

## M104B Performance Task Preventing Pandemics

### The Modeling Cycle

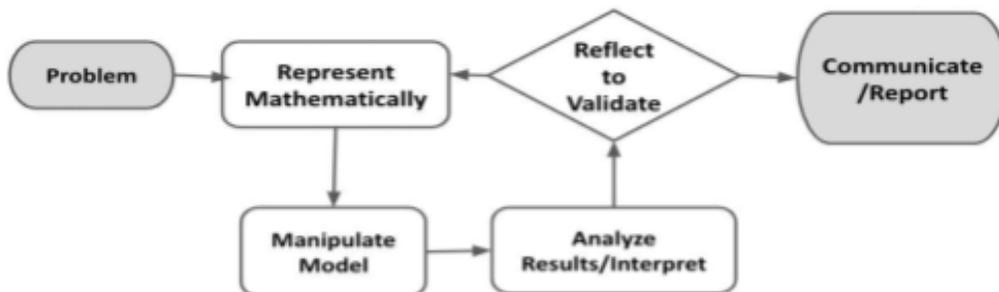
Our world has experienced many pandemics. We are currently trying to eradicate COVID-19. The first reported cases of COVID-19 happened on December 31, 2019, in Wuhan, China. Over the next few months, we would see COVID-19 grow to be a global pandemic. By March 2020, cases in the United States were on the rise. The rate of infection was fast and can be explained with mathematical models.

To follow the course of a disease, we need to know how many people, on average, are infected by an infected person if no precautions are taken. This basic **reproduction number**, or **basic reproduction rate**, is called  $R_0$ .<sup>1</sup>  $R_0$  is about 4 for COVID-19. If mutations occur that make the virus more contagious, the  $R_0$  value increases accordingly. In past infectious outbreaks, the  $R_0$  value for polio was between 10-12; for measles, it was between 12–18. In addition to  $R_0$ , the time,  $D$ , during which the infected person is infectious also plays a role. For COVID-19,  $D$  is about 5 days. For COVID-19, on average, one infected person infects four other people within five days. Watch [Video 1](#) and [Video 2](#) to understand more about what exponential growth means in terms of COVID-19.

The fast rate of infection of COVID-19 prompted the federal and state governments to institute a shutdown of all non-essential activities. Government agencies suggested other preventative measures such as vaccinations, social distancing, masking, increased sanitation and hygiene and other strategies. These preventative measures were intended to “flatten the curve” of new COVID-19 cases.

In this task, you will consider the question, “**How does exponential growth and exponential decay explain the spread and slowdown of COVID-19?**” You will use the models and your takeaways from this task to act as an immunologist and craft a persuasive message the President will use in a press conference. The message should help educate the public about stopping the spread of infection and mitigating future infectious disease and virus outbreaks.

As mentioned already, these rates can be explained with mathematical models. Mathematical models are used to make sense of ideas and phenomena in our world. As illustrated in the image below, the modeling cycle is a process of collecting data about an idea or problem, creating models of that data, analyzing the story told by those models, and reporting the results to the appropriate audience. In this task, you will engage with this mathematical modeling cycle to analyze data, evaluate findings, and identify growth and decay of a global pandemic.



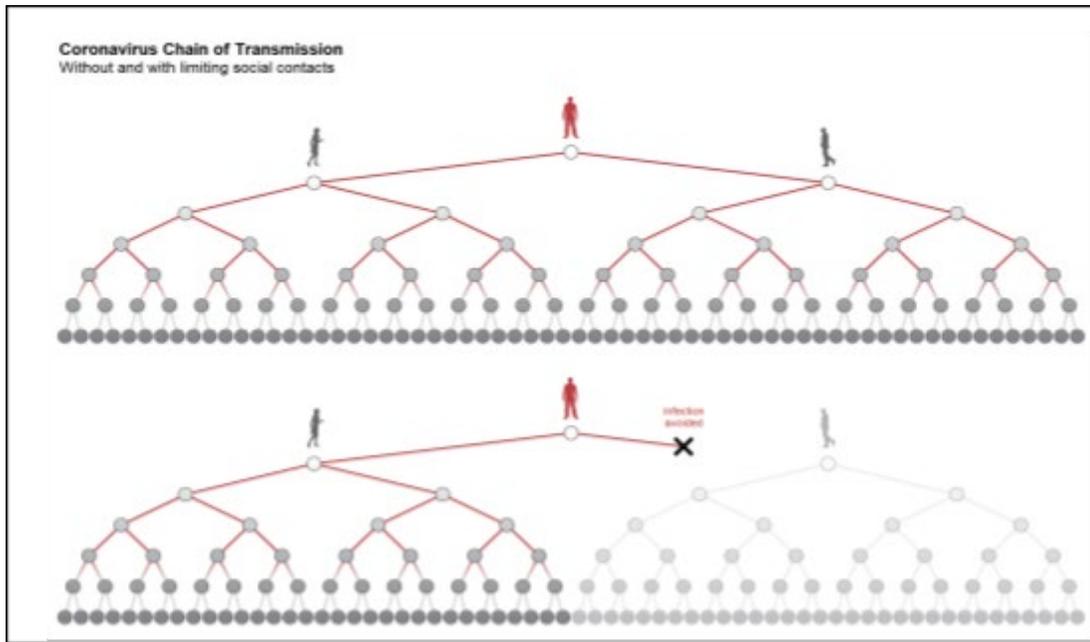
Source: Diagram of Modeling Process. From “Progressions for the Common Core State Standards for Mathematics.”

<sup>1</sup> <https://www.news-medical.net/health/What-is-R0.aspx>

# Preventing Pandemics

## Launch

As the pandemic grew, the numbers associated with the virus grew. Researchers had more data to work with to help identify things like chains of transmission, or how people were spreading the virus to others, and lenses through which to examine the data, like considering whether social contact was being limited or not and how that influenced the spread of the virus. The graphs below are the visual results of some of that data. Inspect the graphs and answer the questions that follow to demonstrate your mathematical, research-scientist thinking.



