Module 2

Lecture 1

Modeling the Spread of Viruses

Sarah Groves, Ph.D.

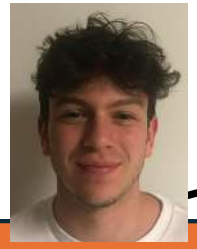
Shayn Peirce-Cottler, Ph.D.



Module 2:



Directors of Product Development



Sam



Micaiah



Katrina



Hudson

Engineers

Elmqvist	
1	Kaitlyn Cole
	Jake Carnell
2	Priya Shan
	Owen Sines
3	Aryan Mhaskar
	Lauren McElfresh
4	Jack Marchesi
	Yancy Martinez Alfaro
5	Abhiram Ruthala
	Tahseen Azad
6	Conner Looney
	Delaney Broderick

Langer	
1	Tomas Daniel
	Theresa Breckley
2	Kai-Tang Tseng
	Lauren Kim
3	Karinna Fink
	Roy Chen
4	Sara Elster
	Dani Folks
5	William Marschall
	Reagan Oswald
6	Mohamed Elfaki
	Isabel Vikesland

Kamen	
1	Christian Grosso
	Vish Ramineni
2	Kat Horn
	Kiran Spencer
3	Luke Friscola
	Christina Johnson
4	Isabella Imburgia
	Amelia Luongo
5	Grace Lee
	Zain Abed
6	Isabella Orlando
	Hayden Rue

Fung	
1	Molly Janousek
	Dane Wleklinski
2	Makayla Adams
	Kidus Belay
3	Eunela Manzano
	Ashley Hayden
4	Oge Ikem
	Megan Sullivan
5	Asma Sannulah
	Melis Ozdemir

Oral Presenters for Module #2

Structure for this module's assignments

- You will have 2 GitHub check-ins + your final project.
  - First check-in: **due Friday, 2/27 at Midnight**
  - Second check-in: **due Monday, 3/9 at Midnight**
  - Final project: **due Tuesday, 3/17 at Midnight.**
  - I suggest you complete the homework from each lecture **by the following class time** to keep up with the Module (in red on last slide of lecture)
  - This may require you to work outside of class with your partner
- You will have a few smaller assignments on GitHub. These should not take longer than 30 min and I will try to give a week/weekend notice!
  - First smaller assignment: making the repo + optimization code ✅
  - Next smaller assignment: watch ODE lectures and comprehension quiz **due 2/24 at class time**

URGENT NOTICE: NOVEL VIRUS OUTBREAK

CONFIDENTIAL OUTBREAK INVESTIGATION
DAY 1 BRIEF

TO: Industry modeling consultants hired by UVA
FROM: UVA Student Health & Wellness
DATE: February 19, 2026

SITUATION:
An outbreak of a **previously uncharacterized viral illness** has been detected among undergraduate students. Confirmed cases have been reported in multiple residence halls. Laboratory testing confirms a viral pathogen; further classification is ongoing. At this time, only partial case data are available.

Population at risk: 17,900 undergraduate students

CURRENT DATA AVAILABLE
- Daily active case counts for the **first 45 days** of the outbreak
- Case confirmation is based on symptom onset + testing delay (details unavailable)
- No post-peak data are available.

