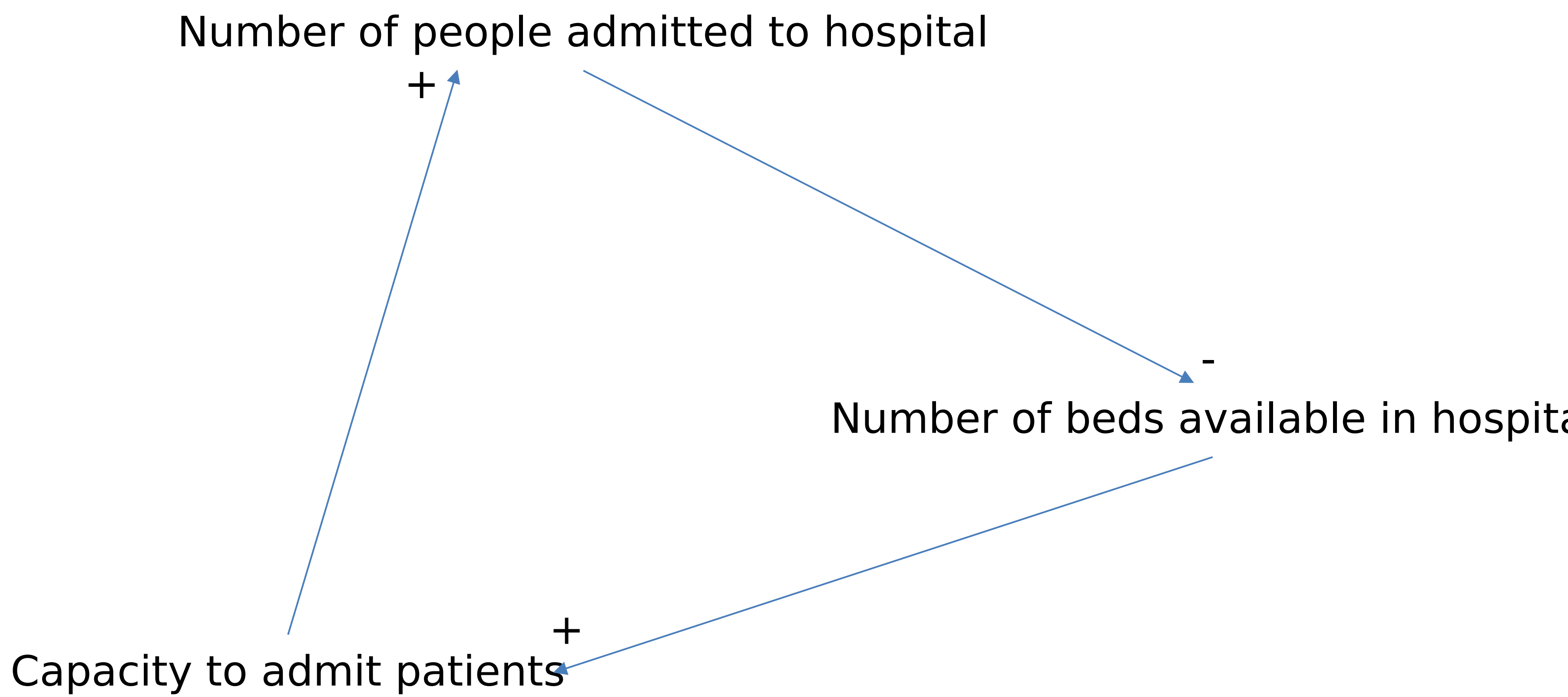
*Therefore the **same conclusion is reached each time you loop.***

Balancing Loops



*Balancing Loops have an **<u>odd</u>** number of minus signs. Therefore a **contradictory conclusion is reached each time you loop.***

Chicken and the Egg

Let’s consider a simple system. That of the chicken and the egg.

Chicken and the Egg

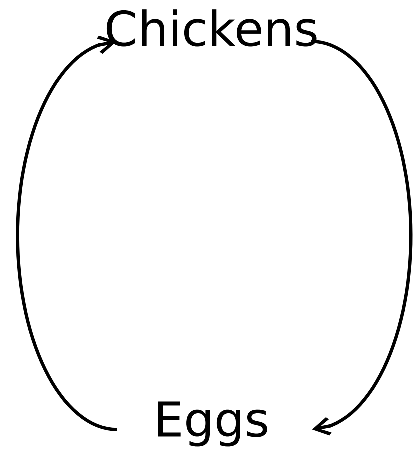
Chickens lay eggs.