Source: Growth of COVID-19 Cases & Decay of COVID-19 Cases.

### QUESTION 1



What's going on in the graphs above? Write a headline (think catchy Instagram post) that captures, in your own words, each graph's main idea.

*[Look for reasonable responses (see teacher-facing guide for ideas). Expect students to answer individually on their own forms, as well as participate in a small group or a class discussion.]*

#### Student A

Graph 1- "Wanna contact? Be prepared to combat."  
Graph 2- "No see No Sickness"

*This response meets the expectations of this question. Two catchy headlines that relate to each graph.*

## Student B

If you are just a little more careful, you can drastically slow the spread of disease! In the top graph, each person spreads the infection to two other people, causing the amount of people affected at a given time to increase exponentially. However, in the second graph, the original person infects only one person, causing there to be half as many infected people after the same amount of time as the first one! This shows that if you are only a little more careful, you can have a big effect on public health.

*Although this student only came up with one headline for the graphs, the student went on to explain the meaning of each graph. While this extra level of explanation was not necessary, it shows evidence of the student thoroughly understanding the graphs. Even if two separate headlines weren't provided, this is still an acceptable response.*

## Student C

### **Stay Inside, Save Lives!**

Studies find that people infected by COVID-19 spread disease to half the amount of other people when staying home instead of being out in public.

### **Stay At Home, Stop The Growth!**

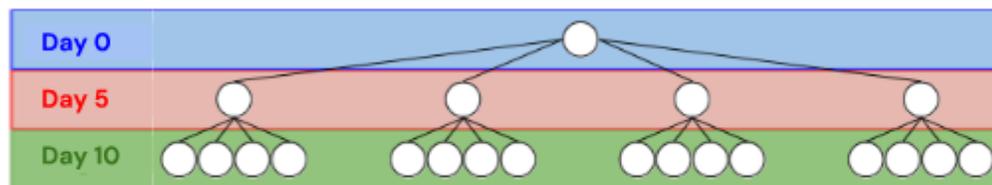
Study finds that COVID cases growth exponentially by 4 per day when infected individuals go out in public.

*Nice, catchy headlines along with a brief explanation of each graph. Having students share their answers to Question 1 in a group discussion will benefit the whole class.*

## QUESTION 2



Analyze this diagram. In your own words, what is it communicating?



Source: Day-by-Day Growth of COVID-19 Cases.

## Student A

The more days you aren't socially distant the more people will get infected by the virus. So what the graph is saying is that you should be more careful when going out. So on the first day you had 1 person infected, because of  $4_0$  it will get multiplied by 4 everyday. So on day 5 there will be 4 people infected because  $1 \times 4 = 4$  then on day 3 there will be 16 people infected because  $4 \times 4 = 16$ .

*This response demonstrates the student is able to identify new covid cases. However, they misinterpreted the number of newly infected people and the total number of people infected. On Day 5, 5 total people are infected because of the 4 new cases and the original case.*

**Student B**

$$R_0 = 4$$

This mean that each time one person is infected that person infects 4 more people

On day 1, only one person is infected. Then on day 5, there are 5 people infected because each day there are 4 more people getting sick from one person. Then on day 10 each one of those four infects another four people, so there are 21 people infected in total.

*This response meets the expectations of this question. The student recognizes the number of new cases and adds the previous infections to represent total cases.*

**Student C**

Every 5 days the people who are infected infect 4 more people every day. The protective measure means that half the amount of the people they infect will Be infected. The graph means that after 1 day, one person is infected. Then on day 5, four people got infected by that one person. Then on day 10, those 4 people infect 4 more people. That means 21 people have covid-19 in only 10 days. This continues for a majority of days.

*This response demonstrates that the student is able to identify the growth of covid over periods of 5 days. The student confuses the infection period of 5 days, and every day in the first sentence. They also seem to confuse the current image with the previous image in Question 1.*

## Problem, Formulate, and Represent Mathematically

In the **Problem, Formulate, and Represent Mathematically** sections, you will examine the growth rate of COVID-19, model its spread using a table, graph, and a formula, and apply that model to calculate and make predictions about new infections and the growth rate. The **Problem, Formulate, and Represent Mathematically Checklist** will be used to ensure you have the necessary components before moving on to the remaining parts of the task.

### Problem

In dealing with a major worldwide pandemic, it is important to understand not only the number of people who are affected, but also the number of people who might become affected and by when. Understanding these things depends on determining **how** the numbers are changing mathematically, **when** they are changing, and **why** they are changing the way that they are, among other factors. The following steps will help you begin to identify this rate of growth and be on your way to understanding and helping solve problems like this in the future!

### Formulate and Represent Mathematically

#### ACTION 1



**Recall or review** the information in the launch and in the graphs presented in the launch.

Considerations:

→ **How**—*mathematically*—did the cases of COVID-19 grow before the preventative measures were put in place?

#### QUESTION 3



Complete the table below.