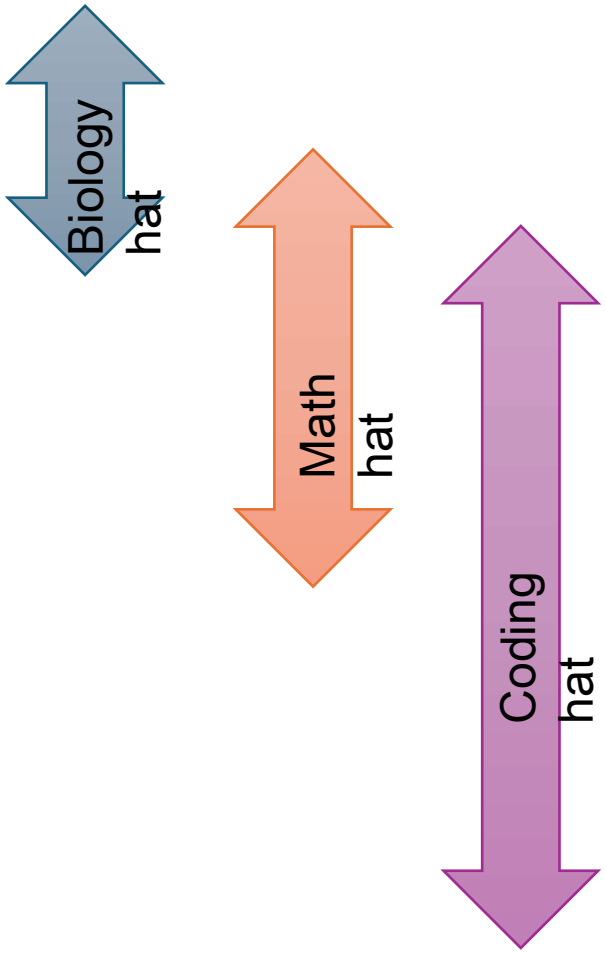
EPIDEMIOLOGICAL FACTS (CONFIRMED)
- Transmission occurs primarily via **respiratory droplets**
- **Pre-symptomatic transmission** has been documented
- No evidence of pre-existing immunity

YOUR TASKS OVER THE NEXT FEW WEEKS
- Estimate the **initial growth rate** from early outbreak data
- **Predict** the spread of the disease and **when cases will peak** using SEIR modeling
- Report best guess for **virus family** based on characteristics of spread
- Recommend a best **intervention strategy to reduce the spread** of the disease while minimizing disruptions to campus life and student learning

What we need to know to meet our goals?

- How do viruses spread within a person and between people?
  - Within a person: **immune system** activation
  - Between people: **epidemiological modeling** of disease spread
- How do we interpret data about outbreaks?
  - Prevalence rate
  - Incidence rate
- How do properties of viruses affect the timing of symptoms?
  - **Latent period**: without symptoms, exposed but not contagious
  - **Infected period**: with symptoms & contagious
  - **Recovered period**: can recovered people become susceptible again?

What's coming up (see ipynb template for structure)



- **Day 1 2/19:** Intro to mystery virus + virus biology
- **Day 2 2/24**: Intro to epidemic modeling parameters (SEIR); estimate initial growth rate/R0
- **Day 3 2/26**: Intro to Euler's method; predict spread of disease and when peak will occur
- **Day 4 3/10:** Modeling interventions; recommend best intervention strategy!
- **Day 5 3/12**: Verification/validation, best guess for virus identification, and tying up loose ends

Project presentations: 3/17

URGENT NOTICE: NOVEL VIRUS OUTBREAK

CONFIDENTIAL OUTBREAK INVESTIGATION
DAY 1 BRIEF

TO: Industry modeling consultants hired by UVA
FROM: UVA Student Health & Wellness
DATE: February 19, 2026

SITUATION:
An outbreak of a **previously uncharacterized viral illness** has been detected among undergraduate students. Confirmed cases have been reported in multiple residence halls. Laboratory testing confirms a viral pathogen; further classification is ongoing. At this time, only partial case data are available.

Population at risk: 17,900 undergraduate students

CURRENT DATA AVAILABLE
- Daily active case counts for the **first 45 days** of the outbreak
- Case confirmation is based on symptom onset + testing delay (details unavailable)
- No post-peak data are available.

