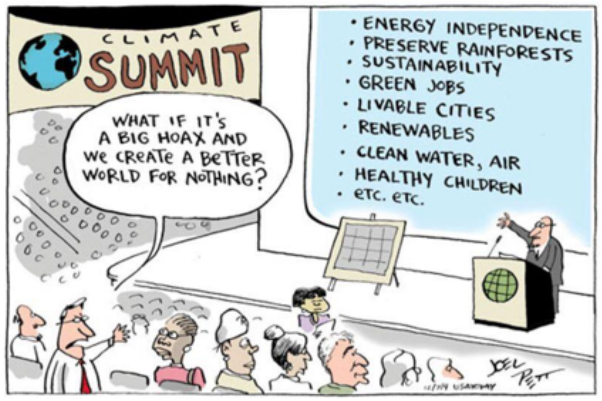
Systems: Stocks, Flows, & Feedbacks



Goals:

1. Define stock, flow, and feedback
2. Explain how the combined history of inflows and outflows determines a stock
3. Predict what happens to stocks and flows when a system is perturbed
4. Construct examples of both amplifying and stabilizing feedbacks.

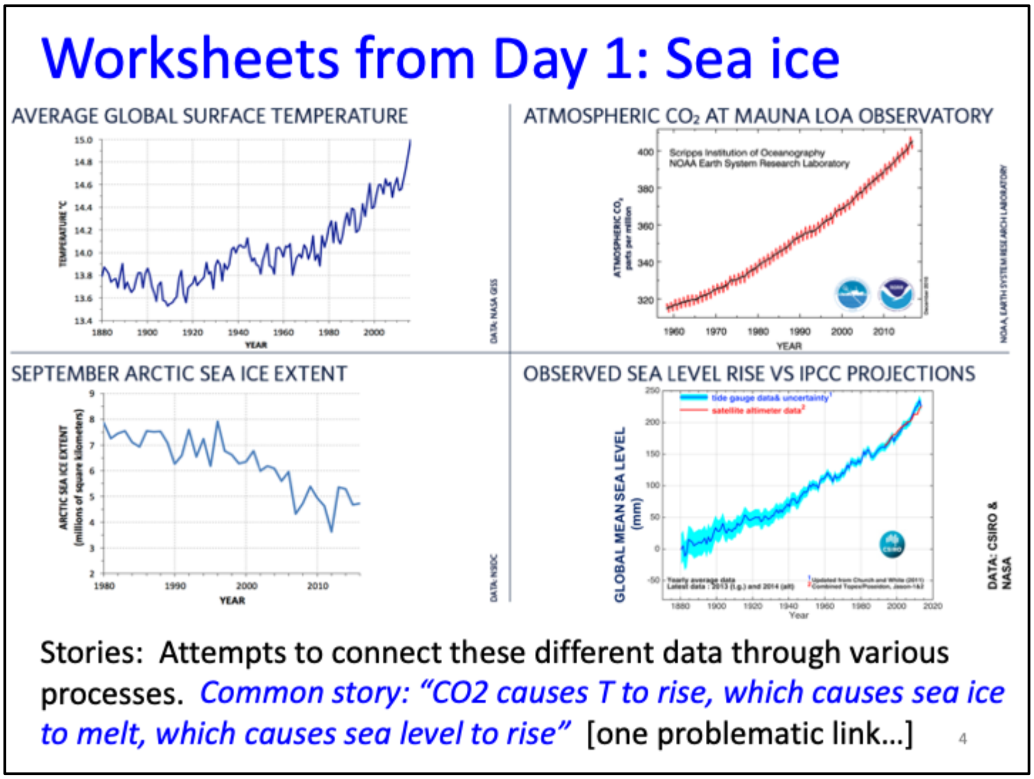
1

Fall 2012: THE WORKSHEET TAKES MORE THAN 45 MINUTES
Fall 2013: The worksheet took about 35 minutes, then the last 10 minutes for debriefing it. We didn't get to the feedbacks and examples.
Fall 2014: Had 7 minutes for the feedbacks. Lost track of time and didn't debrief that activity.

Climate news

- Hurricane Dorian stalls over the Bahamas
- Here's what the original research looks like:
  - Hall and Kossin – 2019
- Fires in Australia

Question: Why don't we put the answers to the clicker questions up on canvas?



LETS DISCUSS THESE IN TERMS OF SYSTEM DYNAMICS: STOCKS AND FLOWS CHANGING OVER TIME

TEMPERATURE → STOCK AND FLOWS OF ENERGY. IMBALANCE IN ENERGY FLOWS → CHANGING STOCK (TEMP)

CO2 → IMBALANCE OF INFLOW AND OUTFLOW

SEA ICE → STOCK DETERMINED BY ICE FORMATION (INFLOW) AND MELTING (OUTFLOW)

SEA LEVEL → STOCK OF WATER DETERMINED BY WATER LEAVING OR FLOWING INTO THE OCEAN…
(VOLUME OF SEA WATER IS ALSO DETERMINED BY TEMP. AND SALINITY).

Discuss that each of these is a product of system dynamics. Stocks and flows changing over time.
Temperate: stocks and flows of energy, imbalance in energy flows leads to changing stock and changing temperature
CO2 – imbalance of inflow and outflow over time
Sea ice – a stock determined by ice formation (inflow) and melting (outflow)
Sea level – the stock of water is determined by water molecules leaving the ocean or flowing into the ocean. The volume that the water occupies is also a function of physical characteristics, like temperature and salinity.

Questions/Comments: Worksheet

1. Sea ice versus land ice
   – impact on sea level

Once this ice melts in this glass, how will the water level be different? Water level will be ______before.

A. higher than
B. lower than
C. the same as

http://commons.wikimedia.org/wiki/File:Menthaleau.jpg

5

If you can write us an email explaining an alternate answer to question 7 on the quiz (the one about sea ice, land ice, and sea level rise), we'll give you credit. There's at least one person who alluded to a small subtlety in the comments. Send us an email by midnight tonight.