Time in Days:	0	5	10	20	30	$x$
Number of newly infected people	1					
Total number of people infected						

**Student A**

Time in Days:	0	5	10	20	30	x
Number of newly infected people	1	4	16	64	256	$y=4(x)^2$
Total number of people infected	1	5	21	85	341	

*This student correctly identifies the values of newly infected people increasing by a factor of 4 every 5 days. The last row correctly shows the total number of infected people based on the numbers in the first row. However, the student did not account for the skipped days (day 15 and Day 25), resulting in values that do not match the stated days. The equation reflects understanding of the importance of 4 as a growth factor, but they chose a quadratic rather than an exponential model.*

**Student B**

Time in Days:	0	5	10	20	30	x
Number of newly infected people	1	4	16	256	4096	$4^x/5$
Total number of people infected	1	5	21	277	4373	

*The student identifies the correct values of newly infected people as well as a correct expression to generate these values. The values for cumulative total of infected people are also correct. This student also accounted for the skipped days (day 15 and day 25).*

**Student C**

Time in Days:	0	5	10	20	30	x
Number of newly infected people	1	1024	1,048,576	1,099,511,627 <sup>12</sup>	1.152921505 <sup>18</sup>	$4^x$
Total number of people infected	1	1025	1,049,601	1.099512677 <sup>12</sup>	1.152922604 <sup>18</sup>	

*The student recognizes the role of powers of 4, however the values are inconsistent with the prompt that each infected person infects 4 people every **five** days. The expression in the final column generates the values in the first row. The values in the last row correctly reflect accumulating the totals from each fifth day. During the first consultation, the teacher should help the student recognize their errors and make corrections before continuing with the task.*

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#### QUESTION 4



Create a **formula** to calculate the number of newly infected people for any number of days,  $x$ .

**Student A**

$$y=4(x)^2+1$$

*The student's function builds on their expression from the table in Question 3 (see Student A above). Their work here is consistent with their work in the previous question—identifying 4 as an important growth value but using a quadratic model. The student intended to write a function for the total number of infected persons, as evidenced by the "+1" in their equation.*

**Student B**

$$y=4^{x/5}$$

*This student correctly identified a function rule that matches the prompt. They correctly identified the argument of the exponential as "x/5" to spread the infection rate over a 5-day period.*

**Student C**

The correct equation to represent the growth rate is  $y=4^x$

*This student identified a function that matched the values they generated in their table for Question 3, even though the function does not match the parameters of the prompt. Again, the teacher should encourage the student to correct their errors before completing the remaining parts of the task.*

### QUESTION 5



Create a graph to visually represent the growth of new COVID-19 cases over a 3-week period.

Use current population data to determine the number of days it would take for the number of newly infected people to equal the population of our —

- Class
- School
- State

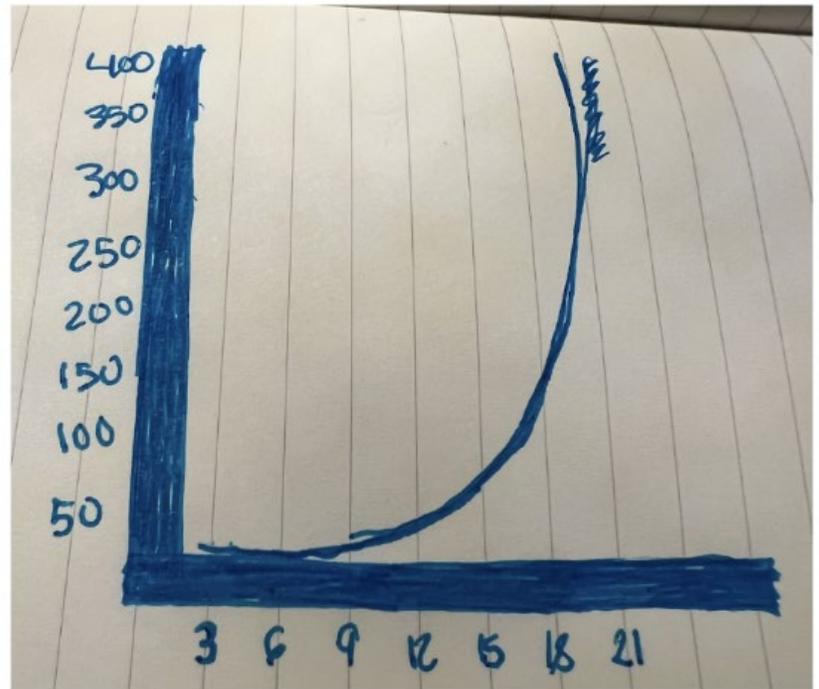
#### Student A

It would take 12 to 13 days for the number of newly infected people to equal the population of our class.

It would take 27 to 28 days for the number of newly infected people to equal the population of our school.

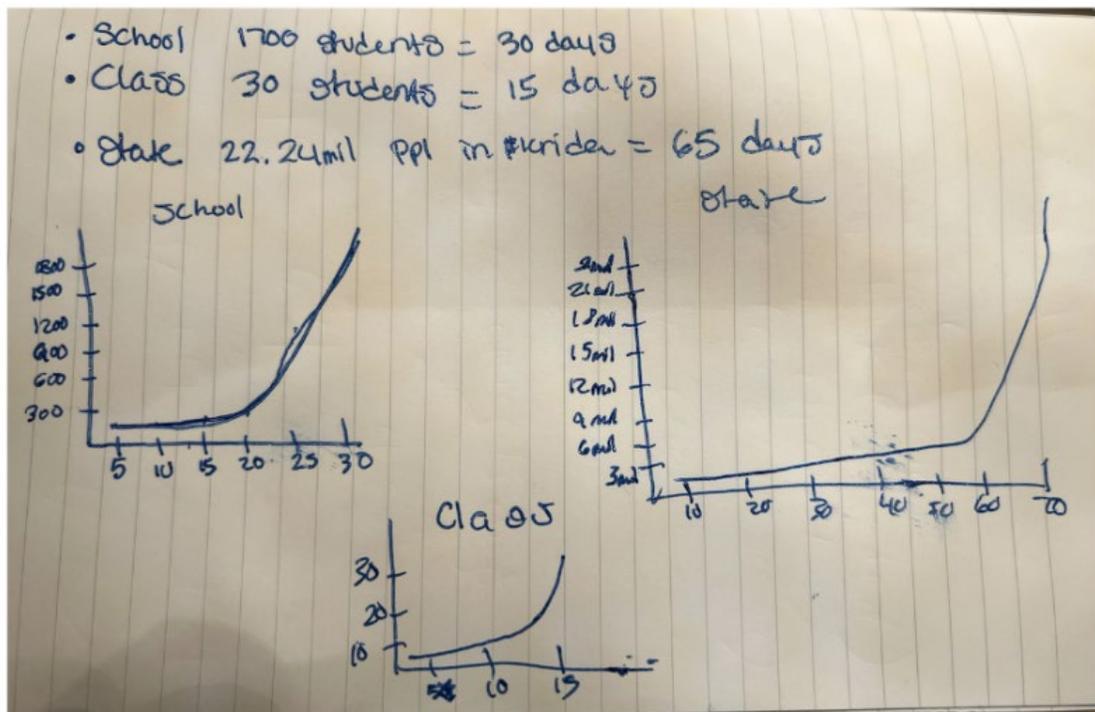
It would take 61 to 62 days for the number of newly infected people to equal the population of our school.

