Don’t You Know That You’re Toxic?

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Fields of Interest: Toxicology, Biology, Chemistry, Medicine

Brief Overview: Mentees will learn about three applicable toxicology concepts through hands-on models with a focus on how dose plays an important role in understanding toxicology.

Agenda:

- Introduction (5 min)
- Module 0: Dose-si-do (5 min)
- Module 1: Liver, Laugh, Love (20 min)
- Module 2: A Heavy Catch (15 min)
- Module 3: You’ve Got a Lot of Nerve (10 min)
- Conclusion (5 min)

Main Teaching Goals/Key Terms:	**Mentor Development Goals:**
➔ Dose ➔ Mercury ➔ Bioaccumulation ➔ Synapse ➔ Neurotoxin ➔ Liver ➔ Cirrhosis/Liver Disease	➔ Connecting to the Real World ➔ Classroom Management and Safety ➔ Logical Reasoning ➔ Improvise, Adapt, Overcome

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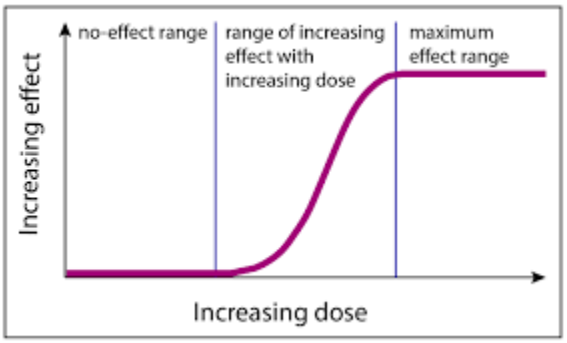
Background for Mentors

Module 0

- Dose
- Body Mass
- Tolerance
- Dose-response curve

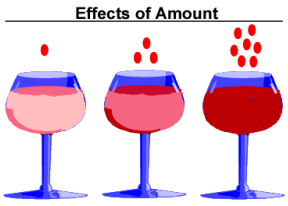
Dose is a toxicological concept describing the amount of something that an individual or group is exposed to at one time. Every substance, including water, is toxic at a high enough dose. However, toxins are generally substances that are toxic at lower, realistic doses.

Dose significantly impacts the effects of a substance which can be described by the **dose-response curve**. Low doses will cause minimal effects, while high doses will cause higher effects, up until a point where higher doses provide minimal increase in effect.



A number of factors such as genetics, **body mass**, age, and overall health influence the response to a dose. Individuals with a higher body mass will generally be affected less by the same dose than an individual with a lower body mass. In addition, a higher dose will affect the same individual more than a lower dose.

The Greater the Dose, the Greater the Effect.



The Smaller the Size, the Greater the Effect.

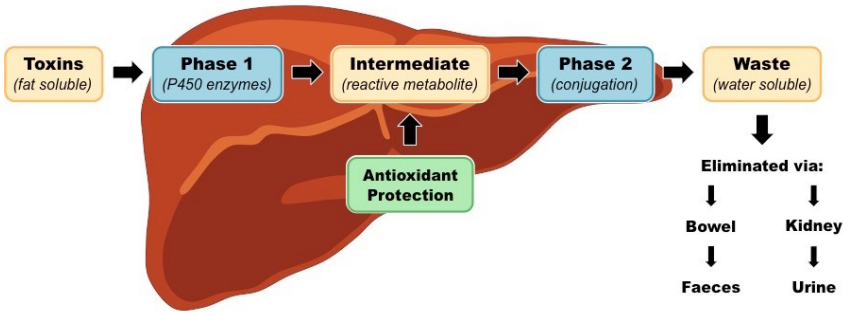
Low doses of a toxin given over time can contribute to a **tolerance**, in which an individual becomes less sensitive to the toxin by the body becoming more and more efficient at removing it.

Mentors can give a basic understanding of dose for younger mentees but can go more in depth to make the module more exciting for older mentees.