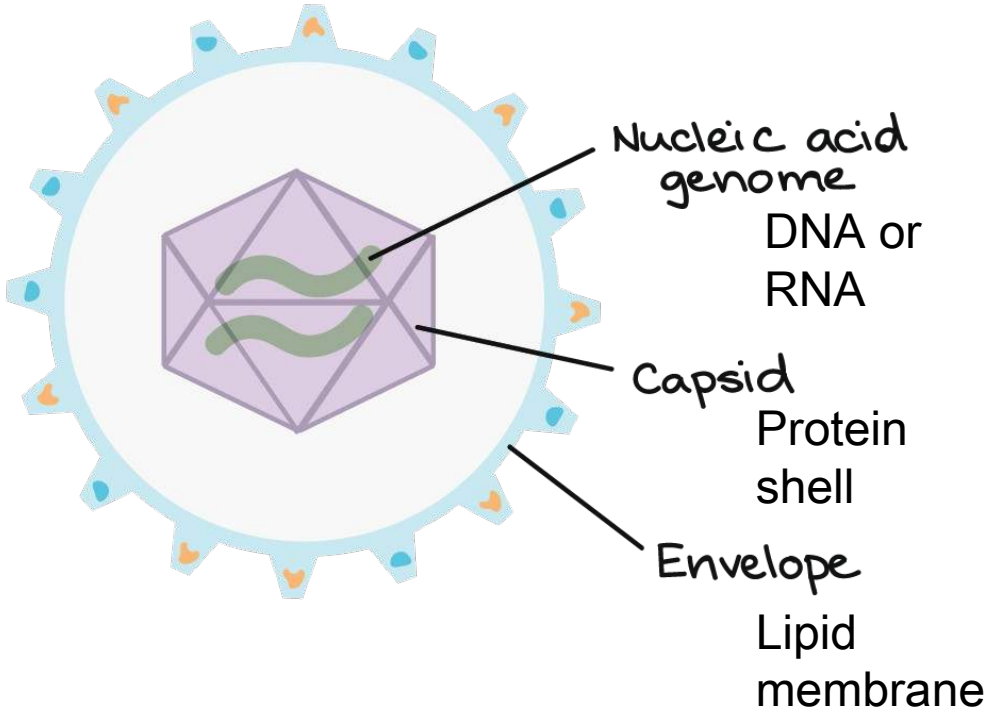
EPIDEMIOLOGICAL FACTS (CONFIRMED)
- Transmission occurs primarily via **respiratory droplets**
- **Pre-symptomatic transmission** has been documented
- No evidence of pre-existing immunity

YOUR TASKS OVER THE NEXT FEW WEEKS
- Estimate the **initial growth rate** from early outbreak data
- **Predict** the spread of the disease and **when cases will peak** using SEIR modeling
- Report best guess for **virus family** based on characteristics of spread
- Recommend a best **intervention strategy to reduce the spread** of the disease while minimizing disruptions to campus life and student learning

What we need to know to meet our goals?

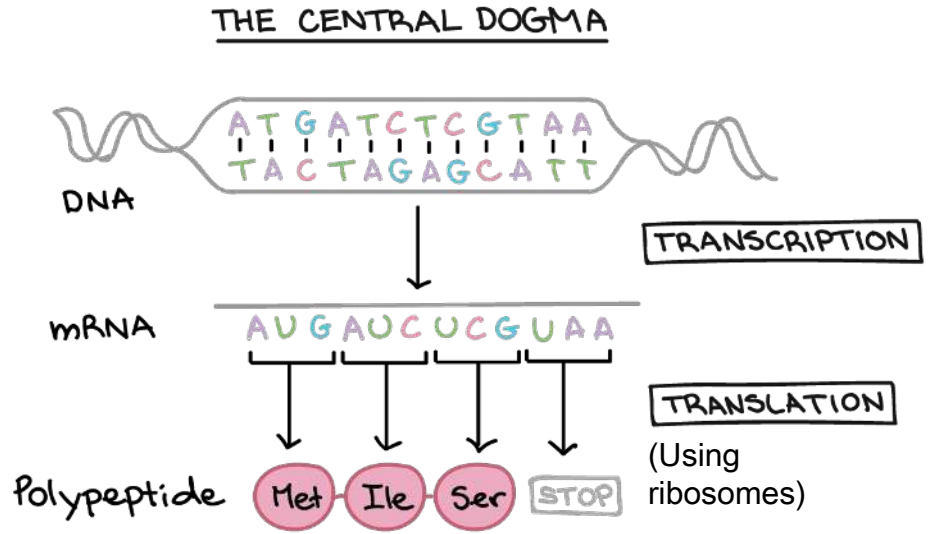
- How do viruses spread within a person and between people?
  - Within a person: **immune system** activation
  - Between people: **epidemiological modeling** of disease spread
- How do we interpret data about outbreaks?
  - Prevalence rate
  - Incidence rate
- How do properties of viruses affect the timing of symptoms?
  - **Latent period**: without symptoms, exposed but not contagious
  - **Infected period**: with symptoms & contagious
  - **Recovered period**: can recovered people become susceptible again?

