

**Real-World Takeaways**

- Addiction to opioids is a public health crisis in the United States.
- Often, patients are prescribed opioids for legitimate pain concerns; over time, many patients experience less relief from the same dosage and so may take more and more to feel okay; eventually, those patients may turn to more powerful and dangerous opioids, like heroin and fentanyl. Overdoses of these drugs is the leading cause of death in Americans under 50.
- Drug companies, doctors, and patients all played a role in created this crisis, and all could play a role in resolving the current opioid crisis in the United States.

**Mathematical Objectives**

- Write and graph an exponential decay function to model a real-world context
- Write and graph an exponential growth function to model a real-world context

**Lesson at a Glance**
**105 min.**

Lesson at a Glance			105 min.
Launch		Watch a short video about the opioid crisis; discuss prior knowledge about opioids and epidemic in the United States.	10 min.
Part One	1	Interpret a graph showing the decline in pain relief a patient might get from the same dosage of an opioid over time and reason about why that decline in relief might occur.	15 min.
	2	Write and graph an equation describing the pattern of pain relief of that standard dosage over time and discuss how that patient might respond.	30 min.
Part Two	3	Write and graph an equation to describe how many doses of an opioid the patient would need to take over time to maintain complete pain relief. Predict when the patient would run out of their prescription and discuss how they might respond.	30 min.
	4	Debate who is most responsible for <i>starting</i> the opioid crisis -- drug companies, doctors, or patients – and who should be responsible for <i>ending</i> it.	20 min.

- L Students watch a news clip about the opioid crisis in Cleveland, Ohio. In the video, a mother explains how her 25 year-old son died from an accidental drug overdose in 2016, one of the many thousands to die in the United States that year. “This pandemic is devastating the very fiber of this country,” the mother explains. “If this were the flu, our county would be under quarantine.”

#### Discussion Questions

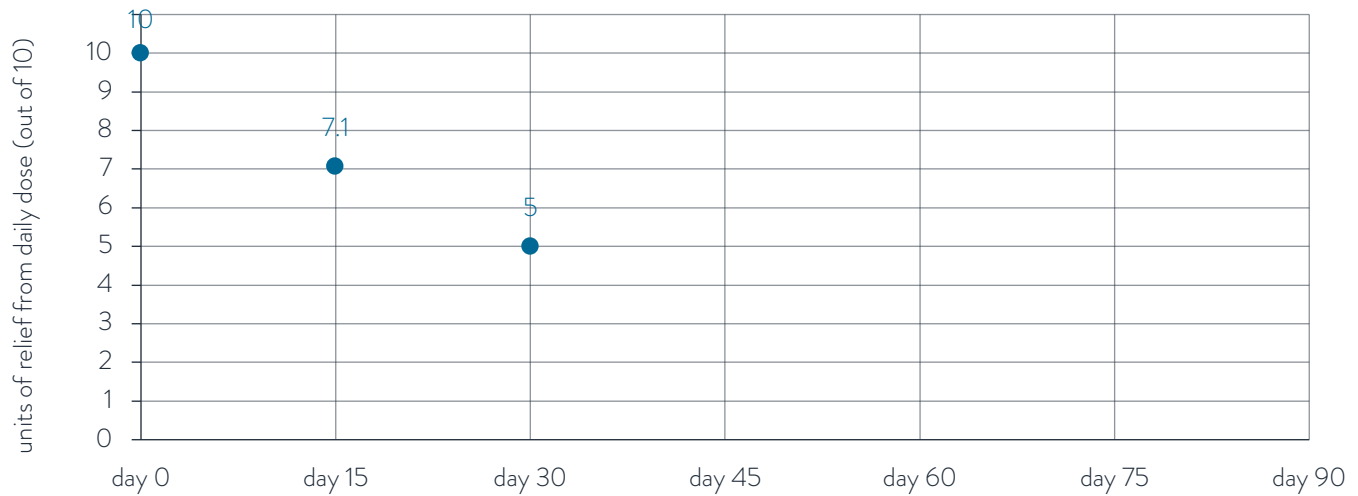
1. *Do you know what an opioid is (or specific examples of opioids)?*
2. *Have you or anyone you know had surgery lately? Did the doctor prescribe pain medication?*
3. *Have you heard of the opioid epidemic in the United States? If so, how do you think it started?*

#### Key Takeaways

- Opioids include powerful pain medications.
- In recent years, thousands of Americans have died from accidentally overdosing on opioids. This has devastated families and communities around the country.