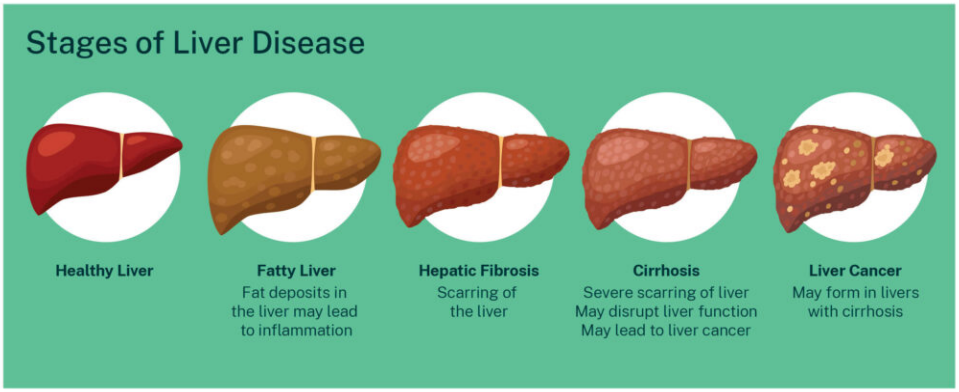
Module 1

- Toxin
- Liver
- Detoxification
- Liver Disease

The **liver** is the main detoxifying organ of the body, cleansing the blood of drugs, nutrients, and other foreign chemicals. Large volumes of blood are constantly passed through the liver, where enzymes in liver cells break down **toxins** into byproducts which are then excreted.



The byproducts produced by **detoxification** can damage liver cells in high quantities. The liver can normally regenerate cells at a high rate, but if high doses of toxins (such as anabolic steroids, alcohol, and NSAIDS) are presented to the liver on a consistent basis, the liver can be overwhelmed, resulting in liver inflammation and **liver disease**. Continued damage can lead to liver failure.



Liver damage primarily results in impaired detoxification but can eventually lead to fluid retention, fatigue, bleeding, and severe brain damage, leading to death.

Mentors should note that the liver is damaged at high **doses** of toxin.

Module 2

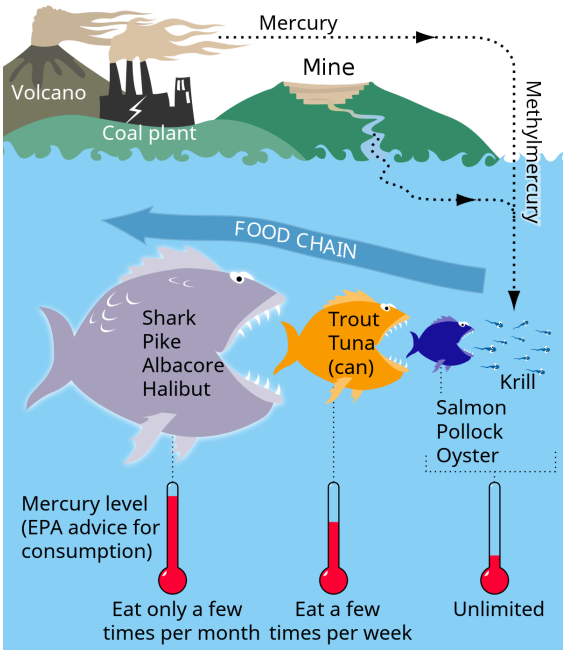
- Mercury
- Predator
- Prey
- Bioaccumulation

Mercury poisoning is caused by high levels of methylmercury, a form of mercury, in the bloodstream. Methylmercury is a neurotoxin and high doses can lead to tremors, pain, unsteadiness, and eventually death.

One of the main causes of mercury poisoning is the consumption of seafood high in mercury such as tuna, shark, and swordfish. These predatory fish become more saturated with mercury than other seafood through **bioaccumulation**. All fish have small amounts of mercury in them that they consume from their environment, but when predatory fish consume **prey**, they retain the mercury in their muscle, causing them to accumulate more and more mercury as they go about their lives and eat more fish.

Since there is no known method to reduce the amount of mercury in a piece of seafood, consumption of large, predatory fish should be limited or avoided.