What is a virus?



Viruses are NOT cells, so they cannot reproduce on their own.

The goal of a virus: get your cells' machinery to replicate its genome.



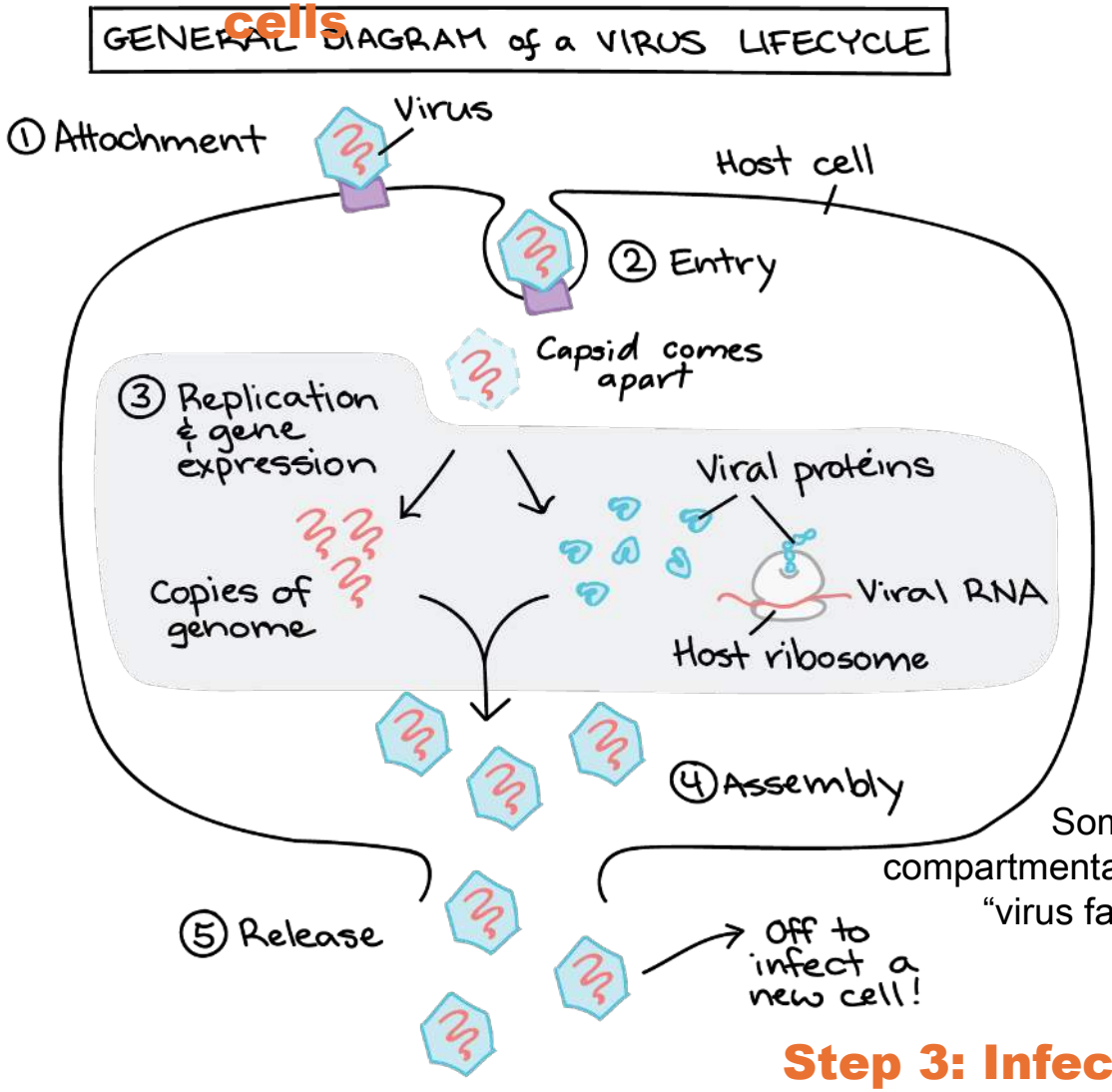
Images from Khan

The infection process

Step 1: Entry into the body

- Infected person coughs, etc.
- Respiratory droplets contain millions of virus particles → you inhale
- Virus reaches cells lining respiratory tract