Class: 32  
School: 1825  
State: 22,240,000



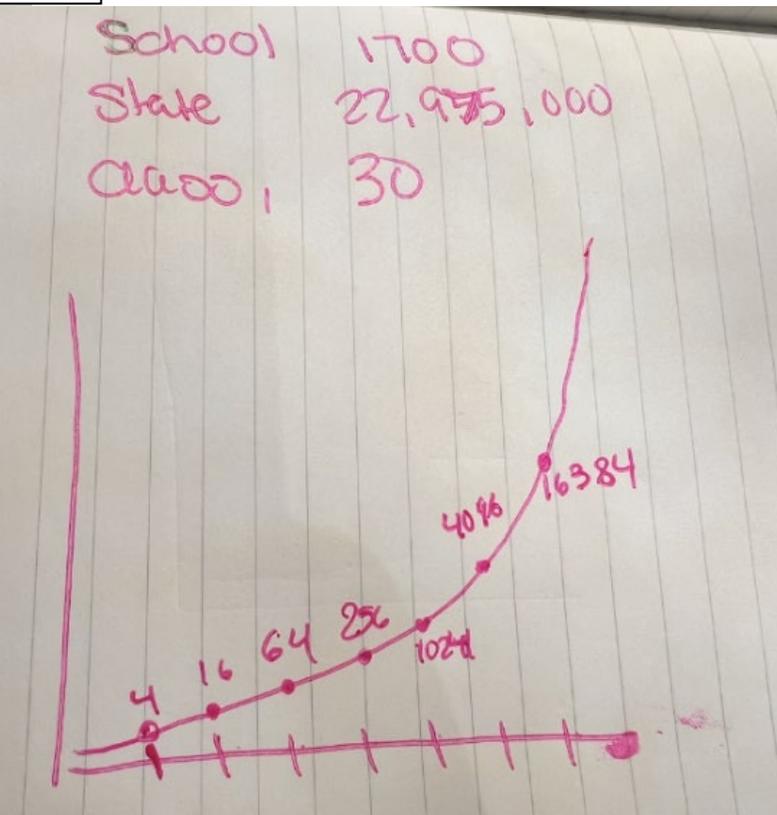
This response meets the expectations of this question. This student accurately creates a graph demonstrating the new covid 19 cases over a 3-week period. They also precisely determine the number of days to reach the population of the class/school/state. This student could benefit from labeling their graph.

## Student B



This student sketched exponential graphs with reasonable scales. The student created individual graphs for each population, instead of 1 graph showing a 3-week period. Additionally, the student's response to the number of days to affect school/class/state were rounded up to the nearest 5. This is most likely due to the prompt being written in intervals of 5 days. This student would benefit from looking at days in between the 5-day periods for more precise values.

## Student C



This student created a visual to show the number of new infections over a 3-week period. The student would benefit from labeling their graph. This student identifies the number of people in their class/school/state, but they do not demonstrate when the number of new daily infections will equal these numbers.

## Problem, Formulate, and Represent Mathematically Checklist

Requirement	Fulfilled?
I modeled the spread of COVID-19 for 0, 5, 10, 20, 30, and x days using a table.	<input type="checkbox"/>
I modeled the spread of COVID-19 over a 3-week period using a graph.	<input type="checkbox"/>
I calculated and explained when the mathematical model would reach the population of the state.	<input type="checkbox"/>
<b>Teacher Consultation:</b>	_____

## Manipulate Model and Compute, Interpret, and Validate

In the **Manipulate Model and Compute**, **Interpret**, and **Validate** sections, you will consider how measures to limit the spread of the virus influence mathematical models of its growth. You will also use formulas and a digital modeling applet to visualize, interpret, and then validate these changes using mathematical terminology and referencing specific variables. The **Manipulate, Compute, Interpret, and Validate Checklist** will be used to ensure you have the necessary components before moving on to the final part of the task.

### Manipulate Model and Compute

#### ACTION 2



Once researchers knew more about COVID-19, responsive measures were put into place to try to stop the spread of the virus as effectively and efficiently as possible. Ideally, effective measures would help slow or even stop the growth rate. Think about the information about growth rates you have learned so far and applied to your mathematical modeling. Now consider how your model might be manipulated to consider the mathematical effects of these measures on growth rate.

Measures like physical distancing and the use of face masks cause the infection to spread more slowly.

- This is expressed by the *effective reproduction number*,  $R_{eff}$ .
- Containment measures (*i.e.*, social distancing, masking) will reduce the  $R$  value.
- If the spread of infection is reduced by  $x\%$ , then the effective reproduction number

would be defined as  $R_{eff} = \left(1 - \frac{x}{100}\right) \cdot R_0$ .

- This means that if the spread of infection is reduced to 20%, then the effective reproduction number  $R_{eff} = 3.2$ .