Chickens

Eggs

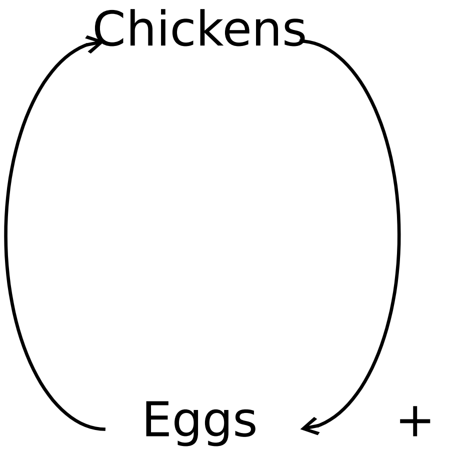
Chicken and the Egg

Eggs hatch into chickens.



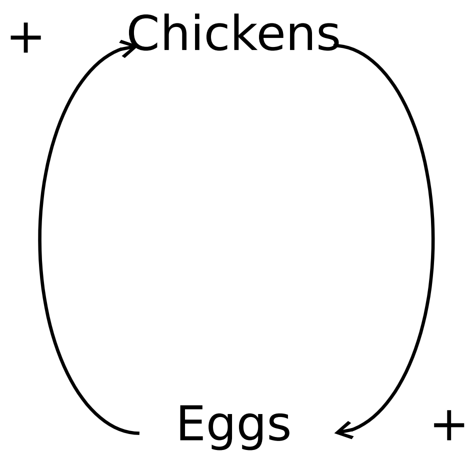
Chicken and the Egg

More chickens mean more eggs laid.



Chicken and the Egg

More eggs mean more chickens hatch.



A Reinforcing Loop

Exercise 1

In groups, you will now try building a causal loop diagram that describes the causal influences influencing people adhering to social distancing and other preventative measures during the COVID-19 pandemic.

You should start in the centre of your page by writing a series of entries covering different measures, such as :

Number of people wearing masks in required settings (shops / public transport etc)

Number of people staying 2m away from individuals not from their household

Number of people washing their hands regularly for at least 20 seconds

Next, start thinking about as many factors as you can that *directly* influence each of these numbers, and which are directly influenced *by* the numbers of people adhering to these measures. For each, note with a + or - whether the polarity of the influence is that they both go in the same direction (+) or as one increases, the other decreases (-).

Then, look at whether any of these factors link up with other factors you've identified, and the polarity of the causal relationship. Then, start building out – which factors directly influence the factors that you've identified, and what do they directly influence.

Keep building up your map, and remember to be on the lookout for reinforcing and balancing loops, and note them as you find them. What insights can you draw from your map?

You have 40 minutes + 5 minute break.

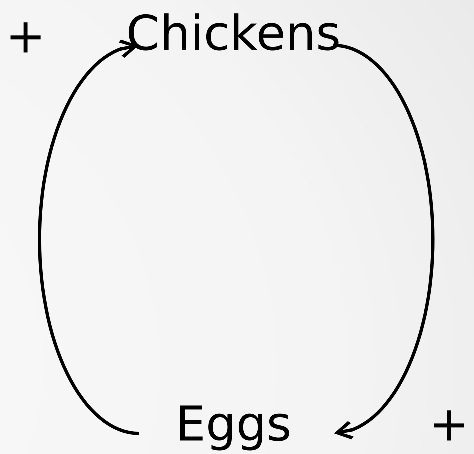
Quantitative System Dynamics

Let’s go back to our chicken and egg system.

Here, we can build a *quantitative* System Dynamics model, because we can attach some numbers to describe the *rate of flow* between elements in the system.

That is, we can say how many eggs chickens lay per unit of time, and how many eggs hatch into chickens per unit of time.

But first, we need to understand some core concepts of Quantitative SD Models...



System Dynamics Building Blocks

Here are the key building blocks of a SD model :

Stock : A stock holds the “stuff” that is flowing around the system. Imagine a water tank.

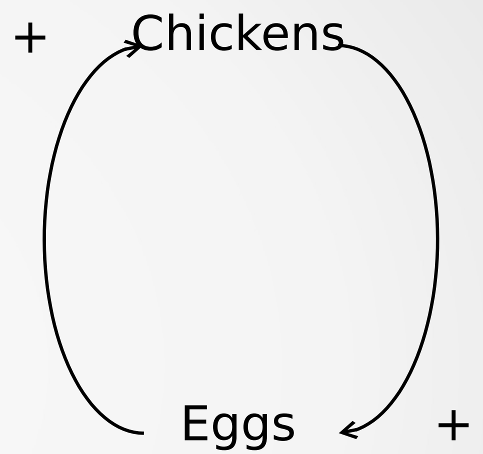
Flow : Flows allow the “stuff” to move around the system. The rate at which the “stuff” flows can be controlled by the valve.
Imagine water flowing through pipes.