SH took off these three text boxes from previous term

2. Arctic versus Antarctic: What's the difference?

3. Temperature anomalies: See lucid explanation at http://www.skepticalscience.com/OfAveragesAndAnomalies_pt_1A.html

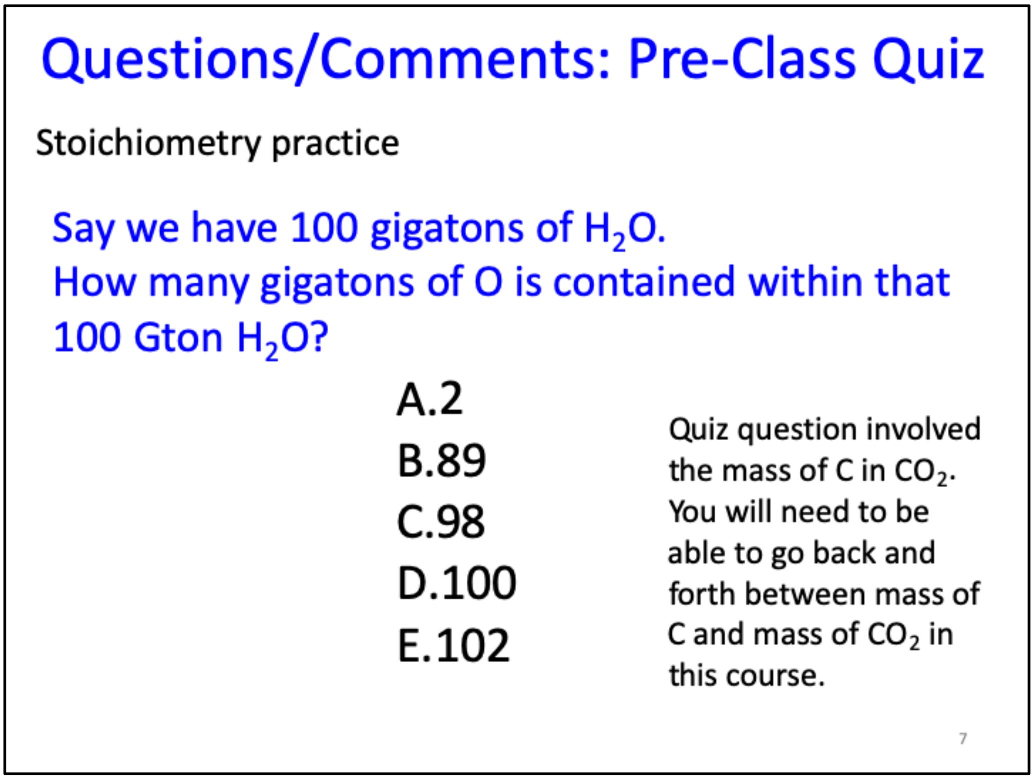
4. *"Does amplifying feedback always result in a negative outcome?"*

More on buoyancy

- Suppose that ice was 70% as dense as water. If you froze a block of liquid water, how much of the volume would be above the surface?

  A) 10%
  B) 30%
  C) 50%
  D) 70%
  E) 90%

6



ANSWER = B

16/18 = 0.888

81% of you got this question right on the quiz

Do individually
Answer: B
16/18 = 0.888

Caldeira, 2012- Pre class reading

"One of the greatest uncertainties in climate prediction is the amount of CO_2 that will ultimately end up in the atmosphere"

Some text from the Dec 2015 Paris agreement:
Emphasizing with serious concern the urgent need to address the significant gap between the aggregate effect of Parties' mitigation pledges in terms of global annual emissions of greenhouse gases by 2020 and aggregate emission pathways consistent with holding the increase in the global average temperature to well below 2 ˚C above pre-industrial levels and pursuing efforts to limit the temperature increase to 1.5 ˚C,

Paris climate agreement

Breakthrough as US and China agree to ratify Paris climate deal

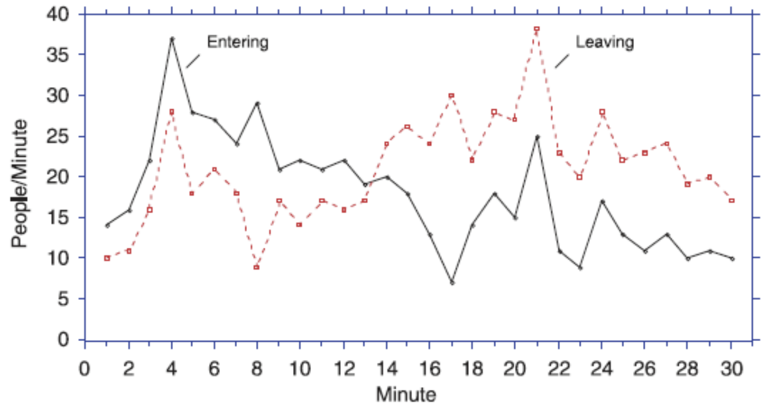
Campaigners hail key moment in battle against global warming as presidents Obama and Xi announce deal on eve of G20 summit in Hangzhou

Tom Phillips in Beijing, **Fiona Harvey** and **Alan Yuhas**

Saturday 3 September 2016 15.12 BST

91% of you got this quiz question right.

We'll work with this plot during class. See post-class slides for more.

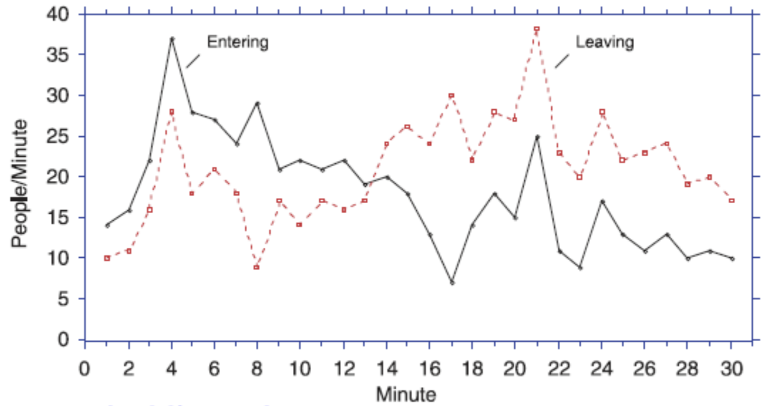


9

Figure: Cronin & Gonzalez, 2007

PUT THIS IN PRE_CLASS SET

Clicker Q: The graph below shows the numbers of people entering and leaving a store each minute. **During which minute did the most people enter the store?**



