

Overview

Students model blood glucose homeostasis using a game board and pasta pieces to simulate how blood glucose levels are regulated by the hormones insulin and glucagon, and how the liver, fat cells, muscle and brain play a role in blood glucose homeostasis. Using their models, students first explore how blood glucose levels in healthy individuals are affected by eating and fasting. They then model how insulin resistance leads to elevated blood glucose levels, and predict the effects of β cell damage, exercise, and medication on blood glucose levels. Students also discuss the limitations of using a model to show relationships and connections within complex systems.

Enduring understanding: Blood glucose levels need to be maintained within specific ranges, and body systems work together to maintain this range through the process of homeostasis. Type 2 diabetes can develop over time if the mechanisms that maintain blood glucose levels are challenged and eventually fail.

Essential question: How do our body systems work together to maintain balanced glucose levels, and how does type 2 diabetes develop when this balance is upset?

Learning objectives

Students will be able to:

- Model the mechanism for maintaining glucose balance.
- Predict how insulin resistance, exercise, medication and β cell damage may affect type 2 diabetes.

Prerequisite Knowledge

Students should have an understanding of the following terms: cell, tissue, organ, glucose, fat, protein, hormone.

Time: Approximately 90 minutes

This lesson connects to the Next Generation Science Standards in the following ways:

Performance Expectations

HS LS1-3 Conduct an investigation to provide evidence that feedback mechanisms maintain homeostasis.

HS LS1-2 Use a model to illustrate the hierarchical organizations of interacting systems that provide specific functions.

HS LS1.A Disciplinary Core Idea

Structure and Function: Feedback mechanisms maintain a living system's internal conditions within certain limits and mediate behaviors, allowing it to remain alive and functional even as external conditions change within some range.

This lesson highlights the Practices of **Using Models**, **Interpreting Data** and the Crosscutting Concept of **System Models**.

Lesson Four: Glucose in balance

Materials

Materials	Quantity
Computer and projector, or 1 computer per student pair	1 per class or pair
PowerPoint presentation found at http://gsoutreach.gs.washington.edu/ (see GEM Instructional Materials)	1 per class
Model set (see Figure 1) Each set contains: <ul style="list-style-type: none"> 1 Manila folder 1 2-page photocopy of model board 1 brad 1 balance made from red card stock, approximately 7.5 in x 1 in, and pointed at one end. Teachers may wish to write the word “homeostasis” on the balance to underscore the concept. 20 pieces of wheel-shaped (rotelle) pasta to represent glucose 20 pieces of I-shaped (penne) pasta to represent insulin 10 pieces of curvy-shaped (macaroni) pasta to represent glucagon 1 small sticky note cut into 4 strips, each with a sticky end Optional: 2 small weigh boats, and 1 large weigh boats to hold pasta 	1 per group
Student Sheet 4	1 per student
<p><i>Optional:</i> A helpful, and surprising, visual for this lesson includes:</p> <ul style="list-style-type: none"> • Container(s) to hold 5 liters of liquid, preferably red, representing the approximate amount of blood adults have in their bodies. • 1 baggie with 4 g of sugar in it, representing the approximate amount of blood glucose a healthy adult would have when waking in the morning (80 mg/dl). • 1 baggie with 16 g of sugar in it, representing very high blood glucose levels of a person with diabetes (320 mg/dl). • 1 baggie with 65 g of sugar in it, representing the amount of sugar in one 20 ounce Coca-Cola. 	1 per class

Lesson Preparation

- The PowerPoint presentation for this lesson is integral to the lesson. If possible, the PPT should be loaded onto student computers so that student groups can proceed at their own pace, with stopping points built in for teachers to check for understanding. If student computers are not available, the teacher may direct the lesson with the whole class.
- Photocopy Student Sheet 4 for each student.
- Make enough model boards for each group, as shown in Figure 1. Add the correct number of pasta pieces and sticky notes.
- Make up the baggies containing sugar and containers with liquid, if showing the optional visual model for this lesson.

Lesson Four: Glucose in balance

Part 2 (Explain):

Who's who of diabetes

(20 minutes)

- Show students the first slide of the PowerPoint presentation and go over the goals of the lesson.

Slide 1



Glucose in balance

Lesson Five

Today we will...