**Explore** the GeoGebra applet to find out more about how to contain the spread of COVID-19. With the help of sliders, you can modify the effects of physical distancing and face masks. You can also change the time at which each or both measures are implemented. As you explore, think about how the usefulness of each of these preventive measures is represented numerically. You will find the applet here: <https://www.geogebra.org/m/qavutkx5>.

## Interpret

### QUESTION 6



What does “flattening the curve” mean in mathematical terms?

*[Each of the following student responses demonstrate an understanding of “flattening of curve” as diminishing the growth rate. However, all of the responses indicate that students need a deeper understanding of the mathematics within the equation for  $R_{\text{eff}}$ . Specifically, that  $R_{\text{eff}} = R_0$  when no containment measures are enacted and that  $R_{\text{eff}}$  decreases toward 0 as the containment measures increase.]*

#### Student A

From what the graph is showing, I think it's to decrease the rate the graph is increasing. For example, with covid cases, when you social distance the rate of infection decreases. If you also include wearing a face mask, you could reduce how much more people you infect.

*This student response shows an understanding of “flattening the curve” as decreasing the rate of increase. They elaborate on the two stated factors—social distancing and masking—to illuminate their understanding. This student would be encouraged to go deeper into expressing their response in “mathematical terms.”*

#### Student B

To slow down and reduce the curve in the graph. Which means that the curve turned into a straight line.

*This student took a very literal view on the term “flattening the curve.” It would be helpful for the student to elaborate on the mathematics of the impact of these variables on the rate at which the graph increases. Specifically, what does “x” represent in the  $R_{\text{eff}}$  equation?*

#### Student C

Flattening the curve means to literally flatten the curve in an exponential graph. In this case, it would refer to stopping the growth of COVID-19, in the graph that measure Covid cases each day.

*This student understands that the goal is to eradicate the spread of the virus. It would be helpful for this student to emphasize the impacts to reduce the spread occur incrementally as containment measures increase and how this can be understood through the  $R_{\text{eff}}$  equation.*

## QUESTION 7



On the graph in the GeoGebra applet, what does “measures start at” mean?

*[Students’ responses to this prompt frequently reflect students interpreting “measures start at” as a reference to the beginning of the spread, rather than the beginning of the mitigation of the spread by implementing the containment measures.]*

**Student A**

When you start applying the other factors like social distance and face mask wear. If you set the measurement to begin at one, your setting the other things to start taking affect then.

*This response indicates that the student recognizes that the “measures start at” value corresponds to the time when the impact of flattening the curve begins. The teacher might ask this student to add more explicit detail, such as identifying that setting the measure to one means that the curve begins to flatten on day 1 after the initial person is infected.*

**Student B**

Measures start at means they are highlighting the days, as in day 5, day 10 and etc.

*This response indicates that the student identifies that the measures start is related to days. It is not clear whether the student understands that the start of the measurement is when the impact on the exponential curve begins.*

**Student C**

‘Measures start at’ refers to the initial value of the equation, specifically the first day and first cases.

*This response indicates that the student identifies that the “measures start at” value relates to days, however this student response indicates that they do not know that it corresponds to when impacts on the rate of increase of the graph begin.*

## QUESTION 8



What do the decimals of “physical distancing effectivity” and “face mask effectivity” mean?

**Student A**

The decimals of these effectivities mean the overall percentage of how well they stop the spread of Covid-19. For example, 0.5 effectivity for physical distancing means that it prevents 50% of potential cases.

*This response indicates that the student understands that the decimal values of these containment measures are related to the percentage by which the  $R_0$  value is reduced. While this response is adequate, the teacher should still encourage this student to communicate how the mathematics in the equation works for  $R_{eff}$ .*

**Student B**

Physical distancing effectivity and face mask effectivity are other variables that affect the outcome of the equation. The addition of face masks and social distancing as precautions lower the amount of lethal COVID-19 cases.

*This response indicates that the student understands that physical distancing and masking reduces the number of cases of COVID-19. It is not clear that they understand the specific way that the decimal values—as percentages—impact the  $R_{\text{eff}}$ . It is recommended that the teacher ask for clarification from the student during the consultation.*

**Student C**

They show the number that x would equal in order to reduce  $R_{\text{eff}}$  to stop or slow the spread of the virus.

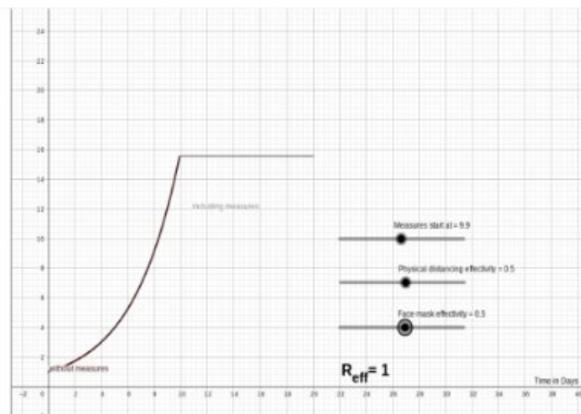
*This response indicates that the student understands that the value of x represents the containment measures which slow the spread of the virus. It is not clear from this response whether the student understands that decimals represent percentages or mitigation or how the calculation of  $R_{\text{eff}}$  works.*

**Validate****QUESTION 9**

What combination of masking and social distancing causes the curve to flatten after 5 days, 10 days, and 30 days? How many cases of infection are you preventing?

