# *Modeling Disease Spread*

## INTRODUCTION

This worksheet will guide you through the “SIR Model Basics” section of the *Modeling Disease Spread* Click & Learn. You will learn about and use a model called the **SIR model** to simulate disease spread in a small population. This activity will deepen your understanding of the SIR model and help you connect the parts of an SIR graph to population changes during a disease outbreak. The concepts you’ll learn here can be applied to many real-life diseases.

This worksheet has six parts:

- In **Part 1**, you will explore infectious diseases and how they spread.
- In **Part 2**, you will learn the components of the SIR model and how it works.
- In **Parts 3–5**, you will use the model to simulate the spread of a pathogen in a small population. You will also build, analyze, and compare SIR graphs in unvaccinated and vaccinated populations.
- In **Part 6**, you will reflect on some assumptions and limitations of the SIR model.
- In the **extension**, you can use another SIR simulator to model disease spread on a larger scale.

## MATERIALS

- access to *Modeling Disease Spread* Click & Learn
- computer or mobile device that can be used to take screenshots, download files, or print images

## PROCEDURE

As you go through the Click & Learn, follow the instructions in this worksheet and answer the questions in the spaces provided. Your instructor may provide additional instructions about when to share your answers with your peers or your whole class.

In some parts, you will be asked to create graphs using the simulators. You can record your graphs by downloading, taking a screenshot, printing, or sketching them. Ask your instructor about which method to use if you’re unsure.

### PART 1: Introduction to Infectious Diseases and Transmission

Open the Click & Learn and read through the “Introduction” section, which discusses factors that influence infectious diseases, how infectious diseases spread, and modeling the spread of an infectious disease.

1. Before watching the video, list three infectious diseases that you have heard of, and which pathogens cause them, in the table below. If you’re unsure, you can do some research online.

| Infectious disease | Pathogen |
|---|---|
| | |
| | |
| | |

2. In your own words, describe how pathogens spread in a population.

**PART 2: What is an SIR Model?**

Continue to the "SIR Model Basics" section. In the "SIR Background" tab, read the section "What is a Susceptible-Infectious-Removed (SIR) model?" and watch the video describing the SIR model.

3. The SIR model divides the population into three distinct groups. In your own words, describe each group in the table below.

| **Group** | **Description** |
|---|---|
| Susceptible | |
| Infectious | |
| Removed | |

4. In the SIR model, both transmission and recovery affect how individuals move from one group to another.
   a. Transmission affects individuals moving between which two groups?

   b. Recovery affects individuals moving between which two groups?

5. Proceed to the "Tutorial" tab. A popup will appear to explain how to use the Outbreak Simulator. You will also learn how transmission probabilities (popup screen 6) and recovery probabilities (popup screen 7) are used to calculate the likelihood of new infections and new recoveries each day.
   a. At the beginning of an outbreak, how would a large transmission probability affect the number of individuals moving *into* the infectious group?

   b. During the middle of an outbreak, how would a large recovery probability affect the number of individuals moving *out of* the infectious group?

**PART 3: Simulate an Outbreak in an Unvaccinated Population**

After completing the tutorial, you are ready to simulate an outbreak. Proceed to the "Simulate an Outbreak" tab to open the Outbreak Simulator.

Select a pathogen to model from this table. All the pathogens in this case are viruses.

| **Pathogen** | **Transmission probability (%)** | **Recovery probability (%)** |
|---|---:|---:|
| Ebola Virus | 15.4 | 14.3 |
| SARS-CoV-2 | 17.3 | 16.7 |
| Mumps virus | 25 | 16.1 |
| Influenza/flu virus | 32.5 | 24.4 |
| Varicella-zoster virus (chickenpox) | 61 | 14.3 |
| Rotavirus | 65 | 8.3 |
| Measles virus | 75.6 | 12.5 |

6. Record the name of your selected pathogen and the transmission and recovery probabilities that you will model below.
   a. Name of pathogen:
   b. Transmission probability:
   c. Recovery probability:

Follow the instructions under "Settings" in the Simulation Board. Enter the transmission probability and recovery probability that you selected into the appropriate boxes.

7. Select an initial case. Record the position of your initial case in the population grid (e.g., 3C, 4E) below.

8. Depending on the transmission probability and recovery probability you selected, the pathogen may spread through the population quickly, slowly, or not at all. Before starting the simulation, predict whether your pathogen will spread throughout the entire population by the end of the simulation (25 days). Explain your reasoning.