- 1 When someone is injured or has surgery, the doctor may prescribe a medication for pain. Some of the most common pain medications are opioids, which include drugs like Norco, Percocet, Vicodin, and OxyContin.

Imagine someone hurts their back and is prescribed a daily dose of Norco. The points below show how much pain relief they get from this amount on day 0, day 15, and day 30 (where 0 = no relief and 10 = complete relief). How is the effectiveness of the daily dose changing over time, and why might this be happening?



The effectiveness of the daily dose is decreasing over time. In the first 15 days, it decreases by  $10 \text{ units} - 7.1 \text{ units} = 2.9 \text{ units}$  of relief. In the second 15 days, it decreases by  $7.1 \text{ units} - 5.0 \text{ units} = 2.1 \text{ units}$ . The effectiveness of a dose is not decreasing at a constant rate.

The longer someone takes the medication, the less effective it is at providing complete pain relief. This could be because the medication itself gets less and less effective. However, this wouldn't make sense; after all, it's not like the pill changes at all. Instead, it could be that the human body reacts differently to the medication over time. The longer someone takes an opiate, the less pain relief the body gets from a single dose.

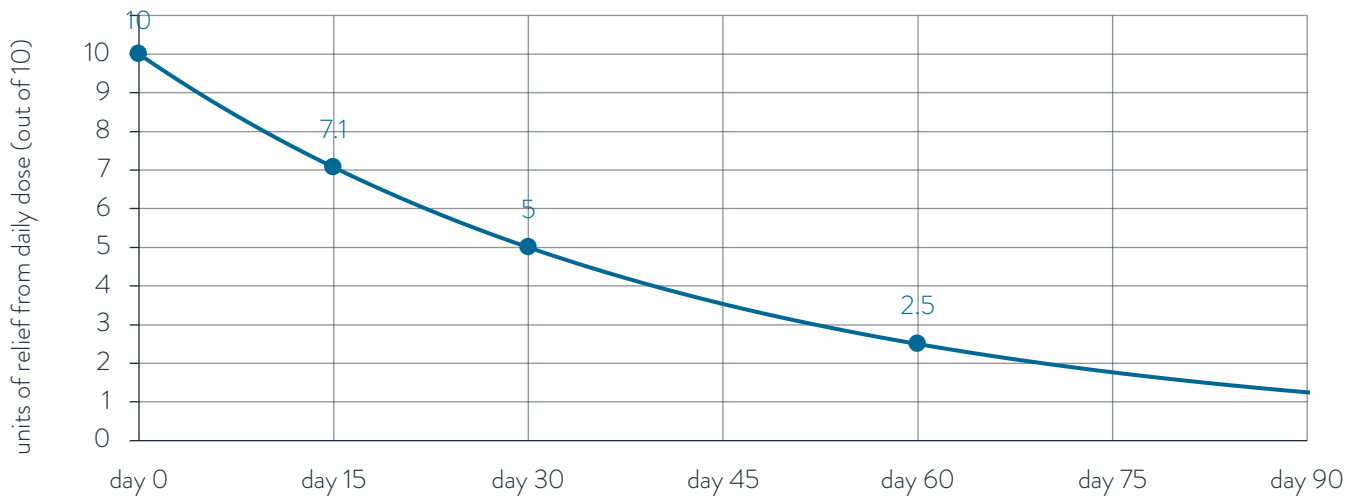
#### Teacher Tip

If you've been following the news about the opioid crisis in the United States, you might have heard the expression "opioid tolerance." That's what the graph above shows: the body becoming more and more accustomed to the pain relief provided by opioids. Even if students are familiar with the crisis, there are two key facts for them to understand.

First, pain isn't physically 'real' the way a broken bone is; rather, pain is *an interpretation by the brain of a signal from the body*. While students may interpret the graph as being about the medication, it's really more about the brain. Second, while the pain-relief figures above are realistic, they're also hypothetical and unique to the sample patient. The body's reaction to opioids will be different for everyone, and students should interpret this lesson as being less about the *numbers* and more about the underlying *phenomenon*.