**Student A**

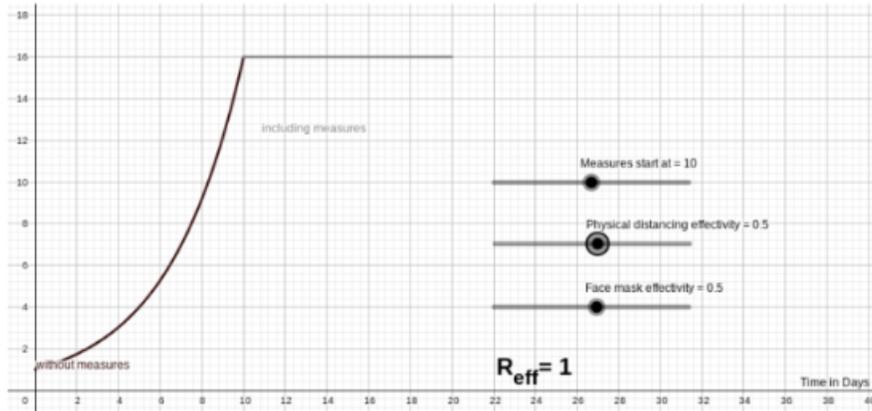
At all 3 points 0.5 effectivity for each measure flattens the curve. So, when the measures are placed at 0.5 effectivity, the curve flattens to the same amount of new cases each day. Meaning, the amount of new daily cases isn't growing, but new cases are still happening.



*This student found a combination of physical distancing and face masking that creates a flat line on the graph, and they infer what the dependent variable of this model represents as the independent variable increases. This student did not provide the number of cases prevented after 5 days, 10 days, and 30 days using this model.*

## Student B

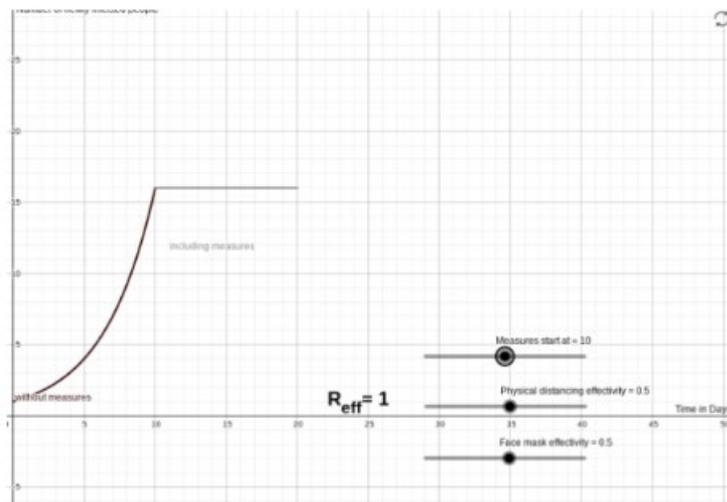
In order for the curve to flatten, the  $R_{\text{eff}}$  must equal to 1. So, days 5, 10, and 30 would all have to have a physical distancing and face mask effectivity of 0.5, or 50%. In other words, 8,105,688,500 cases of infection would have been prevented after 5 days, 8,093,688,500 cases of infections would have been prevented after 10 days, and 8,045,688,500 cases of infection would have been prevented after 30 days.



*This student gave a thorough response. They found a combination of physical distancing and face masking that creates a flat line on the graph, and they correctly calculated how many cases are prevented after 5, 10, and 30 days.*

## Student C

If 50% of people social distance and wear masks, COVID-19 cases will cut in half. This Means 50% of infection cases are decreased.



*This student found a combination of physical distancing and face masking that creates a flat line on the graph, and they recognize that a decimal value of 0.5 represents 50% of people social distancing and wearing masks. However, the student did not correctly explain how many cases are prevented after 5, 10, and 30 days, as they would have needed to calculate these values using the model they created.*

## Manipulate Model and Compute, Interpret, and Validate Checklist

Requirement	Fulfilled?
Explain the concept of <b>flattening the curve</b> in accurate mathematical terms.	<input type="checkbox"/>
Accurately explain the three different variables from the GeoGebra graph.	<input type="checkbox"/>
Mathematically justify my combination of preventative measures after 5, 10, and 30 days.	<input type="checkbox"/>
Accurately calculate the number of cases that have been prevented.	<input type="checkbox"/>
<b>Teacher Consultation:</b>	_____

## Reflect and Report

In the **Reflect and Report** section, you will use the models you created and manipulated to reflect upon what you learned. You will use what you learned to craft messaging about how best to mitigate the spread of viruses and disease in the future with others. The **Reflect and Report Checklist** can be used to ensure you have the necessary components before finalizing your work on this task.

### Reflect

#### QUESTION 10



What have you learned as a result of this task?

#### Considerations:

- How can studying a pandemic that is almost over lead to modeling and data that will serve in limiting the spread of future diseases?
- What is one efficient, concise message that can come from this study to help those in power better respond to a pandemic next time?

#### Student A

Studying a pandemic that is almost over can help prevent future diseases that are in similar circumstances. As an example, we can use models & graphs from the prior pandemic to infer the effectivity face masks and physical distancing will have on future diseases. This will allow for us to enact limitations on the spread of the disease more efficiently and quickly. With this in mind, it's important for those in power to acknowledge previous data of pandemics, as it's capable of suppressing the spread of future diseases with ease.

*This student gives an insightful response.*

## Student B

Learned that exponential functions can get very large, very fast. Before, when we did exponential functions, I was aware that they got large fast, but we always sort of left off as soon as the numbers got too big to easily graph, so I never really comprehended the magnitude of their size.

*The student clearly demonstrates growth of an exponential function and provides an adequate response. However, this response would benefit from further prompting around, "What are the parameters/factors that impact exponential growth?" or, "How does an exponential function model the growth of Covid 19?"*

## Student C

The more people use their mask and social distance from others, they can help to prevent the spread of COVID-19. Even if it is wearing a mask just here and there, or stepping a little farther away from your friends, people can make a difference in flattening the curve and stopping the spread of covid.

*The student provides an adequate response. However, this response would benefit from further prompting around, "What did you learn about exponential growth?"*

## Report

### ACTION 3



You are a world-renowned immunologist and have been given the role of Chief Medical Officer to the President of the United States.