A. Minute 4
B. Minute 8
C. Minute 13
D. Minute 21
E. Cannot be determined

10

Figure: Cronin & Gonzalez, 2007

THE COMBINED HISTORY OF INFLOWS AND OUTFLOWS DETERMINES A STOCK

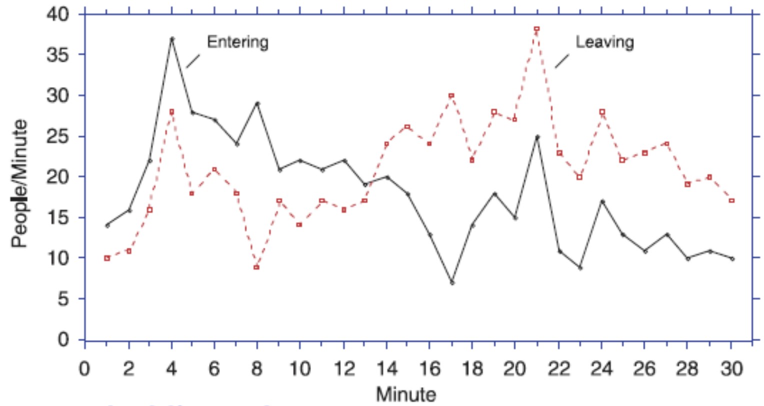
ANSWER = A

LG: Explain how the combined history of inflows and outflows determines a stock

ON to stock and flow (fairly abrupt transition here):
Try doing this series of clicker questions BEFORE the "Stock & Flow" slides. See what people do. Then do a couple of explanatory slides about stock and flow, then the worksheet.

ANSWER: A
Figure from Cronin, M. A., & Gonzalez, C. (2007). Understanding the building blocks of dynamic systems. *System Dynamics Review*, *23*(1), 1–17. doi:10.1002/sdr.356
This journal explicitly allows ("permitted use") info to be posted on learning management systems!

Clicker Q: The graph below shows the numbers of people entering and leaving a store each minute. **During which minute did the most people leave the store?**



A. Minute 4
B. Minute 8
C. Minute 17
D. Minute 21
E. Cannot be determined

11

Figure: Cronin & Gonzalez, 2007

ANSWER = D

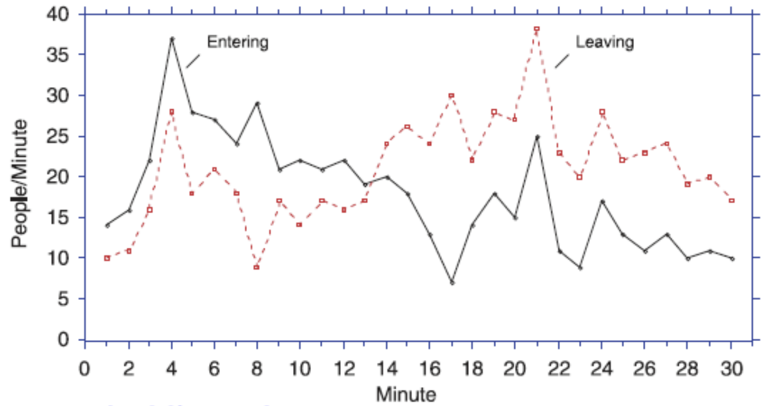
LG: Explain how the combined history of inflows and outflows determines a stock

ANSWER: D

Figure from Cronin, M. A., & Gonzalez, C. (2007). Understanding the building blocks of dynamic systems. *System Dynamics Review*, *23*(1), 1–17. doi:10.1002/sdr.356

This journal explicitly allows (“permitted use”) info to be posted on learning management systems!

Clicker Q: The graph below shows the numbers of people entering and leaving a store each minute. During which minute were the **MOST** people in the store?



A. Minute 4
B. Minute 8
C. Minute 13
D. Minute 17
E. Cannot be determined

12

Figure: Cronin & Gonzalez, 2007

ANSWER = C

AFTER 13 MINUTES, MORE PEOPLE START LEAVING THE APPLE STORE

Would be useful to have a doc cam for explaining this – we had a lot of discussion about why it is not minute 8 – used a Las Vegas analogy: if I start with $2 and I win $13m in first minute and lose $10m how much does my account have in it at end of min 1, then at end of min 2 etc.

LG: Explain how the combined history of inflows and outflows determines a stock

ANSWER: C

Figure from Cronin, M. A., & Gonzalez, C. (2007). Understanding the building blocks of dynamic systems. *System Dynamics Review*, *23*(1), 1–17. doi:10.1002/sdr.356

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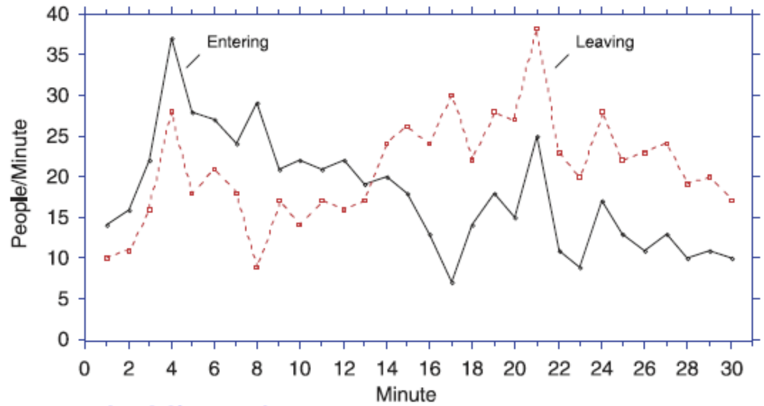
The answer choices selected are based on Table 1 in Cronin, M., Gonzalez, C., & Sterman, J. (2009). Why don’t well-educated adults understand accumulation? A challenge to researchers, educators, and citizens. *Organizational Behavior and Human Decision Processes*, *108*(1), 116–130. doi:10.1016/j.obhdp.2008.03.003

Clicker Q: The graph below shows the numbers of people entering and leaving a store each minute. During which minute were the **FEWEST** people in the store?