- Model the mechanism of type 2 diabetes
- See how homeostasis works to keep the body in balance
- Learn about the organs and hormones involved in glucose homeostasis
- Learn about the factors that contribute to type 2 diabetes

- Pass out *Student Sheet 4* for students to take notes on during the lesson

- Let students proceed through slides 2 through 9.

Slide 2



Meet the players

Who's who of diabetes:

Glucose! Many of the foods we eat are broken down during digestion to this simple sugar. Glucose is carried to every cell in our body by the blood stream, where it is used as the source of energy for our bodies.



In our model, the 6-sided glucose sugar is represented by a round pasta piece.

Glycogen! The stored form of glucose is called glycogen. Glycogen is made up of many connected units of glucose.



Please fill out the first section of Student Sheet 4 as you proceed through the next few slides.

Slide 3



Meet the players

Who's who of diabetes:

Insulin! This hormone is released into the blood when blood glucose levels are high. It enables glucose to be transported into the cell in some tissues.



In our model, insulin is represented by a piece of I-shaped pasta.

Glucagon! This hormone is released into the blood when blood glucose levels are low. It enables glucose to be released from some tissues back into the blood stream.



In our model, glucagon is represented by a piece of curly-shaped pasta.

Please fill out the first section of Student Sheet 4 as you proceed through the next few slides.

Slide 4

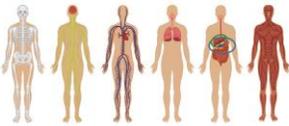


Meet the players

The body organs:

Pancreas: One of the major players in glucose homeostasis, the pancreas releases the hormones, *insulin* and *glucagon*, that control blood glucose. The cells in the pancreas that produce insulin are called β (beta) cells.

Liver: This organ takes up glucose when levels are high and releases glucose when levels are low. It stores glucose in chains as glycogen. It is key for glucose regulation.



Slide 5



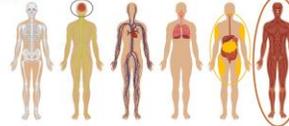
Meet the players

More body organs:

Muscles: Our muscles are able to take up and store lots of glucose when insulin is present. More muscles mass means more of a reservoir for glucose.

Fat cells: Fat cells take up glucose when insulin is present. Fat cells use glucose to make more fat.

Brain: The brain takes up glucose whenever it needs energy. Glucose is the only fuel the brain can use.



Slide 6



Glucose in balance



All of these systems work together to keep our blood glucose level balanced. For our model, 3 pasta wheels represent a balanced amount of blood glucose.

Slide 7

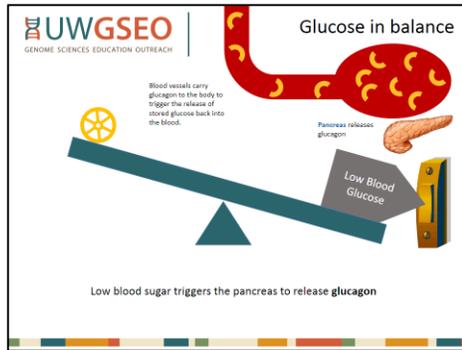


Glucose in balance



High blood sugar triggers the pancreas to release **insulin**

Lesson Four: *Glucose in balance*



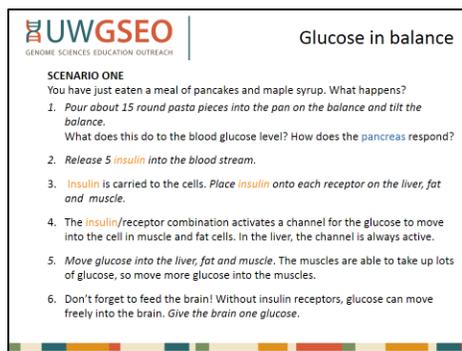
Slide 8



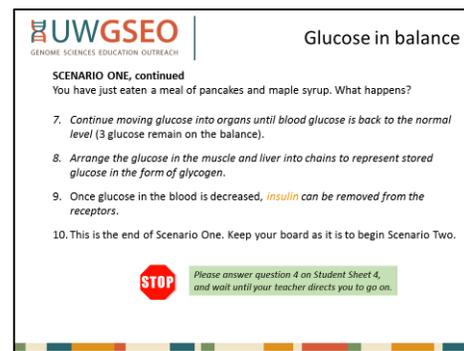
Slide 9

Part 3 (Explore): Glucose in and out of balance (30 minutes)

8. Hand out the model boards to each student group of 2-3 students. Make sure that students have a supply of the three types of pasta (rotelle, penne and macaroni).
9. Check for student understanding of the previous slides and let students explore the balance mechanism of their game boards.
10. Have students progress through Scenario One using Slides 10 and 11.