Given your new role, how would you use your knowledge about the spread of infection, the data you have collected, and the impact of COVID-19 to provide guidance to the president on mitigating future infectious disease and virus outbreaks?

**Write** a concise, clear message that the President can use in a press conference. Make sure your message is:

- At least 1-2 paragraphs;
- Technically sound mathematically and conceptually yet understandable by the average household television audience; and
- Persuasive enough to convince the President and the audience that these measures are statistically sound and absolutely necessary.



Have a classmate try reading your message aloud; help each other with a peer review to refine your messages, making them as concise and clear as possible.

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## Reflect and Report Checklist

Requirement	Fulfilled?
I have reflected upon what I have learned in this task and how it can be used to help limit the spread of future infectious diseases.	<input type="checkbox"/>
I created a clear, concise message that is appropriate for the identified audience and platform and will be influential in effecting change.	<input type="checkbox"/>
<b>Teacher Consultation:</b>	_____

*[What follows are three examples of student work related to Action 3. The students were allowed to work in pairs or groups of three on this part of the task.]*

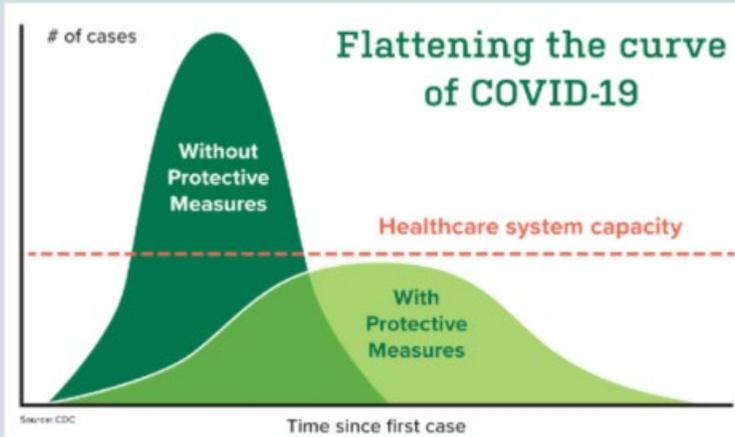
### Group A



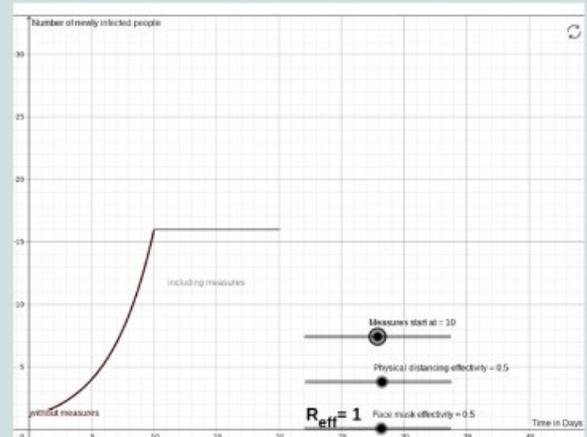
[Link to Video](#)

*These students conducted a press conference in their class and recorded it. They delivered a high-level overview of the information learned in the task and used it to communicate to "The American People."*

## Graphs!



Graph of Covid-19 After Flattening the Curve

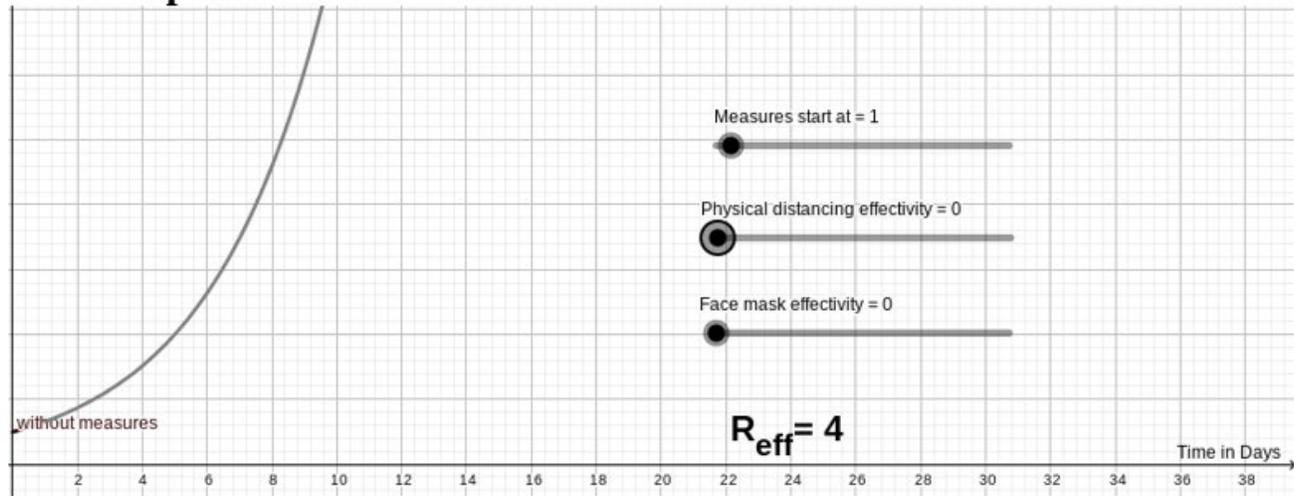


*These students presented this slide to the class to tie in the concept of “flattening the curve” as discussed in this activity with the common language and imagery of flattening the curve that was common during the early stages of the COVID-19 pandemic. It is not clear whether the students understand why the graphs on the left do not look like exponential curves and how these two usages of “flatten the curve” are connected.*