Variable : A variable represents something that is not otherwise captured by the model, but will influence a stock’s level or a rate of flow.

Link : A link indicates that a stock’s level or a flow rate is affected by a stock’s level or a variable.

Quantitative System Dynamics

Now, let’s say we know that :
- chickens lay, on average, 5 eggs per week
- fertilised eggs take, on average, 21 days to hatch



In our model, we’ll start with 100 chickens and no eggs (answering that age old question…)

Let’s say we want to track our chicken and egg populations over time.

What do you think will happen in our system?

Key “Quirks” of SD Models

SD models are a little different from the models that you’ve seen so far. In particular :

- the entities that are flowing through the model are not represented as individual entities, but as a continuous mass (think of water)
- SD models are not stochastic, but *deterministic*. That means that every time you run a SD model, you’ll get exactly the same results.
- with SD models, we’re typically interested in general patterns / dynamics within the system, rather than accurate predictions such as “you need x doctors to meet this demand y% of the time”.

Let’s look at an example of some of these “quirks” for the Chicken and Egg model. We said that eggs take, on average, 21 days to hatch. Let’s imagine we have our time unit representing weeks (as we know chickens lay an average of 5 eggs per week).

How do you think we will describe the number of eggs hatching per week?

Key “Quirks” of SD Models

How do you think we will describe the number of eggs hatching per week?

ANSWER : Number of Eggs / 3

WHY?
If we had 1 egg, it would take 3 weeks (21 days) to hatch. In SD world, this means that one third (or 1/3) of the egg would hatch per week.

If we had 2 eggs, each week one third of each egg would hatch. Which means after week 1, we’d have two one-thirds of eggs hatched (or 2/3 of an egg hatched). Think about it after three weeks, we’d expect 2 chickens. 3 x (2/3) = 6/3 = 2

Essentially, we’re saying :
eggs hatching per week = number of eggs x 1 / 3 (a third of each egg we have).
Which we simplify to : Number of Eggs / 3

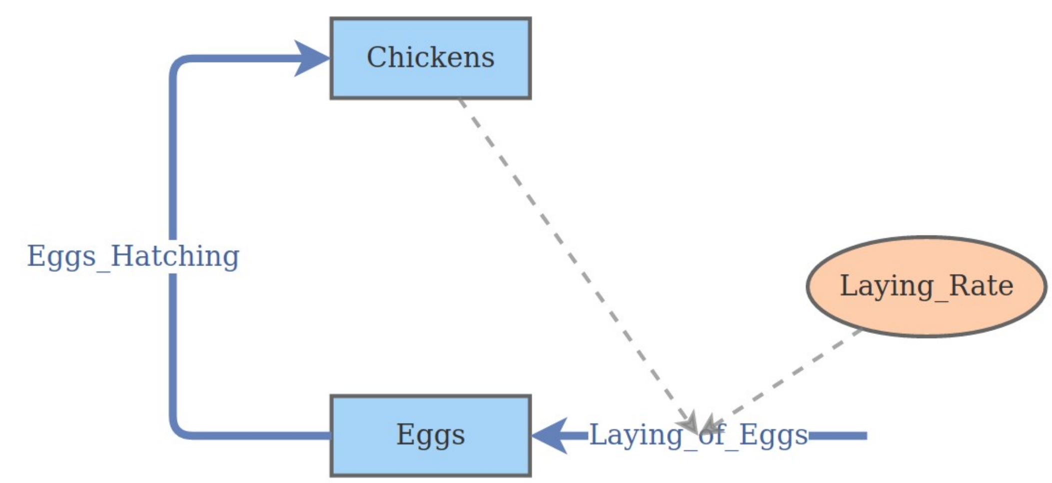
InsightMaker

InsightMaker (https://insightmaker.com/) is an online model building development tool that allows for the development of System Dynamics and Agent Based Simulations.

It uses a simple drag-and-drop interface to allow anyone to put together models quickly and easily, without installing any software, and allowing for models to be shared with anyone anywhere in the world.

Let’s have a look at it.