A. Minute 1
B. Minute 13
C. Minute 17
D. Minute 30
E. Cannot be determined

13

Figure: Cronin & Gonzalez, 2007

ANSWER D

TIME WHEN MOST PEOPLE HAVE LEFT

LG: Explain how the combined history of inflows and outflows determines a stock

ANSWER: D

Figure from Cronin, M. A., & Gonzalez, C. (2007). Understanding the building blocks of dynamic systems. *System Dynamics Review*, *23*(1), 1–17. doi:10.1002/sdr.356

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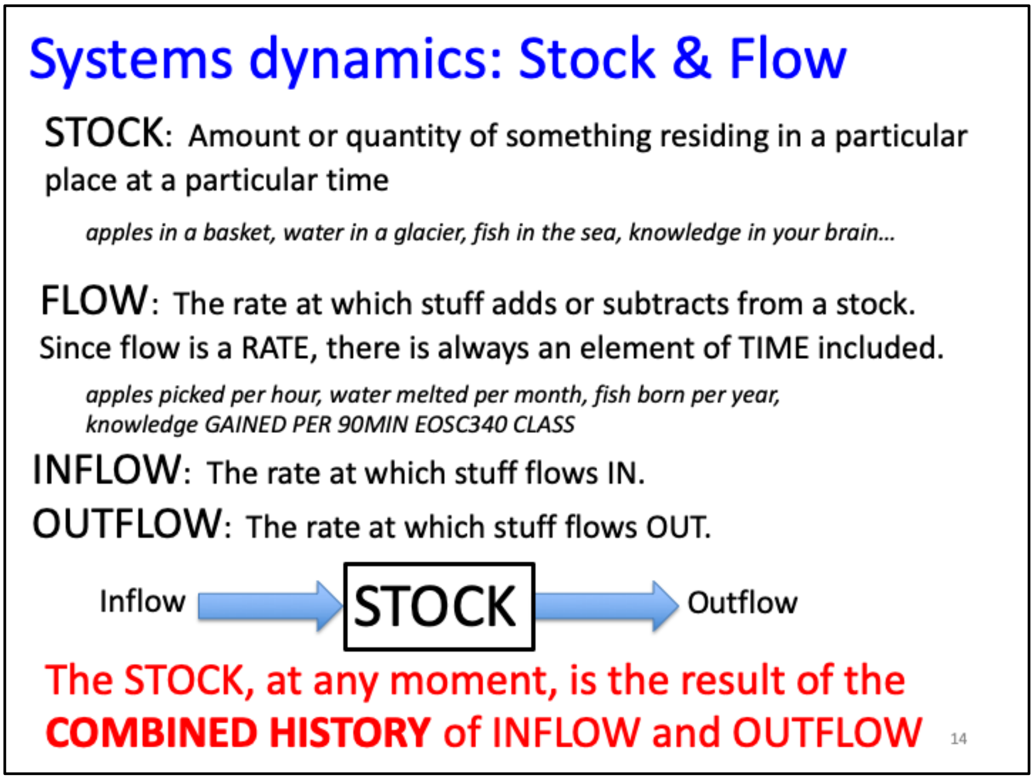


FALL 2013 – did not talk about this. Just said “you all have read about this, so I’m not going to talk about it”

LGs: Define stock, flow, and feedback

Explain how the combined history of inflows and outflows determines a stock

Link to previous clicker Q sequence.

Systems dynamics: Stock & Flow

The **RATE AT WHICH THE STOCK CHANGES**, is the difference between the INFLOW & the OUTFLOW

$$\frac{d(stock)}{dt} = Flow_{in} - Flow_{out}$$

If $Flow_{in} = Flow_{out}$
→ no change in stock over time
→ EQUILIBRIUM

If $Flow_{in} \neq Flow_{out}$ → stock will change over time

15

Fall 2013 – did very briefly – said, again, that they'd read about it already, and it's going to be relevant for the worksheet.

LG: Explain how the combined history of inflows and outflows determines a stock
Predict what happens to stocks and flows when a system is perturbed

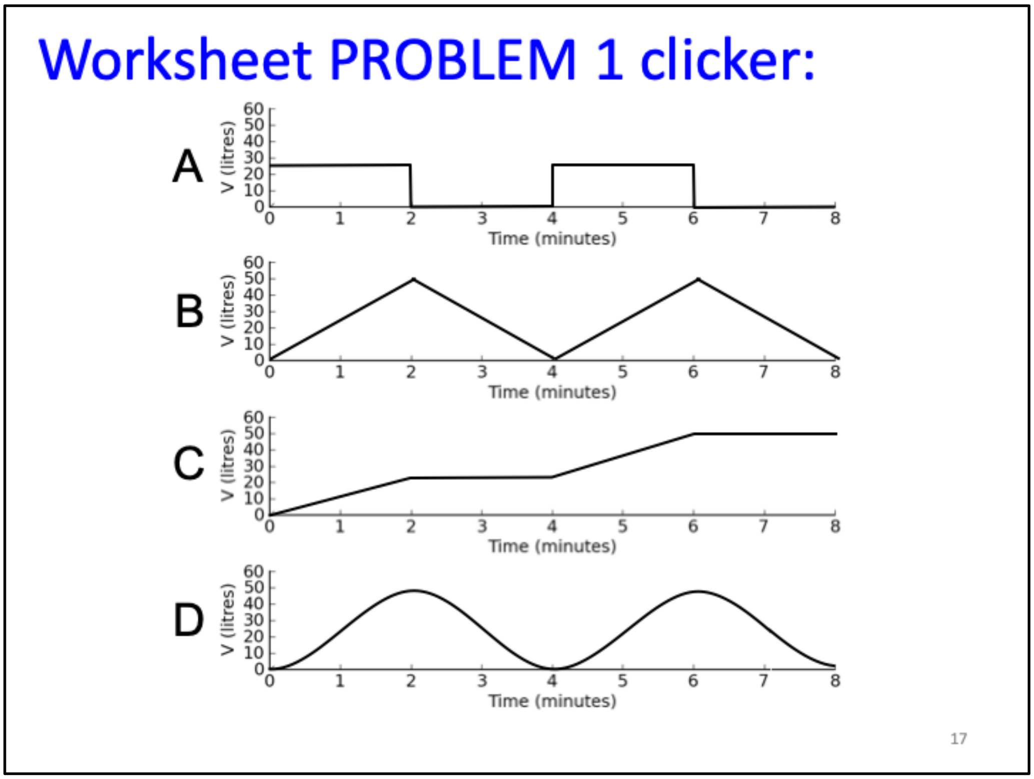
If you have in inflow rate of 3 apples per minute and an outflow rate of 1 apple per minute, your stock will change by +2 apples per minute.