Select "Start Simulation" to simulate the spread of the pathogen you selected. We'll assume that no individuals in this population are vaccinated, so skip the vaccination step throughout the simulation.

At the end of each day, record the number of individuals in each group in the "SIR Data Table." Continue the simulation until everyone in the population grid has recovered or you reach Day 25.

9. Once you complete the simulation, answer the following questions:
   a. Describe how quickly or slowly the pathogen spread in your population. For example, how long did it take for the pathogen to begin spreading?
   b. How does the spread you observed in the simulation compare to what you predicted in Question 8?

10. In the table below:
    a. At the top of the last column, record the last day of your outbreak (the day when everyone has recovered or Day 25, whichever comes first).
    b. In the rest of the table, record the number of individuals in each group on Day 0 (i.e., when the initial case was selected) and the last day of the outbreak. You will come back to this data in Part 4 of this worksheet.

| **Group** | **Day 0** | **Day _________**<br>(last day of outbreak) |
|---|---|---|
| Susceptible | | |
| Infectious | | |
| Removed | | |

c. Using this table, the "SIR Data Table," and/or the "SIR Graph" in the Click & Learn, describe how the number of individuals in each group changed throughout the outbreak (i.e., from Day 0 to the last day of the outbreak).

11. Following the guidance of your instructor, download, print, or sketch an image of your graph. <u>Make sure to include your graph when submitting this worksheet, in whichever format your instructor asks for.</u>
12. Examine each curve (line) in the graph individually, then fill in the table below. For each group in the first column:
    a. In the second column, describe how the curve representing the number of individuals in that group changes throughout the outbreak.
    b. In the third column, describe where individuals in that group move to. For example, for the first row, which other group(s) can susceptible individuals move to? Write "None" if no groups fit.
    c. In the fourth column, describe where individuals in that group come from. For example, for the first row, which other group(s) can susceptible individuals come from? Write "None" if no groups fit.

| **Group** | **How does this group's curve change over time?** | **Where do individuals in this group *move to*?** | **Where do individuals in this group *come from*?** |
|---|---|---|---|
| Susceptible | | | |
| Infectious | | | |
| Removed | | | |

Review the "Summary" section of the "SIR Model Basics" module to learn more about the graph.

13. Consider the relationship between the three curves on the SIR graph. Refer to your answers in Question 12 as you consider how individuals move between the three groups.
    a. What happens to individuals in the susceptible group over time?
    b. What happens to individuals in the infectious group over time?
    c. How many days did it take to reach **peak infection** (the day with the most infectious individuals)?
    d. During peak infection, how would you describe the movement of individuals in the infectious group?
    e. What happens to individuals in the removed group over time?
    f. Do individuals enter the susceptible group or leave the removed group in this model? Why or why not?

14. Consider how many individuals become infected during the outbreak.
    a. Which curve(s) shows the number of infectious **cases** (i.e., infectious individuals) on a given day?

    b. How could you determine how many people have been infected up until a certain point in the outbreak?

    c. How many individuals were infected up until peak infection? (For example, if peak infection occurred on Day 13, how many individuals in the population have been infected up to and including Day 13)?

    d. How many individuals were infected over the entire outbreak?

15. Compare your SIR graph to the example graph shown in the "Summary" tab.
    a. Describe one difference between your SIR graph and the example SIR graph. What do you think caused this difference?

    b. What might this mean about your population or the settings (i.e., transmission and recovery probabilities) you simulated?

**PART 4: Simulate an Outbreak in a Partially Vaccinated Population**

In Part 3, you simulated an outbreak in a population in which no one was vaccinated. You will now simulate an outbreak in a population in which one individual is vaccinated each day.

Return to the "Simulate an Outbreak" tab and select the "Reset Simulator" button in the upper-right corner. Enter the same transmission and recovery probabilities as you used in Part 3 (recorded in Question 6) and select the same position for the initial case (recorded in Question 7).

16. Before starting the simulation, answer the following questions.
    a. Predict whether the pathogen will spread throughout the population by the end of the simulation (25 days) if one individual is vaccinated per day. Explain your reasoning.