(BTW, you may be wondering about the difference between *opiate* and *opioid*. As described on the Center on Addiction website, "an opiate is a drug naturally derived from the flowering opium poppy plant. Examples include heroin and morphine. Opioid is a broader term that includes opiates and refers to any substance, natural *or* synthetic, that binds to the brain's opioid receptors. Examples of synthetic opioids include Vicodin and OxyContin." Since all opiates are opioids – but not vice-versa – this lesson uses the broader term "opioids," since it includes both natural and synthetic drugs.)

- 2 For the patient above, write and graph an equation for the pain relief they get from a daily dose of Norco over time. How much relief would they get on day 60, and how do you expect they'd respond? Explain.



#### Method 1:

guess and check to find deterioration rate

Assume effectiveness deteriorates by a constant percent.  
Put another way, it keeps a constant percent each day.

On day 0, relief = 10 units

On day 30, relief = 5 units

Let  $k$  = percent of relief kept

$$10 \text{ units} \cdot k \cdot k \cdot k \dots (30 \text{ times}) = 5 \text{ units}$$

$$10 \cdot k^{30} = 5$$

$k$	Relief after 30 days	
0.90	$10 \cdot (0.90)^{30} = 0.42$	too low
0.98	$10 \cdot (0.98)^{30} = 5.45$	too high
0.97	$10 \cdot (0.97)^{30} = 4.01$	too low
0.977	$10 \cdot (0.977)^{30} = 4.98$	very close

Each day, the recommended dose of medication provides 97.7% as much relief as it did the day before.

Relief =  $10 \cdot 0.977^d$ , where  $d$  = days on medication

On day 15, relief =  $10 \cdot 0.977^{15} \approx 7.1$  units (as expected)

On day 60, relief =  $10 \cdot 0.977^{60} \approx 2.5$  units

#### Method 2:

write and solve equation to find deterioration rate

on day 0, relief = 10 units

on day 30, relief = 5 units

let  $r$  = deterioration percent

$$10 \cdot (1 - r)^{30} = 5$$

$$(1 - r)^{30} = 0.5$$

$$[(1 - r)^{30}]^{(1/30)} = 0.5^{(1/30)}$$

$$1 - r = 0.977$$

$$1 = 0.977 + r$$

$$0.023 = r$$

Each day, the recommended dose of medication provides 2.3% less relief than it did the day before. This is the same as saying that the recommended dose provides 97.7% as much relief as it did the day before.

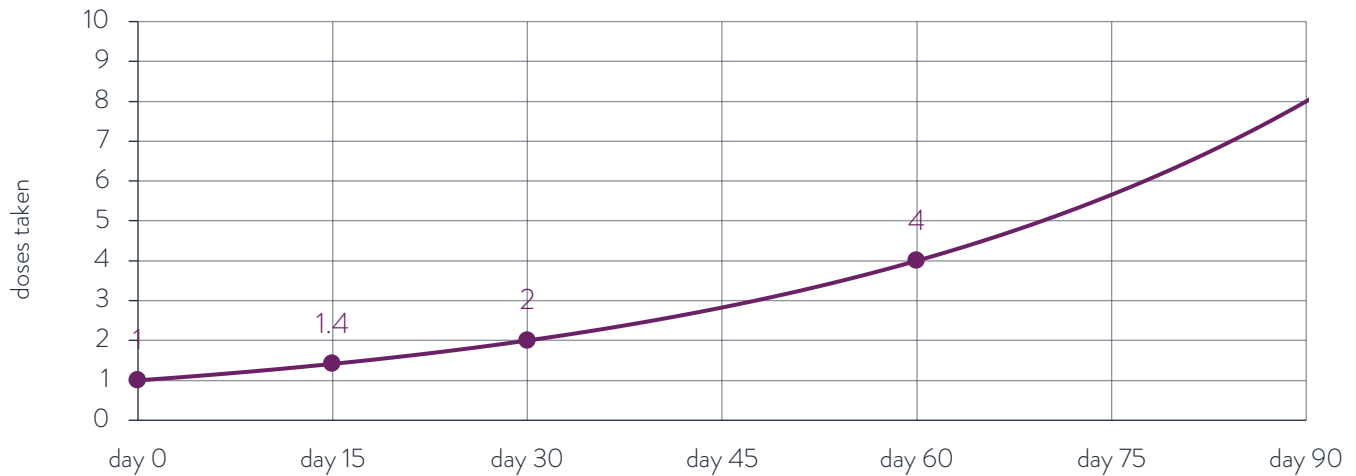
Relief =  $10 \cdot (1 - 0.023)^d$ , where  $d$  = days on medication

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On day 60, relief =  $10 \cdot (1 - 0.023)^{60} \approx 2.5$  units

After 60 days, the patient only gets 2.5 of 10 units of relief from the daily dose. Assuming they don't want to feel pain, they may respond by taking a higher dose than is prescribed.