Stock & Flow Worksheet

Work in pairs or 3s. Once you have a pair or a 3, raise your hands and we'll get you a worksheet

16

Jordan's worksheet, using Q1, modified 2, modified 3 (still need to modify)



ANSWER: B

Bring blank worksheet for doc cam. Go through answer, drawing on the paper on the doc cam.

Worksheet PROBLEM 2 clicker:

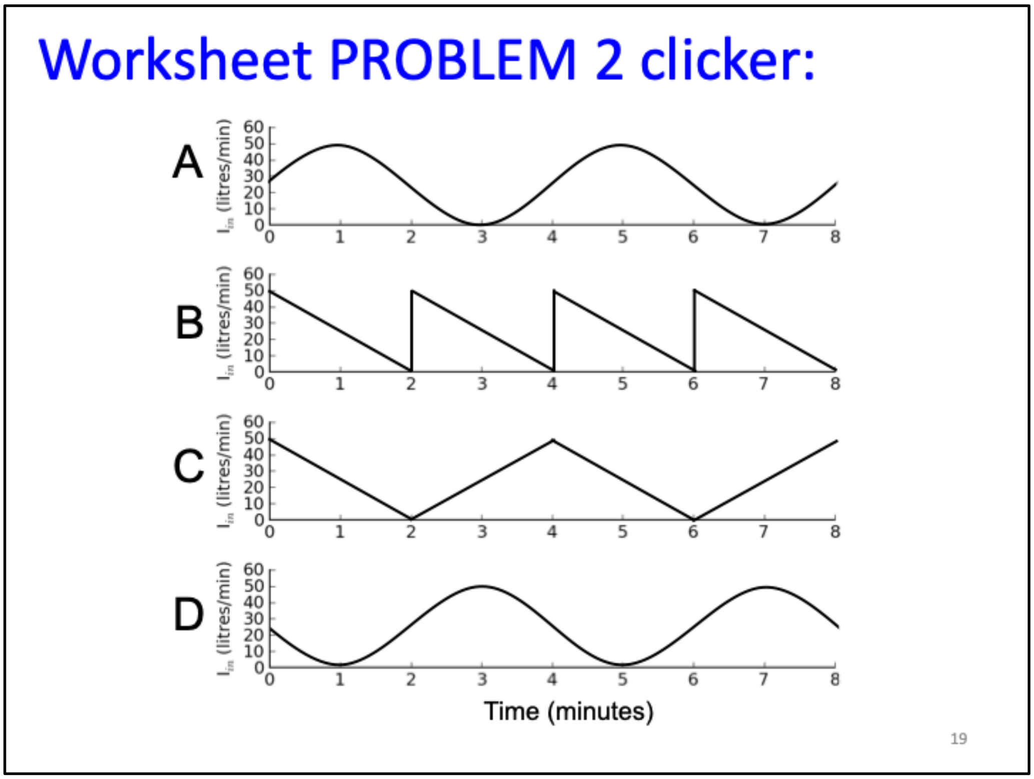
Worksheet problem 2:
At what minute are inflow and outflow equal?

A. 0
B. 1
C. 2

18

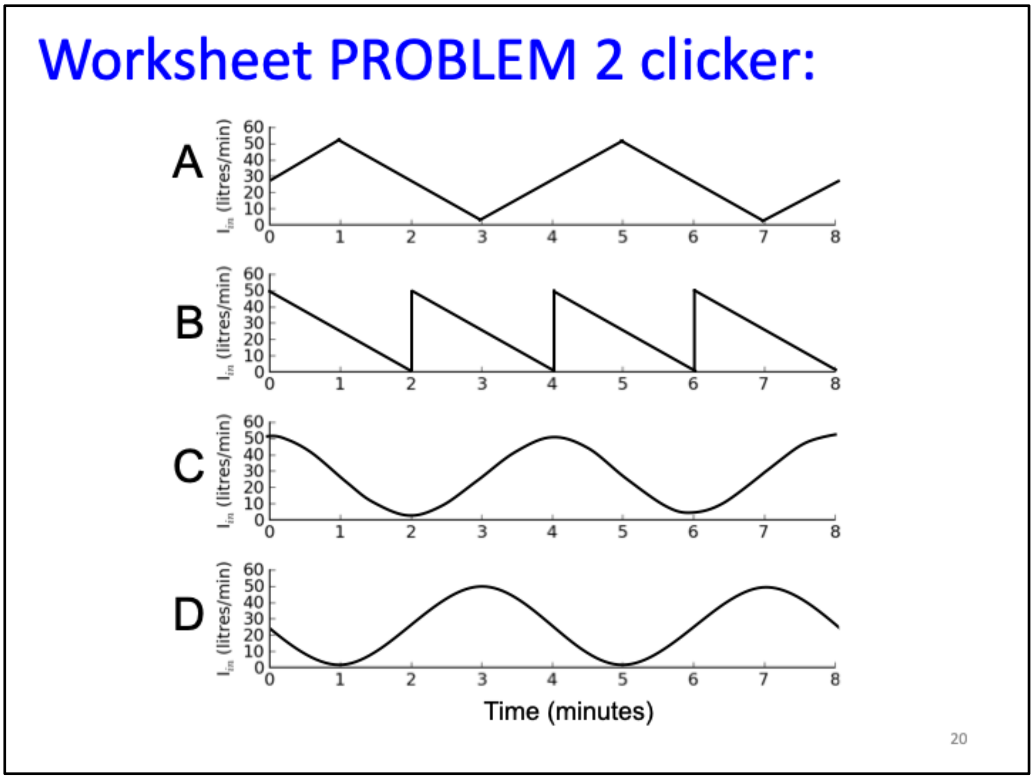
ANSWER: B

Fall 2014: Did a second on-the-fly clicker question: At what minute are inflow and outflow equal? A. 0 B. 1 C. 2 Got a split between B and C, then did it again and got mostly B (good).