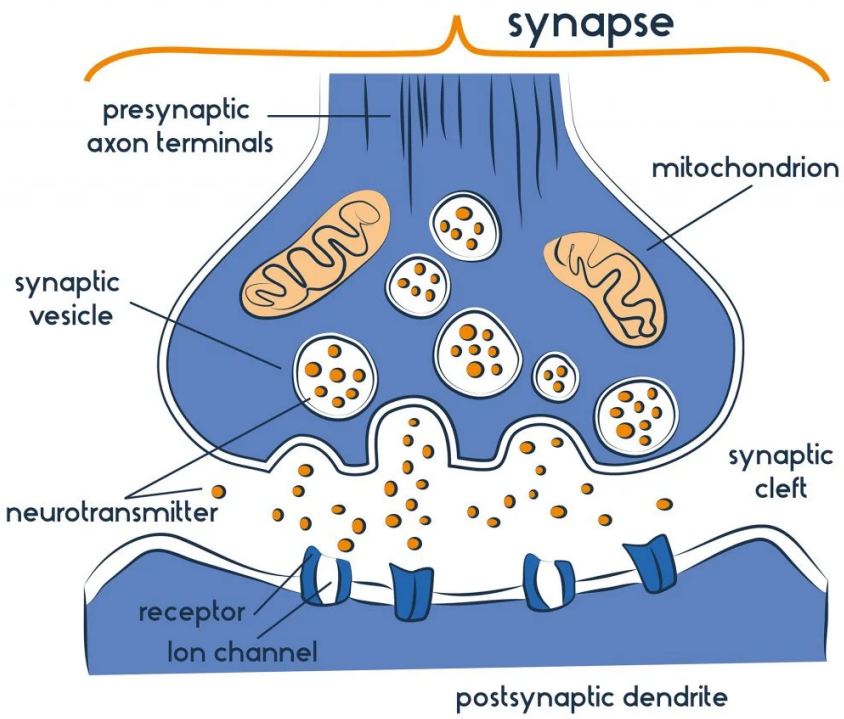
Mentors should note that larger fish provide a larger **dose** of mercury, which will have a greater toxic effect.



Module 3

- Neuron
- Neurotoxin
- Neurotransmitter
- Synapse

Neurons are the cells that make up the nervous system and allow the body to perceive the world and move in response to it. They communicate with each other by releasing chemicals called **neurotransmitters** across the space between neurons, called a **synapse**.



Neurotoxins are any chemicals that interfere with the normal function of the neuron. Some inappropriately promote or prevent the release of neurotransmitters, while others bind to receptors, blocking the detection of neurotransmitters. In the activity for this module, the neurotoxin will be one that blocks the dendritic receptors from receiving a neurotransmitter.

Mentees should understand that a higher **dose** of neurotoxin causes a more intense interference with synaptic function.

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Introduction

Concepts to Introduce ● The lesson is based around analogies, but some to further explain are: ○ Draw a food chain on the whiteboard to illustrate bioaccumulation before or after the activity ○ Neurotransmitters are like phone calls and a neurotoxin is like bad cellular connection that prevents a call from being received ○ The liver is like a coffee filter that removes the coffee grounds from the coffee, but it can get clogged if too many coffee grounds are passed through it	**Questions to Pique Interest** ● Mentors can ask whether mentees know what a toxin is and if they can give examples ○ Words like poison and venom can guide mentees to the correct answer ○ Mentees can also be asked if they know what an antidote is ● Mentors can ask mentees about what happens if too much or too little of a medicine is given (inappropriate dose) as well as whether they should be given the same doses of a medicine as their parents ○ This can segue into Module 0
Scientists, Current and Past Events ● Rachel Carson ○ Wrote Silent Spring, exposing the effect of the pesticide DDT on bird populations ● Concern about microplastics and “forever chemicals” that show up in food ○ https://www.ncbi.nlm.nih.gov/pmc/articles/PMC7084551/ ● OTC drug overdoses are unfortunately common, especially in children ○ https://www.ncbi.nlm.nih.gov/pmc/articles/PMC3509295/	**Careers and Applications** ● Toxicology is a growing field of science that will always have usage as long as there are foreign chemicals that harm humans ● Toxicology is applicable in biotechnology, food science, medicine, and many other careers

Module 0: Dose-si-do

Mentees will learn about how different doses affect the same individual and how different individuals will respond differently to the same dose. Mentees should be able to explain at a basic level how dose and body mass contribute to the effect. This module is a small group demo and the colored water will be used in the next module.