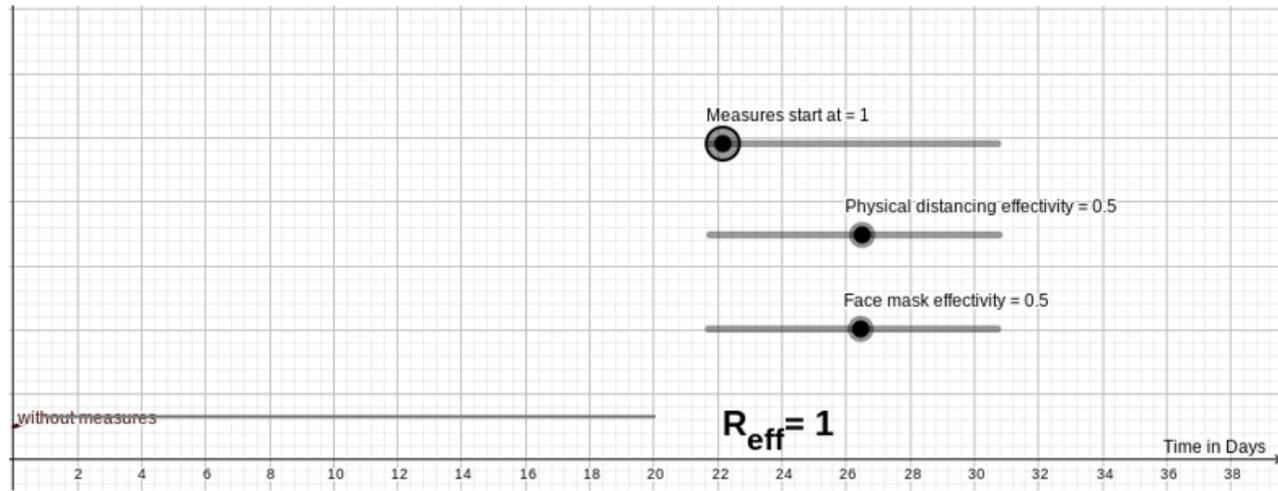
## From Crazy to Controlled

Hello Mr. president, thank you for allowing us to talk to you about the issue of pandemics and the rising issue that covid 19 presents in the country and world. The  $r_0$  is the amount of people someone who is infected with the diseases will infect before they are better. The  $r_0$  of covid 19 is 4. This means someone who is infected will infect four more people before getting better on average. This will lead to an exponential growth of covid 19. If we do nothing, then within only days most of our population will have been infected. This is why it is urgent that we do something to stop the spread of it. This is where social distancing and face masks play a large role in preventing the spread of covid 19. Face masks and social distancing both have an effectivity of 0.5 which means they can cut the amount of people one person infects in half. If we use social distancing and face masks, then we can slow down the spread of covid 19 drastically. If we cut the  $R_0$  in half two times, then it will go from 4 people infected from each person to only 1 person infected by every sick person turning this into a linear graph which will save everyone. If we do not take these measures, then if we start with one person infected it will grow to 1,152,921,504,606,846,976 people infected but if we use the two preventive measures that we propose then we can low the number of currently infected people to four saving many lives.

### Without preventive measures



### With Preventive measures



This is not going to fix the pandemic, but it can give us time to develop a vaccine to stop this pandemic permanently. Another thing we can do to take advantage of this situation is to learn other ways to control the pandemic and then apply this knowledge to future worst pandemics. As you know we have experienced much worse epidemics such as Polio with a  $r_0$  of 10 and Measles with a  $r_0$  of 15. If worse pandemics do occur in the future and they will then we will need to find as much knowledge on how to stop the spread of much worse pandemics to give us time to develop a vaccine. We should learn from what is happening now to prepare us for the future. Thank you for your time, Mr. president and I hope you can issue some of the policies we propose.

*These students wrote a message to the president. Their message was very thorough and delivered important information learned in the task.*

## Extension **Optional**

Students can further engage with the concepts from this task with the extension featured below.

1. Consider the following as it relates to what you have already learned about the mathematics behind the spread of infectious diseases and viruses:
  - a. The percentage of people who are immune (through vaccination or recovery from the virus),  $P_I$  in the total population also affects the  $R_{eff}$  value.
  - b. Taking this effect into account is more complicated because this group becomes larger over time.
  - c. At the beginning of the pandemic,  $P_I$  is zero, whereas at the end, when everybody is immune, the value is 100. The way in which  $P_I$  is used to calculate  $R_{eff}$  is the same as that for physical distancing or face masks:  $R_{eff} = \left(1 - \frac{x}{100}\right) \cdot R_0$
2. Find the minimum value  $P_I$  required to contain the spread of the virus (*i.e.*, to reduce the R value to 1.)
3. What would happen if, at the start, more than 1 person was infected?
4. Compare the percentage of the population that needs to be immunized to achieve herd immunity for the following illnesses:
  - a. COVID-19 ( $R_0 = 4$ )
  - b. Measles ( $R_0 = 15$ )
  - c. Polio ( $R_0 = 10$ )

*[The extension is optional for students. However, one student's response is shown below that is fairly typical of the kinds of responses you might expect from students.]*

2. Find the minimum value of  $P_I$  required to contain the spread of the virus (*i.e.*, to reduce the R value to 1.)     The minimum of  $P_I$  is 75.
3. What would happen if, at the start, more than 1 person was infected?  
More people would end up becoming infected at a faster rate. The  $P_I$  minimum value would also have to be greater.
4. Compare the percentage of the population that needs to be immunized to achieve herd immunity for the following illnesses:

a. COVID-19 ( $R_0 = 4$ )	75%	Diseases that have a bigger $R_0$ need a higher percentage of none infected people to achieve full immunity. Diseases with a smaller $R_0$ need a less amount of people not infected to achieve full immunity. COVID-19 has the smallest $R_0$ , and measles $R_0$ is the biggest $R_0$ .
b. Measles ( $R_0 = 15$ )	93%	
c. Polio ( $R_0 = 10$ )	90%	