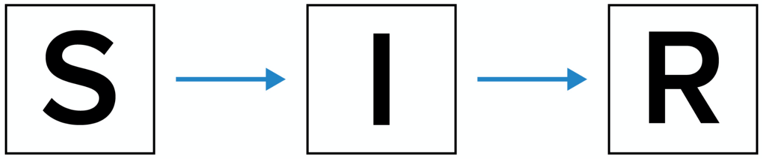
    b. Do you expect the pathogen to spread similarly to how it did in your previous simulation (for the unvaccinated population)? Why or why not?

Select "Start Simulation" to simulate the spread of the pathogen. This time, vaccinate one "Susceptible and Close Contact" (i.e., icons with striped background) each day.

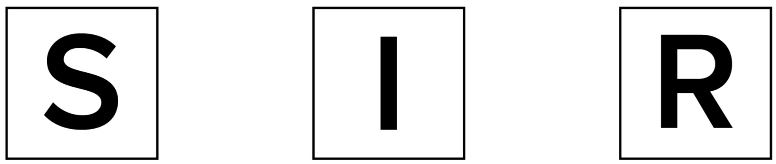
17. Following the guidance of your instructor, download, print, or sketch an image of your graph. Make sure to include your graph when submitting this worksheet, in whichever format your instructor asks for.
18. Once you complete the simulation, answer the following questions:
    a. Describe how quickly or slowly the pathogen spread in your population. For example, how long did it take for the pathogen to begin spreading?

    b. How does the spread you observed compare to what you predicted in Question 16?

19. The arrows in the diagram below represent how an individual in the population could move between the three groups. In this case, a susceptible individual becomes infectious and eventually recovers.




   a. Consider how a susceptible individual *who gets vaccinated* would move between these groups. Describe the directions of their movements or add arrows to the diagram below.




   b. In Part a, which group(s) did the individual move between? Which group(s) (if any) did they skip?

**PART 5: Compare Simulated Outbreaks in the Unvaccinated and Vaccinated Populations**

You will now compare your simulations from Parts 3 and 4.

20. Compare your SIR graphs for the unvaccinated population (Question 11 in Part 3) and the vaccinated population (Question 17 in Part 4).
   a. How are your two graphs similar?

   b. How are they different?

   c. Based on your comparison of these graphs, how did vaccination affect the spread of the pathogen?

21. Complete the table below to compare how many individuals were in each group at the start and end of each simulation.
   a. At the top of the third and fifth columns, record the last day of your outbreak (the day when everyone has recovered or Day 25, whichever comes first).
   b. For the "Unvaccinated population" columns, you can copy your data from Question 10 in Part 3.
   c. For the "Vaccinated population" columns, note that the removed group is separated into recovered and vaccinated individuals. You will have to manually count the number of recovered and vaccinated individuals in the population grid at the end of your simulation, then enter those values into the table.

| Group | Unvaccinated population | | Vaccinated population | |
|---|---|---|---|---|
| | **Day 0** | **Day _________** (last day of outbreak) | **Day 0** | **Day _________** (last day of outbreak) |
| Susceptible | | | | |
| Infectious | | | | |
| Removed (Total) | | | | |
| Removed (Recovered) | | | | |
| Removed (Vaccinated) | 0 | 0 | | |

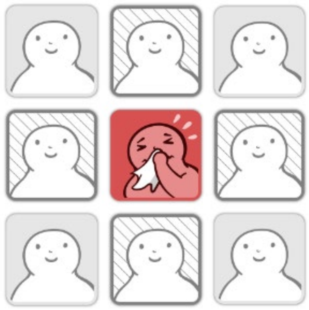
22. For your simulated outbreak in the *vaccinated* population:
    a. How many days did it take to reach peak infection? How does this compare with your answer in Question 13c?
    b. How many individuals were infected up until peak infection? How does this compare with your answer in 14c?
    c. How many individuals were infected over the entire outbreak? How does this compare with your answer in 14d?
    d. How many uninfected individuals remained in the unvaccinated vs. vaccinated population at the end of the outbreak? Use the table in Question 21 to answer this question.

**PART 6: Assumptions and Limitations of the SIR Model**

All models are based on assumptions. In the "SIR Background" tab and throughout the "Tutorial," you learned about various assumptions in our SIR model.