Teaching Goals

1. **Dose:** The amount of a substance administered to an individual or group.
2. **Body mass:** A metric used to determine how much of a medicine should be administered/how severe the effects of a toxin will be.
3. **Dose-response curve:** A curve that maps out the response to a substance on the y-axis and the dose on the x-axis.
4. **Tolerance:** A desensitization to a dose so that larger doses are required to have the same response.

MD Goals

- **Connecting to the REAL WORLD** 🌎👫⛓️

When mentees learn about dose, keep in mind to make sure to connect it to the real world! Dose is around us everywhere (drinks 🍷, food🥐, medicine😷). Mention the amount of Tylenol they take, or how pill bottles have different amounts to take for children vs for adults. Try to have the kids come up with examples, too!

Materials

- Per 4-5 mentees:
  - 2 clear drinking cups
  - 1 small sauce cup
  - 1 bottle green food coloring

Different Methods for Teaching

1. A number of analogies can be used to help mentees understand dose-response. Pick the ones you think will help the most: what happens when too much or too little medicine is given to someone, whether they take the same dosage of medicine as their parents, why some medicines are for kids and some are for adults, how the amount of salt/sugar affects the saltiness/sweetness of water or food, how it takes less water to fill up a smaller bucket than a larger bucket, and that children get full with less food than an adult.
2. Drawing out the dose-response curve, or even just a simple y = x graph could be

helpful for illustrating the concept that higher dosage leads to a greater effect.

Procedure

1. Fill the two drinking cups and the sauce cup with water.
    a. The 2 drinking cups should have the same amount of water and the drinking cups should have more water than the sauce cup. A recommendation is shown in Figure 1.
2. Put 1 drop of food coloring in one of the drinking cups and 4 drops in the other.
    a. Discuss with mentees how this represents a different dose of a substance in two similar people.
    b. Ask mentees which person/bottle would be more affected.
3. Put 1 drop of food coloring into the sauce cup.
    a. Compare this with the drinking cup with 1 drop.
    b. Discuss with mentees how this represents the same dose in two people with different body mass. You can use an adult and a child as examples to make the comparison more intuitive.
4. Save the larger cups for the next module. Do not throw anything away.

Figure 1: *Recommended setup.*

Figure 2: *Different dosage comparison.*

Figure 3: *Different body mass comparison.*

Classroom Notes

Try and keep this module quick for younger mentees, but for advanced mentees able to engage with the advanced teaching goals, spend more time discussing the relationship between dose, effect, and tolerance. You can also spend more time on the dose-response curve and draw it out on the board.

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Module 1: Liver, Laugh, Love

Mentees will be building a model liver and passing colored water through it to show the effects of small and large amounts of toxins on liver health and function. Mentees should understand that large doses of toxins cause liver damage by overwhelming its ability to detoxify and that this damages the liver and overall health.

Teaching Goals

1. **Liver:** A human organ that detoxifies blood and is located in the abdomen.
2. **Toxin:** A harmful substance created by a living organism.
3. **Detoxification:** The process by which the liver uses enzymes to break down toxins which are then excreted.
4. **Liver Disease:** Permanent scarring of the liver caused by repeated inflammation, damage, and stress. Also known as cirrhosis.

MD Goals

- **Logical Reasoning**

Try to have mentees predict ahead of time the outcome of the activities. See how their hypothesis/prediction relates to the final results and how this changes their prior thinking.

Materials

- Per mentee
  - 1 2”x3” ziploc bag
  - 6 cotton balls
- Per table
  - 1 paper bowl
  - 1 pair of scissors
  - 2-3 droppers
- Colored water from previous module

Different Methods for Teaching

3. The color green was chosen because mentees will likely associate it with “toxic” or “poisoned.” Take advantage of this and compare a liver with darker green to lighter green as representing different levels of poison.
4. For advanced mentees, after the activity, you can further encourage critical thinking, asking whether a bag with more cotton balls (adult with a larger liver) would be able to soak up more or less water (detoxify more or less toxin). Relate this back to dose.
5. You can analogize the liver to a trash can: if you put in a normal amount of trash, the trash is easy to take out and won’t affect the rest of your living space (your body). However, if you have too much trash, the trash will overflow, and even if you want to take out the trash, it will be hard! Trash in this case represents toxins in the liver, and the liver is the trash can.