Step 2: Virus hijacks your cells

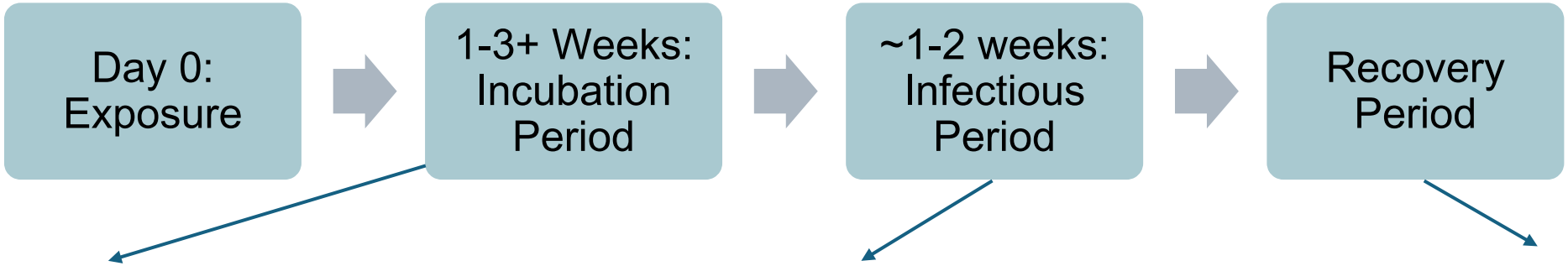


Sometimes compartmentalized in "virus factories"

The speed of this replication cycle determines how quickly infection spreads WITHIN your body.
Fast replication = symptoms appear sooner = you become infectious sooner.

Step 3: Infect new cells!

Timeline of infections: Exposure to recovery



- **Definition**: Time from virus entering your body to when symptoms appear
- **Biologically:**
  - Virus replicating in initial infection site
  - Beginning to spread to new cells and tissues
  - Viral load increasing
  - Usually no symptoms yet
  - Usually not infectious yet
- **Length of incubation period depends on:**
  - Replication speed
  - Viral travel within body
  - Initial dose of virus
  - Immune system activation
- **Examples**
  - Flu: 1-4 days (fast replicator, stays local)
  - COVID19: ~5 days (slow initially, spreads further)
  - Measles: 10-14 days (travel to lymph

- **Definition**: Time when you can transmit the virus to others
- **Biologically:**
  - Viral load peaks in respiratory tract
  - Producing millions-billions of particles
  - Symptomatic, usually
  - Immune system is fighting back
- **Biological factors affecting infectiousness:**
  - Viral shedding
  - Location of infection
  - Symptoms that spread virus
    - Coughing = aerosolize virus
    - Runny nose = contaminate surfaces
- **Examples**
  - Measles: 100K viruses per cough (very high!)
  - COVID19: can be infectious 2 days before symptoms

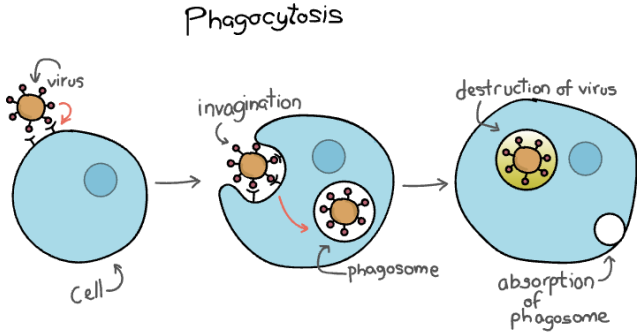
- **Definition**: No longer infectious + gained immunity
- **Biologically:**
  - Immune system has cleared most/all virus
  - Symptoms resolving
  - Memory cells forming
  - Viral load drops below transmission threshold