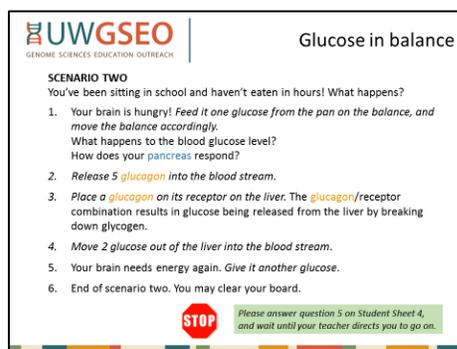


Slide 10



Slide 11

11. Check for understanding of Scenario One and proceed to Scenario Two on Slide 12.



Slide 12

Lesson Four: *Glucose in balance*

12. Show students the *first step* of Slide 13 (black line only), which illustrates the normal fluctuations in glucose. Use the following prompts to have students make predictions (in pencil) on *Student Sheet 4* about how insulin and glucagon might respond after a healthy individual eats a meal.

- For the blood glucose line, in **black**:

What are normal levels of fasting blood glucose? *Between 80 – 90 mg/dL.*
About how long are glucose levels elevated after a meal? *About two hours.*

The next line will show insulin. What do you predict the line will look like?
It should go up when blood glucose goes up, and go down when blood glucose goes down.

- For the insulin level line, in **gold**:

Does the line show what you predicted it would? Why or why not?

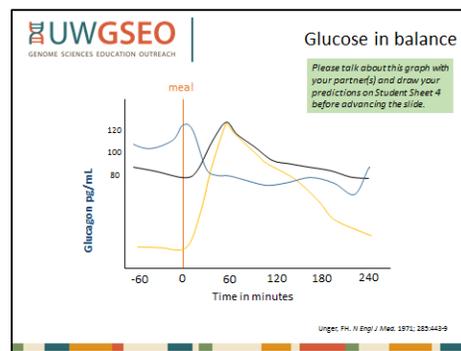
The next line will show glucagon. What do you predict the line will look like?
It should go up when blood glucose is low, and go down when blood glucose is high (i.e. inverse relationship).

- For the glucagon level line, in **blue**:

Does the line show what you predicted it would? Why or why not?

If student predictions are not very accurate, have them re-draw the three lines on *Student Sheet 4* to show the correct relationships. Point out for students that the even though glucose, insulin and glucagon are shown on the same graph at the same scale, they are all measured in different units.

Slide 13



13. Go through Slides 14 through 18, either as a class or in small groups, discussing Scenario Three, insulin resistance and β cell damage, and the ways in which prediabetes and diabetes are defined and diagnosed.

Lesson Four: Glucose in balance

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Glucose out of balance

So far, everything we've seen has been the body's healthy response to glucose.

When our bodies are overweight, especially around the middle, our insulin receptors become changed and do not bind insulin as well. This is called **insulin resistance** and can lead to the development of type 2 diabetes.

SCENARIO THREE
What happens to blood glucose after eating a meal when the body becomes **insulin resistant**?

- Place a small sticky note on each insulin receptor to show that it is insulin resistant.
- Pour about 15 round pasta pieces into the pan on the balance. What does this do to the blood glucose level? How does the **pancreas** respond?
- Release 5 **insulin** into the blood stream.

Slide 14

UWGSEO GENOME SCIENCES EDUCATION OUTREACH

Glucose out of balance

SCENARIO THREE

- The resistant insulin receptors cannot bind insulin at this concentration. Muscle, liver and fat do not take up glucose.
- The glucose levels are still high, so the pancreas releases more insulin. **Release 5 more insulin into the blood stream.**
- At this higher insulin level, some insulin receptors bind insulin. **Put insulin on some of the receptors.**
- Liver, fat and muscle can take up some of the glucose in the blood. **Put some of the blood glucose into these tissues.**
- Blood glucose is still high, so the pancreas releases more insulin. **Release 5 more insulin in the blood stream.**
- More receptors bind insulin. **Put insulin on all its receptors.**
- Liver, muscle and fat take up more glucose from the bloodstream. **Put more glucose in liver, muscle and fat.**

Slide 15

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Glucose out of balance

What happens?
Insulin resistance occurs because insulin receptors don't bind insulin as well. This causes the pancreas to work hard all the time to release enough insulin to bring down blood glucose levels.