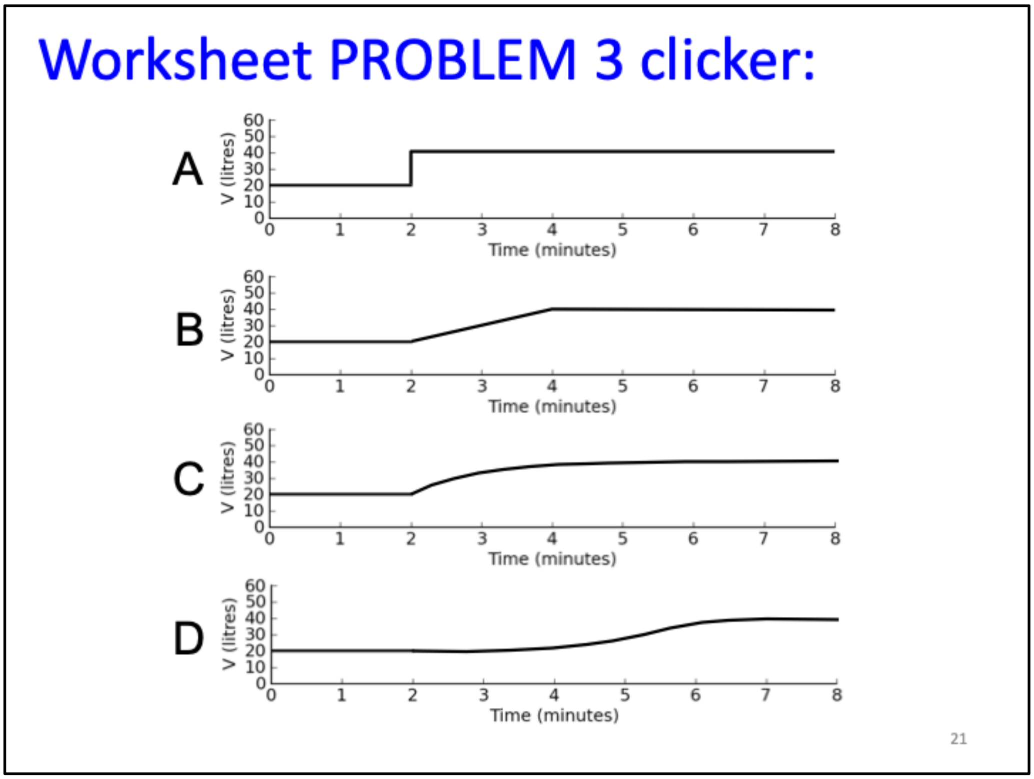
ANSWER: C (ALSO SHOW NEXT SLIDE)

They might have created a sine curve, but the phase of neither A nor D is appropriate.
[series of parabolas]
Warn the students before this clicker question that there are a couple of viable lines they might have drawn. Only one of the choices in the clicker question is viable though. When choosing, they should choose the one that best follows the pattern of highs and lows that they generated.

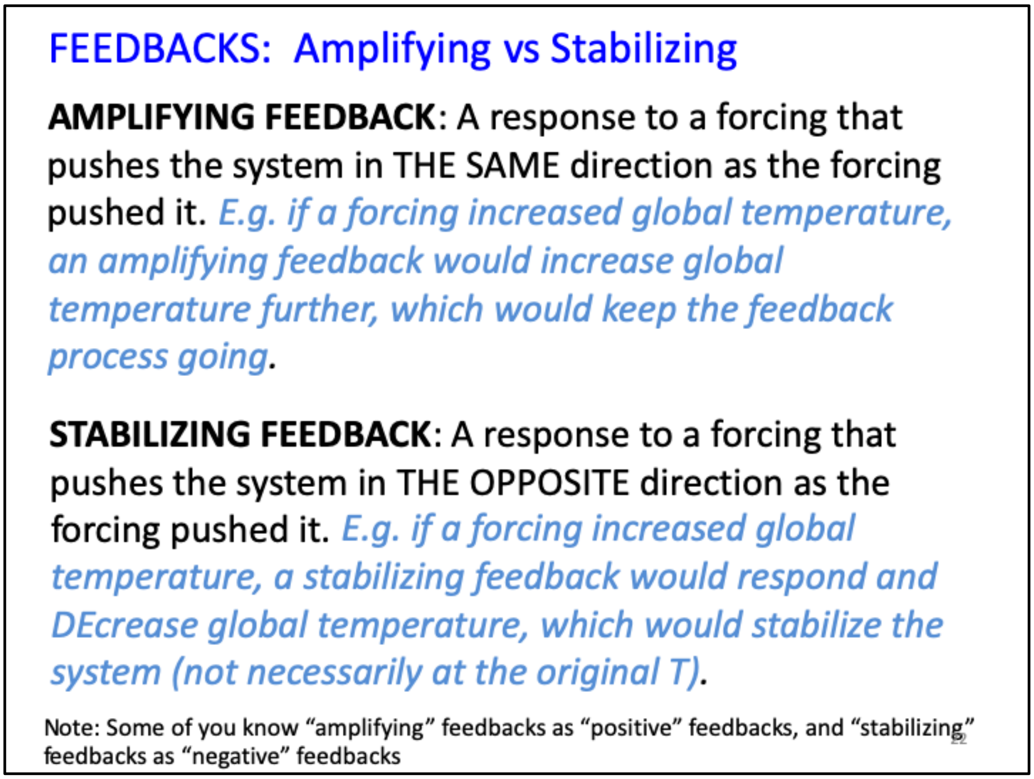


ANSWER = C

Alternate answer choices turning the right answer (C) into a curve rather than straight lines. Made A have straight lines, same phase as before.
ANSWER: C
They might have created a sine curve, but the phase of neither A nor D is appropriate.
[series of parabolas]
Warn the students before this clicker question that there are a couple of viable lines they might have drawn. Only one of the choices in the clicker question is viable though. When choosing, they should choose the one that best follows the pattern of highs and lows that they generated.