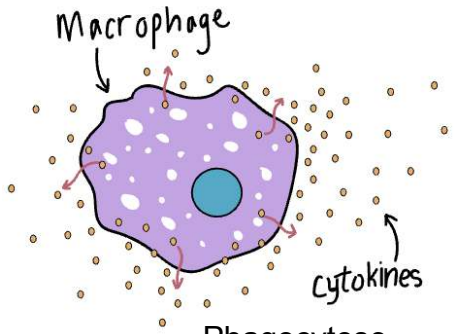
We will use this timeline information to fit our model parameters later!

How does the immune system respond?

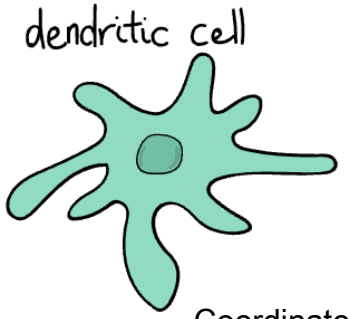
- Immunity happens at the **cellular level** (within your body)
  - Viruses have antigens that you body recognizes as “not self”
- When enough individuals are immune, it affects **population-level** transmission (next class)

• Innate immunity





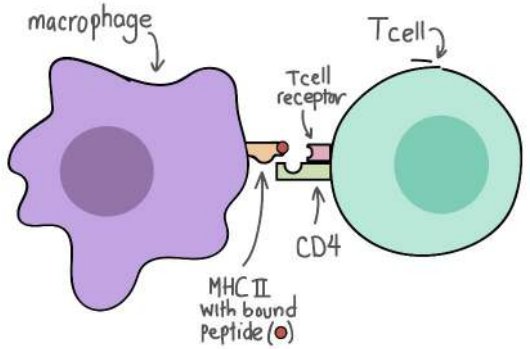
Phagocytose
Recruit through cytokines



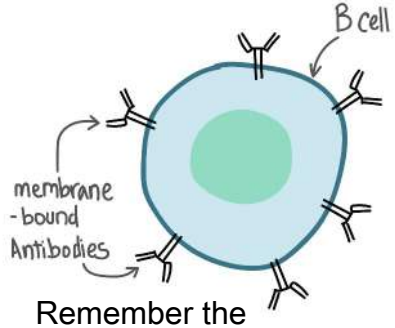
Coordinate attack
Antigen-presenting cells

+ many more that kill threat and virus-infected cells!

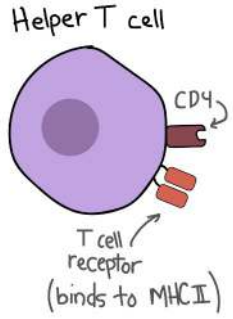
• Adaptive immunity



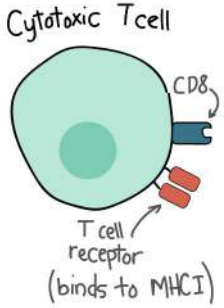
T cells recognize receptors on macrophages & become active



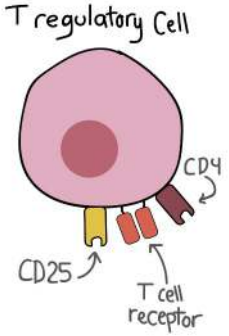
Remember the pathogen



Activate B cells and killer T cells



Kill infected cells & pathogens



Put the breaks on immune system

The Immune System Game

We are going to act as immune system cells, healthy cells, and infected cells to play out the immune response.

Game play

- The game is played over two rounds: **innate** and **adaptive** immunity. In round 1, only healthy cells, infected cells, and macrophages play.
- The game mechanism is rock paper scissors (RPS).
  - “Rock paper scissors shoot” [reveal on shoot]
- Walk up to another player, “challenge” them, play RPS, and then reveal identities to decide each player’s fate!
- When you reveal your identities & determine your cell fates, you can be as secretive or not secretive as you want. You never know who is paying attention!