Procedure

1. Give each mentee a small ziploc bag and 6 cotton balls.
2. Give each table 2 droppers and a paper bowl.
3. Instruct mentees to cut a small triangle off of the corner of their plastic bag and insert 6 cotton balls through the main opening of the bag. (Make sure the cut is not too big.)
4. Instruct mentees to begin adding a dropper-full of light green water to their bag with the dropper. Mentees should position their bags over the bowl while adding water to not make a mess.
    a. The water will be absorbed by the cotton balls, representing the liver successfully detoxifying blood. Discuss with mentees.
    b. About 2-4 droppers of water can be absorbed by the cotton balls depending on the size of the droppers added, so as long as mentees stay under that, the water should not leak out of the hole.
5. Instruct mentees to start adding dark green water to their bag.
    a. The water should still be absorbed by the cotton balls, but will color them a darker green. Discuss with mentees how this represents liver damage caused by a higher dose of toxins.
    b. As mentees continue to add dark green water to their bags, it will start to leak out of the hole they have made. Discuss how this represents the diseased liver detoxifying less effectively and the continued presence of toxins in the bloodstream. Mention liver disease.

Figure 4: *Bag with cut.*

Figure 5: *Bag with 6 cotton balls.*

Figure 6: *Addition of lightly colored water.*

Figure 7: *Addition of dark colored water.*

c. It usually takes 2-4 more dropper-fulls of water on top of those added in the previous step for water to start leaking out of the hole.

Classroom Notes

Determine a water source beforehand so the activity is not delayed while looking for one. Teach mentees how to use the droppers if they have not used one before. Be prepared for a mess and lay out paper towels beforehand.

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Module 2: A Heavy Catch

Mentors and mentees will be playing a modified form of tag to model the bioaccumulation of mercury. Mentees should understand why larger fish accumulate more mercury than other fish. This is an outdoor activity.

Teaching Goals

1. **Mercury:** A metal that is harmful to humans when consumed in the form of methylmercury.
2. **Predator:** An animal that consumes other animals.
3. **Prey:** An animal that is consumed by a predator.
4. **Bioaccumulation:** When animals accumulate chemicals faster than they can excrete them. One way is through animals near the top of the food chain consuming animals lower on the food chain.

MD Goals

- **Classroom Management and Safety**

Since kids are going outside and running around, it's important to be mindful of everyone's enjoyment and safety within the activity. Make sure that all kids are included and that kids aren't just playing tag without understanding the analogy behind it. 🏃

Materials

- Per mentee + mentor
  - 1 ping pong ball
- Per mentor
  - 1 grocery bag
  - 1 nametag

Different Methods for Teaching

1. Pause the activity at regular intervals to remind mentees what the ping pong balls represent. This should also help keep the activity more contained.
2. Ask mentees what happens when one person has all of the ping pong balls.
3. Make sure mentees understand that we are not discussing the planet Mercury, but mercury as a poison.

Procedure

1. Give 1 mentor a “shark” nametag and other mentors “tuna” nametags.
2. Give each mentee a ping pong ball.
3. Give each mentor a grocery bag with a ping pong ball.
    a. Discuss with mentees how this setup represents small fish having lower levels of mercury. Explain that mentors are predatory fish and mentees are their prey.
4. Play tag, with the mentors chasing mentees to tag them and collect their ping pong balls.
    a. Show mentees how the predatory fish have accumulated mercury by eating smaller fish.
5. After all of the mentees have been tagged, and if there is time, have one mentor be a shark and play tag with the remaining mentors to collect their ping pong balls.
    a. Show mentees how sharks, who consume other large predatory fish, will have the highest levels of mercury.
6. End the activity by emphasizing that consuming larger fish with more mercury will provide a higher dose of mercury to humans, making it more hazardous.