Please answer question 7 on Student Sheet 4.

β cell damage
When the β cells in the pancreas are working hard all the time, they gradually become damaged and cannot make enough insulin to overcome insulin resistance.

Once β cells are damaged, diabetes becomes a life-long condition that will always require management.

Slide 16

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Glucose out of balance

Type 2 diabetes
Blood glucose levels are always high because of high insulin resistance and/or low insulin levels.

Pre-diabetes
At this stage, blood glucose levels are higher than normal after a meal and at a resting state, but not high enough to be classified as full-blown type 2 diabetes. People with pre-diabetes are at increased risk for type 2 diabetes.

Normal
Blood glucose levels are well-regulated.

Oral Glucose Tolerance Test (OGTT)

Slide 17

UWGSEO GENOME SCIENCES EDUCATION OUTREACH

Glucose out of balance

How is diabetes diagnosed? By measuring blood glucose levels.

Fasting glucose test: After fasting for at least 12 hours, a person's blood is drawn and tested for glucose. A healthy person would have a fasting blood glucose level of about 80-90 mg/dL.

Oral Glucose Tolerance Test: After measuring fasting glucose, a person is given a glucose-rich drink. Blood is then drawn at time intervals to see how that person's body is processing the glucose.

A third test, the **A1C test**, measures how much of a person's hemoglobin is coated with sugar. Since red blood cells (which carry hemoglobin) turnover every few months, the A1C test gives an average blood sugar level over the past 2-3 months.

Slide 18

14. For Slide 19, again make sure students pause between each step of the animation to predict blood glucose levels for individuals who are healthy, have prediabetes, and have diabetes. Students can make predictions using *Student Sheet 4*. If their predictions are incorrect, make sure that they correct their graphs in order to have accurate information.

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Oral Glucose Tolerance Test

Please talk about this graph with your partner(s), and draw your predictions about glucose levels—the graph on the left—on Student Sheet 4 before advancing the slide.

Blood Glucose levels (mg/dl)

Time (min)	Healthy (n=240)	Prediabetes (n=191)	Diabetes (n=100)
0	~100	~100	~100
20	~150	~180	~220
40	~120	~150	~200
60	~100	~120	~180
80	~100	~120	~180
100	~100	~120	~180
120	~100	~120	~180

Blood Insulin levels (µU/ml)

Time (min)	Healthy (n=240)	Prediabetes (n=191)	Diabetes (n=100)
0	~20	~20	~20
20	~80	~60	~40
40	~60	~40	~20
60	~40	~20	~10
80	~40	~20	~10
100	~40	~20	~10
120	~40	~20	~10

Jensen CC et al. Diabetes 51:2170-2178, 2002

Slide 19

Note: This is a good place to show students the visual representation of normal and high levels of blood sugar using the baggies and 5 L of liquid (see the **Materials** section). 80 mg/dl translates to 4 grams of sugar in 5 liters of liquid (the approximate amount of blood in an adult). Students can also compare this to the amount of sugar in a 20-oz Coca-Cola.

Lesson Four: *Glucose in balance*

Part 4 (Elaborate/Evaluate): What happens if...? (25 minutes)

15. Slides 20 through 23 can be used in a number of ways (see note below). They challenge students to use what they have learned to predict how the body would react in three different situations— if β cells are damaged, if a person exercises, or if a person is put on diabetes medication. Additional information about symptoms of type 2 diabetes for each circumstance is provided for each situation.

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What happens if...

Using what you've learned, predict what would happen in the following situation:
ONE: The β cells in the pancreas can only produce a very small amount of insulin.
Please make your prediction on 9a of Student Sheet 4.

Answer: Without adequate insulin, glucose cannot enter the cells and glucose levels continue to rise in the blood.