Rules for everybody

- You cannot lie.
- You should not reveal your identity, unless an activated B cell (in Round 2) requires you to do so.
  - After you play RPS, you quietly reveal your identities to each other to determine what each person's fate is.
- If you are challenged to RPS, you must play.
- You cannot challenge the same player to RPS two times in a row. (i.e. after playing, go find a different person to play against!)

Innate Immunity Round:
Virus-Infected cells VS Healthy Cells + Macrophages

- The goal of the infected cells is to infect all healthy cells by winning RPS against them.
- The goal of the healthy cells is to avoid being infected by winning RPS against infected cells.
- The goal of the macrophages cells is to eliminate infected cells by winning RPS against them.
- However… you don't know who is who!
- The game is over when:
  - All healthy cells have been infected
  - All infected cells have been eliminated
  - After the round time is over, whoever has more players (healthy vs immune) wins.
- The adaptive immunity cells don't play round 1; they hang out in the "lymph nodes." But they can strategize and decide who wants to be each cell type.

Round 1 end

- Was it easy to complete your goal?
- What was your strategy for this round?
- How did this mirror what cells in the body look like under threat from a viral infection?
- Adaptive immunity: did you watch what was happening to come up with any strategies for round 2?

Adaptive Immunity Round:

- Macrophages have a NEW role. When they win RPS, they eliminate an infected cell AND can go activate a helper T cell.
- When a helper T cell gets activated, they can choose to activate a B cell or a killer T cell.
- When a B cell is activated, their goal is to label infected cells by telling others to reveal their identities. If they find an infected cell, they can announce it- “I found an infected cell!”– and give them a sticker label.
  - Note, you can only ask others who are not actively playing RPS.
- When a killer T cell is activated, they:
  - Automatically eliminate any **labeled** infected cell by tapping them on the shoulder
  - Win ties in RPS against **unlabeled** infected cells.