The Chicken and Egg Model



https://insightmaker.com/insight/112161/ChickensEggs

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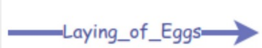

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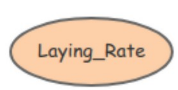

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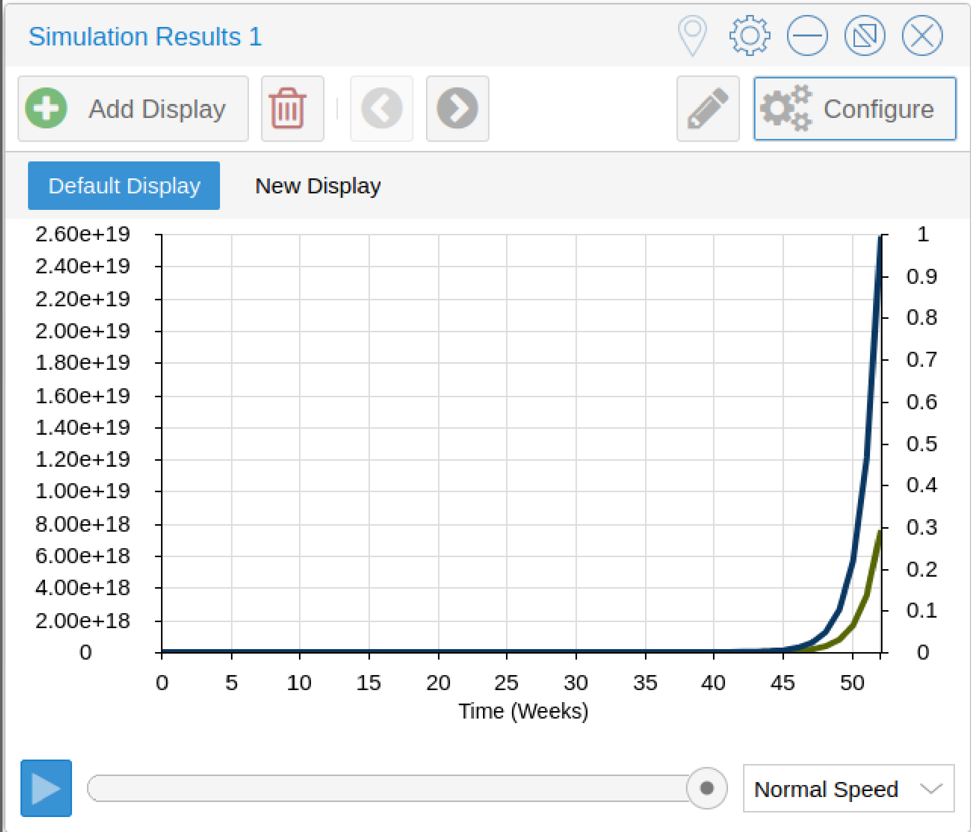
The Chicken and Egg Model



Simulation Results 1

Add Display | Configure

Default Display | New Display

Time	Chickens	Eggs
0	100	0
1	100	500
2	266.666666667	833.333333333
3	544.444444444	1,888.888888889
4	1,174.074074074	3,981.481481481
5	2,501.234567901	8,524.691358025
6	5,342.798353909	18,189.300411523
7	11,405.898491084	38,840.192043896

Download

Normal Speed

100 old + (500 / 3) new

500 previous + 500 new –
(500 / 3 ready to hatch)

Exercise 2

Your task now is to expand the chicken and egg model. You'll take a copy of the model (by "cloning" the insight) and then make the following changes to the new copy :

- Not all eggs are fertilised. Make the proportion of eggs fertilised a user-definable variable (with slider), defaulting to 1. You should only model fertilised eggs in your model.
- Chickens can either die through natural causes or predation by foxes.
- Chickens have an average lifespan of around 7 years.
- Foxes give birth to around 5 kits per year. Start with 100 foxes in the model, and no kits.
- Kits move into adulthood (when they start finding their own food) at around 12 weeks of age.
- Foxes have an average lifespan of 4 years.
- We'll make an initial assumption that each fox kills 1 chicken every 5 weeks. Make this a user definable variable (with slider).

Once you've built this new expanded model, use it to answer the following questions :

a) Assuming all else is as above, what is the minimum proportion of eggs that need to be fertilised to ensure our chicken population doesn't die out within 1 year?

b) If 80% of eggs were fertilised, how much more regularly would a fox need to kill a chicken to make the species extinct within a year?

You should work in groups. You have 1 hour.