Fall 2013 – I accidentally went through an explanation of this on the doc cam, before showing them the clicker question.
ANSWER: C

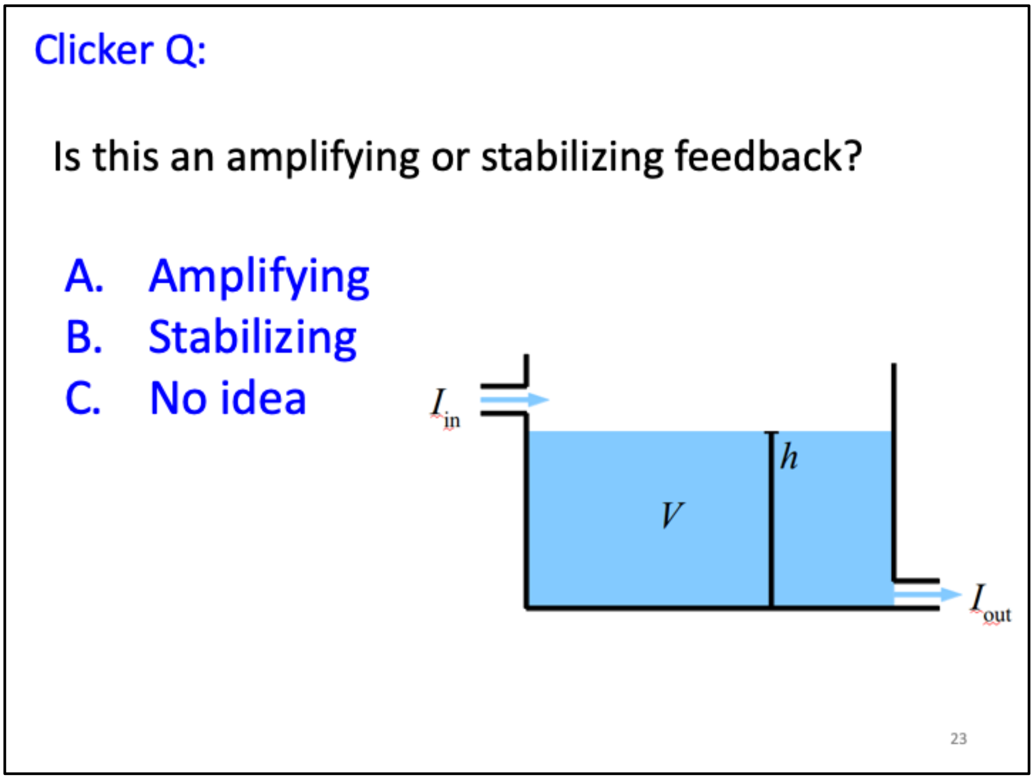


Fall 2013- this was the last slide shown. Didn't get to the feedbacks examples. Fall 2013 – because I skipped the clicker question for Q3 on the previous slide, I made this into a clicker question, corresponding to the question about whether Q3 is an amplifying or stabilizing feedback. So this is the screenshot. A = amplifying, B=stabilizing. Forgot that this clicker question is on the next slide.

LG: Define climate "forcings" versus climate "feedbacks, with examples of each

Trenberth, K. E., Fasullo, J. T., & Kiehl, J. (2009). Earth's Global Energy Budget. *Bulletin of the American Meteorological Society*, *90*(3), 311–323. doi:10.1175/2008BAMS2634.1

Try to create some microphone feedback?
Hansen uses the terms (+) and (-) feedback.



LG: Define climate "forcings" versus climate "feedbacks, with examples of each.

ANSWER: B. The perturbation increases the water volume (stock), which increases the outflow, which lowers the water volume. An amplifying feedback would be one in which, say, increasing the volume of the tub cause more particles to clog the drain, increasing the volume even further.
Note that the water level stabilizes NOT at the original level, but at a new, higher level, after the faucet is turned up (inflow doubled).

Trenberth, K. E., Fasullo, J. T., & Kiehl, J. (2009). Earth's Global Energy Budget. *Bulletin of the American Meteorological Society*, *90*(3), 311–323. doi:10.1175/2008BAMS2634.1

Now with math

- You have 5 gigatons of carbon and two sources, one adding 0.5 Gigatons per year and another source that is increasing every year. In other words, something like:

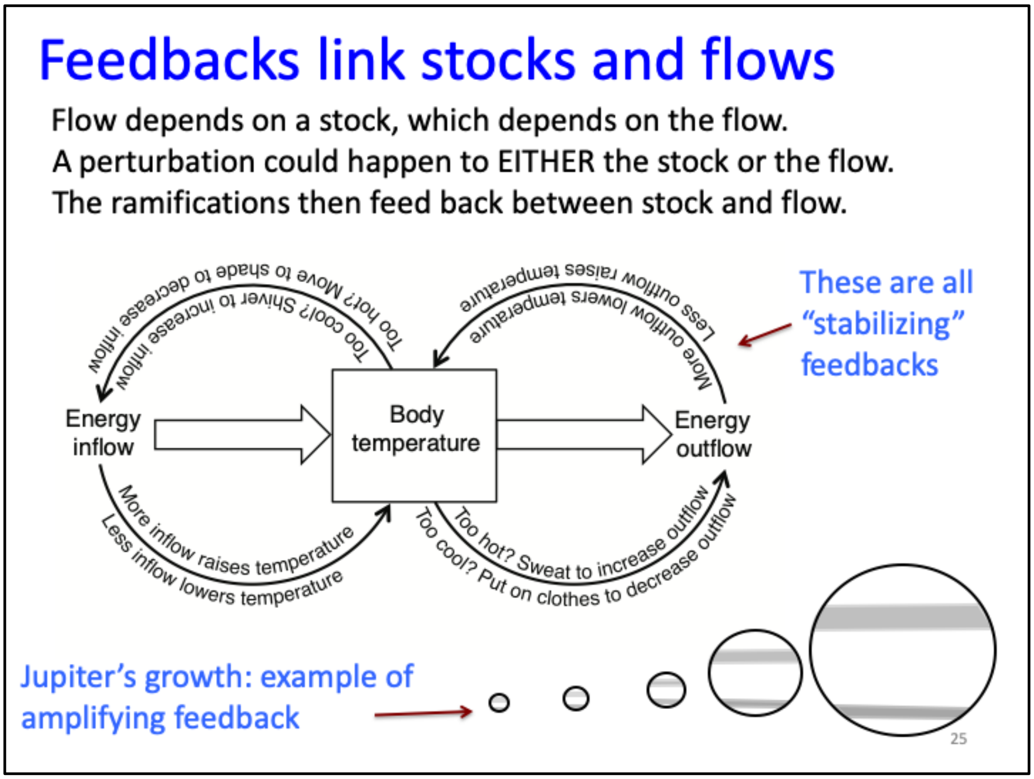
$$\frac{dy}{dt} = y' = 0.5 + 0.1t$$

  - After 10 years how many Gtons of carbon are there? i.e. what is y(10)? Pick the closest answer.