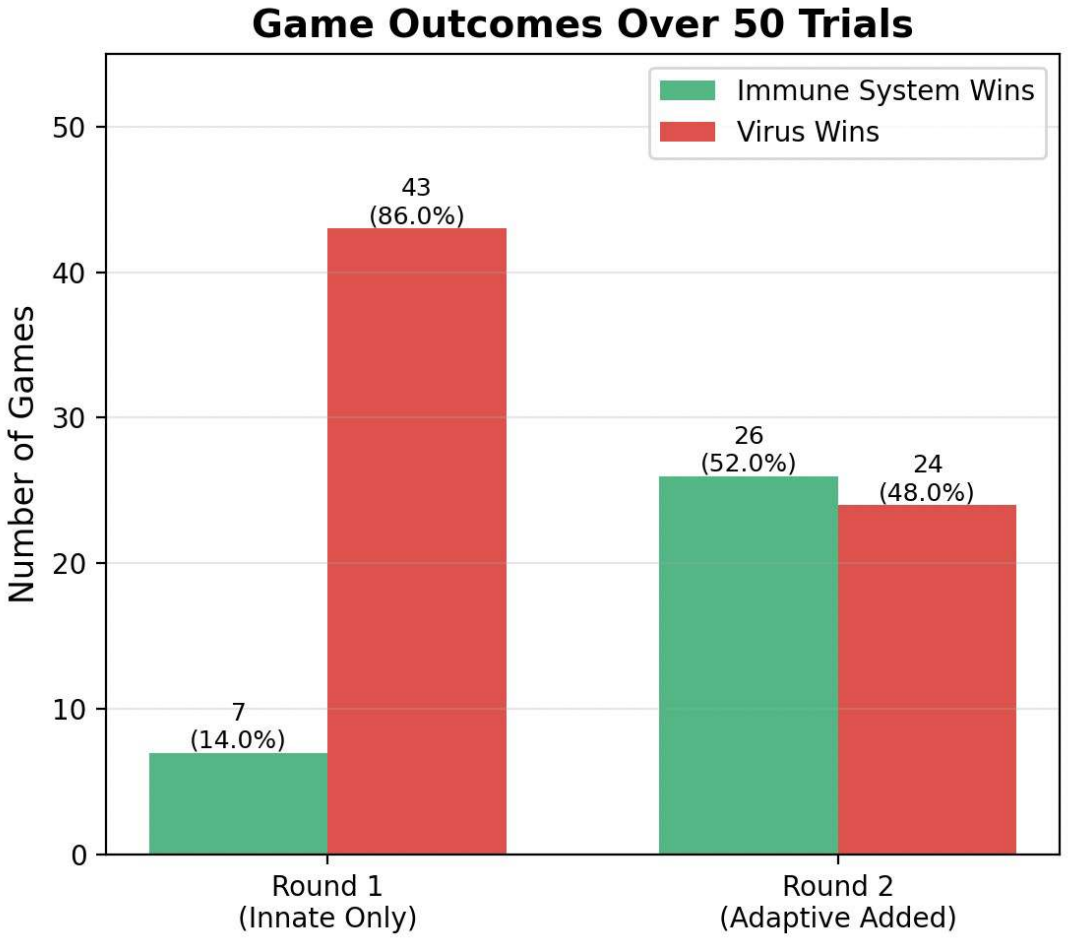
Round 2 end

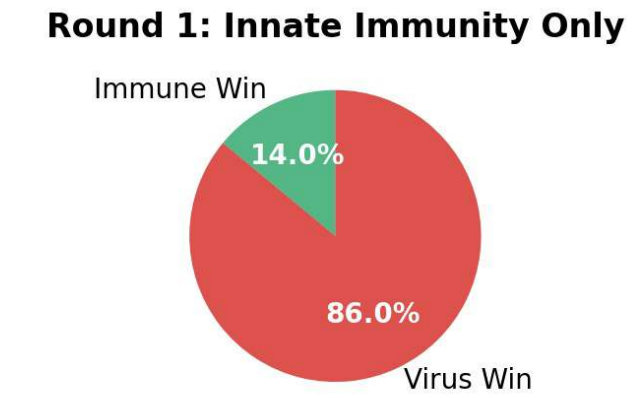
- How did this round compare to round 1?
- What was your strategy for this round?
- How did this mirror what cells in the body look like under threat from a viral infection?

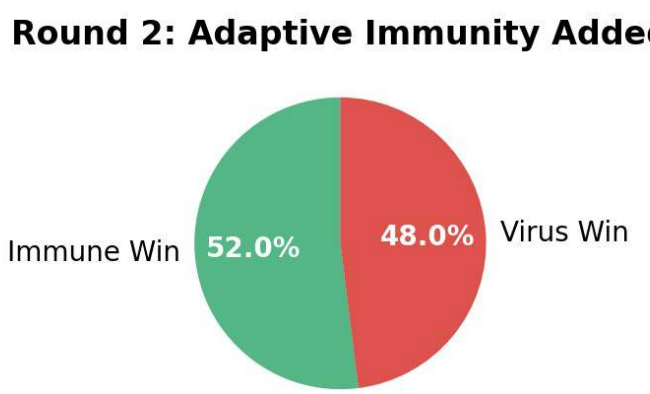
Simulated game play after 10 minutes

```python
# Round 1: Innate immunity only
round1_config = {
    'n_healthy': 23,
    'n_infected': 5,
    'n_macro': 3,
    'n_helper': 0,
    'n_b': 0,
    'n_killer': 0,
    'max_time': 600
}

# Round 2: Adaptive immunity added
round2_config = {
    'n_healthy': 23,
    'n_infected': 5,
    'n_macro': 3,
    'n_helper': 2,
    'n_b': 4,
    'n_killer': 4,
    'max_time': 600
}
```







Looking ahead…

- How do we use biology at the **individual** level to understand outbreaks at the **population** level?
- What does the initial data release look like?
  - HOMEWORK: Plot the DATA RELEASE #1 data: day vs. active infections, and answer the following questions:
  - What do you notice about the initial infections?
  - How could we measure how quickly its spreading?
  - What information about the virus would be helpful in determining the shape of the outbreak curve?
- HOMEWORK due next class: Watch ODEs background video and take video comprehension quiz