23. Our model, and many others, works by combining assumptions with real data to predict a likely outcome.
    a. Describe one assumption of our SIR model.
    b. Explain when this assumption may not be true in real life.
    c. Why do you think we still made this assumption? For example, why is it helpful to simplify in this way?

24. In the Outbreak Simulator, our model assumes that close contacts are located directly next to, but not diagonal to, infectious individuals. In the image shown here, the icons with striped backgrounds indicate the close contacts of the infectious individual (red icon) in the middle.



    a. If our model assumed that close contacts include those on a diagonal, what would be the maximum number of close contacts per infectious individual?

    b. How would increasing the number of close contacts affect transmission in our model?

25. Models allow us to predict a likely outcome based on certain factors and inputs, such as the transmission and recovery probabilities.
    a. What's one factor that the model in the Outbreak Simulator does not include?

    b. When might omitting this factor from the model be appropriate or useful?

    c. When might including this factor in the model be appropriate or useful?

    d. How might you change the model to include this factor?

**EXTENSION: MODELING AN EPIDEMIC**

In the Outbreak Simulator, you modeled disease spread in a small population of just 36 individuals. Most populations, like those in cities and countries, have many more people. In addition, the Outbreak Simulator lets you vaccinate only one person per day. In real life, vaccination rates might be much higher.

In this extension, you will use another SIR model simulator, the Epidemic Simulator, to model disease spread on a larger scale and with different vaccination rates.

Select the "SIR Model Advanced" section to open the "Simulate an Epidemic" page.

- The top of the page explains the differences between the Outbreak Simulator and the Epidemic Simulator.
- The bottom of the page contains the Epidemic Simulator and some additional information. Select the "How to Use the Simulator" and "How to Model a Partially Vaccinated Population" buttons to read more about this simulator and learn how to model a partially vaccinated population.

Select a pathogen to model from this table. All the pathogens in this case are viruses.

| Pathogen | Transmission Rate (%) | Recovery Rate (%) |
|---|---|---|
| Influenza/flu (1918 strain) | 83 | 24 |
| Influenza/flu (seasonal strain) | 37 | 22 |
| Ebola (2014 epidemic) | 25 | 14 |
| Rhinovirus/common cold | 20 | 11 |
| SARS-CoV-2 (ancestral variant) | 37 | 10 |
| SARS-CoV-2 (omicron variant) | 79 | 8 |

1. Record the name of your selected pathogen and the transmission and recovery rates that you will model below.
   a. Name of pathogen:
   b. Transmission rate:
   c. Recovery rate:

Enter the transmission and recovery rates into the "Settings" section of the Epidemic Simulator.

2. For your first simulation, you will model disease spread in a population of 1,000 individuals with a 30% vaccination rate. Determine the number of initial individuals in each group to reflect this scenario. Assume one infectious individual started the outbreak. List the settings below and enter them into the simulator.
   a. Initial susceptible individuals:
   b. Initial infectious individuals:
   c. Initial removed individuals:

Select "Simulate" to start the simulation. The SIR graph will automatically appear in the "Results" section.

- Adjust "Total Days" in the "Settings" section so you're able to view data points throughout the epidemic (e.g., 60 days). Reselect "Simulate" if you need to readjust the total number of days.
- You can hover over points on the SIR graph to display the number of individuals in each group on a particular day.

3. Following the guidance of your instructor, download, print, or sketch an image of your graph. <u>Make sure to include your graph when submitting this worksheet, in whichever format your instructor asks for.</u>

4. Next, you will model disease spread in an *unvaccinated* population of 1,000 individuals using the same pathogen, transmission rate, and recovery rate as in Question 1. You will need to adjust the number of individuals in each group to model an unvaccinated population. List your new settings below:
   a. Initial susceptible individuals:
   b. Initial infectious individuals:
   c. Initial removed individuals:

Enter your new settings and start the simulation as before.

5. Again, following the guidance of your instructor, download, print, or sketch an image of your graph. Make sure to include your graph when submitting this worksheet, in whichever format your instructor asks for.
6. Compare the graphs for the vaccinated population (Question 2) and unvaccinated population (Question 4).
   a. Describe one similarity between these graphs.

   b. Describe one difference between these graphs.

   c. How does the “removed” curve differ between graphs?

7. When might it be more beneficial to model vaccination like you did in the Outbreak Simulator (Part 4), instead of modeling it like you did in the Epidemic Simulator here?