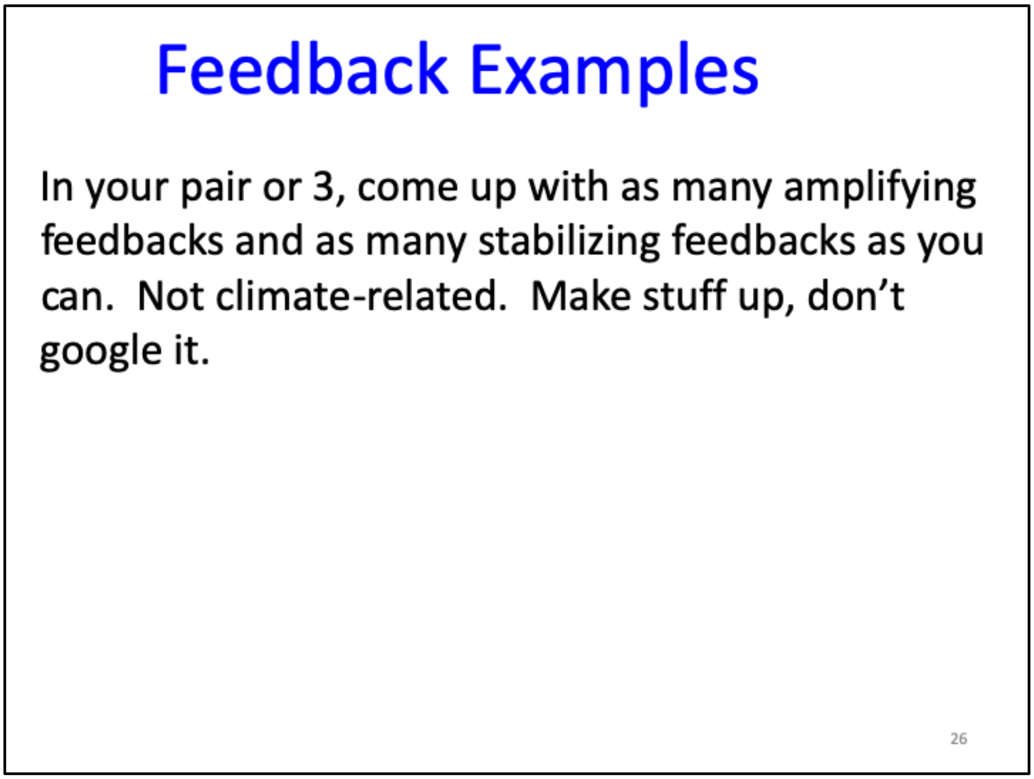
A) 2 Gt
B) 5 Gt
C) 15 Gt
D) 20 Gt
E) A little help please

24

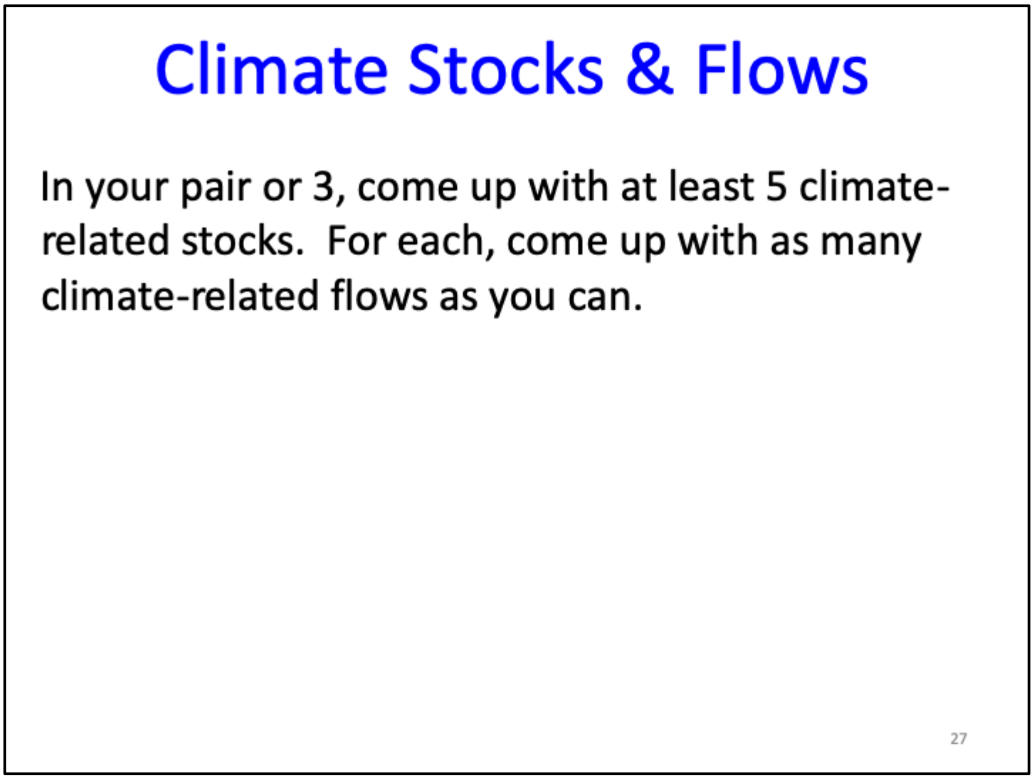
C=5, 0.5*t + 0.1*t**2/2. + 5 = 5 + 5 + 5 = 15 -- followup – add a feedback?



e.g. here perturb inflow. System may change to stabilize inflow directly or to adjust the outflow.



New activity – use if there's time.
Fall 2014: Started this with 7 minutes left in class. Didn't debrief it though.



New activity – use if there's time.

Summary

1. Earth's climate system is essentially a whole bunch of interconnected stocks, flows, and feedbacks.
2. The combination of inflows and outflows over time determines a stock.
3. Both stocks and flows can be perturbed. When a perturbation happens, the system responds.
   - Perturbations in stocks can influence flows, which in turn can influence stocks again.
   - Perturbations in flows can influence stocks, which in turn can influence flows again.
4. Amplifying feedbacks destabilize a system by reinforcing perturbations. Stabilizing feedbacks counteract perturbations and help move a system toward a stable state.

28