- 3 Even when a doctor prescribes a specific dosage of a medication, patients will often take more if they're still in pain. Sketch how many doses of Norco our patient would take each day if they wanted to be pain-free. If the doctor only wrote a prescription for 60 days' worth of medication, what do you expect the patient will do when they run out?



<u>Day</u>	<u>Units of Relief from Single Dose</u>	<u>Doses Needed for Full Relief (10 units)</u>
0	10 units	$\frac{10 \text{ units}}{10 \text{ units per dose}} = 1 \text{ dose}$
15	7.1 units	$\frac{10 \text{ units}}{7.1 \text{ units per dose}} = 1.4 \text{ doses}$
30	5.0 units	$\frac{10 \text{ units}}{5 \text{ units per dose}} = 2 \text{ doses}$
60	2.5 units	$\frac{10 \text{ units}}{2.5 \text{ units per dose}} = 4 \text{ doses}$
d	$R = 10 \cdot 0.977^d$	$N = \frac{10}{10 \cdot 0.977^d} = \frac{1}{0.977^d}$

The longer the patient is on the medication, the less effective the medication becomes, so the more doses they may take each day to get complete pain relief. Since the doctor only prescribed them one dose per day, they may run out of medication before the doctor will prescribe a refill. It's possible they'll compensate by trying to get pills from someone else. They might also try to find another kind of pain reliever.

#### Teacher Tip

For students who finish early or want an additional challenge, consider asking *when* the patient will run out of medication. This involves the sum of a geometric series, i.e.  $N(1) + N(2) + N(3) + \dots = 60$ . Students can calculate and add up the doses day-by-day, or they can try to write a function for the cumulative doses over time. Whatever method they use, they will discover that in the scenario above, a 60-day supply of medication will only last around 37 days.

- 4 While opioids can help relieve pain, they have a dangerous side-effect: If a body has too much, it can stop breathing. For years opioids were given mostly to cancer patients, but in the 1990s pharmaceutical companies started urging doctors to give them to more people. Many became addicted, and many of *them* turned to more powerful opioids like heroin and fentanyl. Today, accidental overdoses are the leading cause of death of Americans under 50.

- a. Who do you think is most responsible for starting the crisis: drug companies, doctors, or patients?

Possible responses:

- *Pharmaceutical companies* assured doctors that opioids like OxyContin were less addictive than they really were.
- *Doctors* continued to prescribe powerful opioids to their patients instead of using less addictive alternatives.
- After their medical procedures, *patients* requested the most powerful pain relievers available. When they became addicted, many sought more powerful opioids. It would have been better had they sought treatment or accepted pain as a natural and temporary consequence of surgery.

- b. Who do you think should be responsible for ending the opioid crisis? Explain.

Possible responses:

- *Pharmaceutical companies* knew that opiates were addictive and could be deadly. It's their responsibility to invest in treatment programs and compensate victims.
- *Doctors* have a responsibility to not prescribe medications that could be harmful to patients. If a doctor contributes to a health crisis, they are in violation of their Hippocratic oath.
- *Patients* should educate themselves and not accept prescriptions that will harm them. When they get addicted, it's their responsibility to seek treatment and avoid even more dangerous medications/drugs.

#### Teacher Tip

This question includes a 4-minute video about the history of opioids and the rise of drugs such as heroin and fentanyl. While the video is longer than most, we encourage you to show the whole thing. Not only does the video discuss the different players in the story – drug companies, doctors, and patients – but it also does an excellent job of highlighting just how dangerous some of the newer opioids are; for instance, it mentions that a police officer in Ohio almost died when a single speck of fentanyl landed on his shirt. By showing this video to students, you may help to save someone's life.