Figure 8: *Tag.*

Classroom Notes

A debrief after the activity will help to solidify the relevant concepts for mentees and reign in mentees for the next activity. Site leaders should check with teachers if they can take the mentees outside. An alternative activity can be similar to this one, but with walking around and handing off ping pong balls instead of playing tag. When running around with the bag, make sure to hold it tight so that the balls do not fall out.

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Module 3: You've Got a Lot of Nerve

Mentors and mentees will be playing "monkey in the middle" to illustrate the normal function of a synapse as well as how a synapse is affected by a neurotoxin. This is an outdoor activity.

Teaching Goals

1. **Neuron:** A nerve cell that transmits signals throughout the body.
2. **Neurotoxin:** A chemical that interferes with the normal function of a synapse.
3. **Neurotransmitter:** A chemical released by an axon to carry a nerve signal across the synapse to receptors on the dendrite.
4. **Synapse:** The space between an axon and a dendrite that neurotransmitters move across.

MD Goals

- **Improvise, Adapt, Overcome**

Depending on the class, gauge mentee engagement in the activity and adjust accordingly. If a classroom is very energetic and excited, try to make sure they don't overwhelm the mentors. On the other hand, if mentees are not engaged, use the activity to engage them more!

Don't feel rushed to finish all the modules. If the kids are enjoying Module 2, make sure to thoroughly go through that activity instead of rushing to get to the last activity! Focus on engagement with the concepts of the lessons instead of completing the lesson.⚡

Materials

- Per site
  - 2 tennis balls

Different Methods for Teaching

1. The dendrite and axon can be mentioned for very advanced or curious mentees. Otherwise, just talk about the neurotransmitters as going from one cell/neuron to another or even a message going from the brain to a body part.
2. Again, pause the activity if mentees are getting carried away to remind them what the tennis balls and different groups of people represent.

Procedure

1. Arrange mentors standing in two lines across from each other.
2. Have mentors play a simple game of catch between the two groups.
    a. Discuss how this represents the normal function of a synapse where neurotransmitters can cross the synapse.
3. Add mentees a few at a time and play monkey in the middle. The mentors should try and continue passing the tennis balls while the mentees try to block the passes.
    a. Discuss how this represents a neurotoxin blocking the passage of a neurotransmitter across the synapse. Have mentees think about ways a neurotoxin could affect someone's health.
4. Finish with pointing out that as the dose of neurotoxin increases, the effects will be more severe, similar to how more mentees added to the game makes it more difficult for mentors to pass the ball.

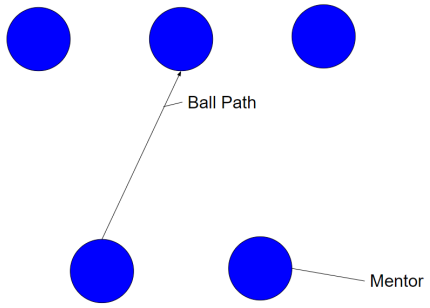

Figure 9: *Beginning of activity with 0 mentees.*

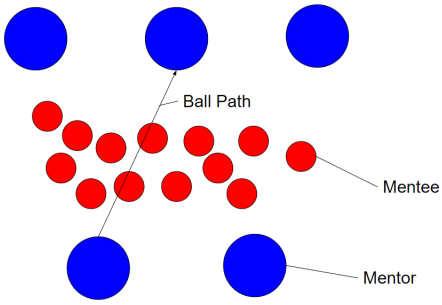

Figure 10: *End of activity with all of the mentees.*

Classroom Notes

This activity could become chaotic while mentees are having fun, so it's alright if mentees find it difficult to connect the game to the toxicology concept. Mentees may also be overwhelmed with teaching goals since this is the second outdoor activity. If all else fails, just let them have fun. For your age group at site, make sure you pass the ball in a way that the mentees have a chance at blocking. Also consider switching the role of mentors and mentees.

Conclusion

Mentors can review the basic concepts of the lesson and how mentees can apply them in their lives. Asking questions about which fish have the most mercury, what the liver does, etc. can be helpful to solidify knowledge.

References

- The Society of Toxicology, main website
    - https://www.toxicology.org/
- Source for the dose activity
    - https://www.toxicology.org/education/k12/k12.asp