Why does this matter? Excess glucose in the blood binds to proteins, cells and tissues and they no longer work the way they should. This can lead to:

- Constant thirst and urination, as the kidneys are unable to cope with high blood glucose levels. Other mechanisms can eventually lead to kidney failure.
- Blindness, as the small blood vessels in the back of the eye become broken.
- Infection in the toes, legs and feet, caused by poor circulation and a lack of feeling due to nerve damage.
- Heart failure as large blood vessels become clogged and small blood vessels become fragile and leaky.

Slide 20

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What happens if...

Using what you've learned, predict what would happen in the following situation:
TWO: You go from a sedentary lifestyle to one that includes daily exercise.
(Hint: Muscles can take in about five times as much glucose as liver and fat can. Muscles also burn glucose for energy.)
Please make your prediction on 9b of Student Sheet 4.

Answer: Regular activity can lower blood glucose levels. Muscles can use their own stored glycogen as energy, as well as taking in glucose from the blood. When glucose levels are low, the liver can also release stored glycogen as glucose for the muscles to use.

Why does this matter? Exercise lowers blood glucose levels in the following ways:

- Building muscle provides more mass to store and use blood glucose.
- When you are active, cells become more sensitive to insulin so it can work more efficiently; in other words, insulin resistance decreases.
- Burning calories through exercise also helps maintain or decrease weight, which are important factors in type 2 diabetes.

Slide 21

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What happens if...

Using what you've learned, predict what would happen in the following situation:
THREE: You have been diagnosed with type 2 diabetes and have been prescribed the drug Metformin. *(Hint: Metformin acts to lower glucose production in the liver, and increase insulin sensitivity in the muscles.)*
Please make your prediction on question 9c of Student Sheet 4.

Answer: By lowering glucose production in the liver, glucose released by the liver won't add to already high levels of blood glucose. In addition, the muscles will be able to better utilize the insulin in the blood—sort of like removing some of the sticky notes from the insulin receptors.

Why does this matter? Treating diabetes often requires medication. Other drug treatments for type 2 diabetes include:

- Insulin injections when the β cells can no longer produce enough insulin.
- Drugs that increase insulin production in the remaining functional β cells.
- Drugs that slow the digestion of starches to glucose and/or slow the emptying of the stomach in order to lessen sudden spikes of glucose in the blood.

Slide 22

Note: Teachers could use these scenarios in a number of ways, such as going through each slide as a class, assigning scenarios to different groups and having them report back to the class, or assigning scenario(s) for homework with follow up the next class period.

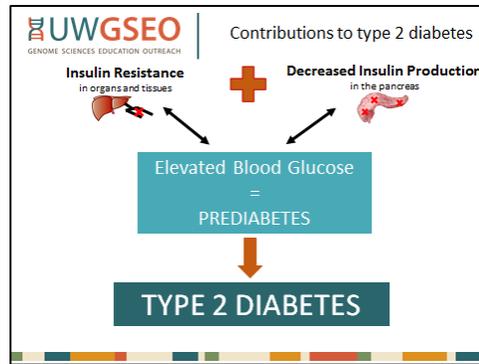
Closure The Big Picture (5 minutes)

16. Close the class by showing Slide 23. Some important points to make are:

- *Insulin resistance* and *decreased insulin production* are interconnected processes that lead to type 2 diabetes.
- Both processes can be affected by environmental and genetic influences. For example, a person may be genetically predisposed to have β cell damage.
- Lifestyle changes that lead to increased exercise and/or weight control can have a major impact in reversing prediabetes (point out reversible arrows).
- Once type 2 diabetes is diagnosed, it can be controlled and managed, but not “cured” as yet (point out the one-way arrow).
- Especially if caught early, prediabetes and type 2 diabetes are preventable and/or treatable.

Lesson Four: *Glucose in balance*

Slide 23



17. Give students a chance identify any limitations to the model they used today.

Call to Action Product

17. Ask students how this lesson contributes to their understanding of the Driving Question: **How can the growth of type 2 diabetes in the Yakima Valley be slowed?**

18. Look through the questions currently on the Question Wall to identify questions that have been answered by today's lesson and can help students in their Call to Action product.

19. Ask students if they have any new questions to add to the Question Wall.

20. Let students know that no matter the specific topic or focus of their Call to Action product, each student will need to have a solid understanding of the roles of glucose, insulin, glucagon in blood glucose homeostasis.

Glossary

Glucose: A simple, single-ring sugar that serves as the main source of energy for most living things.

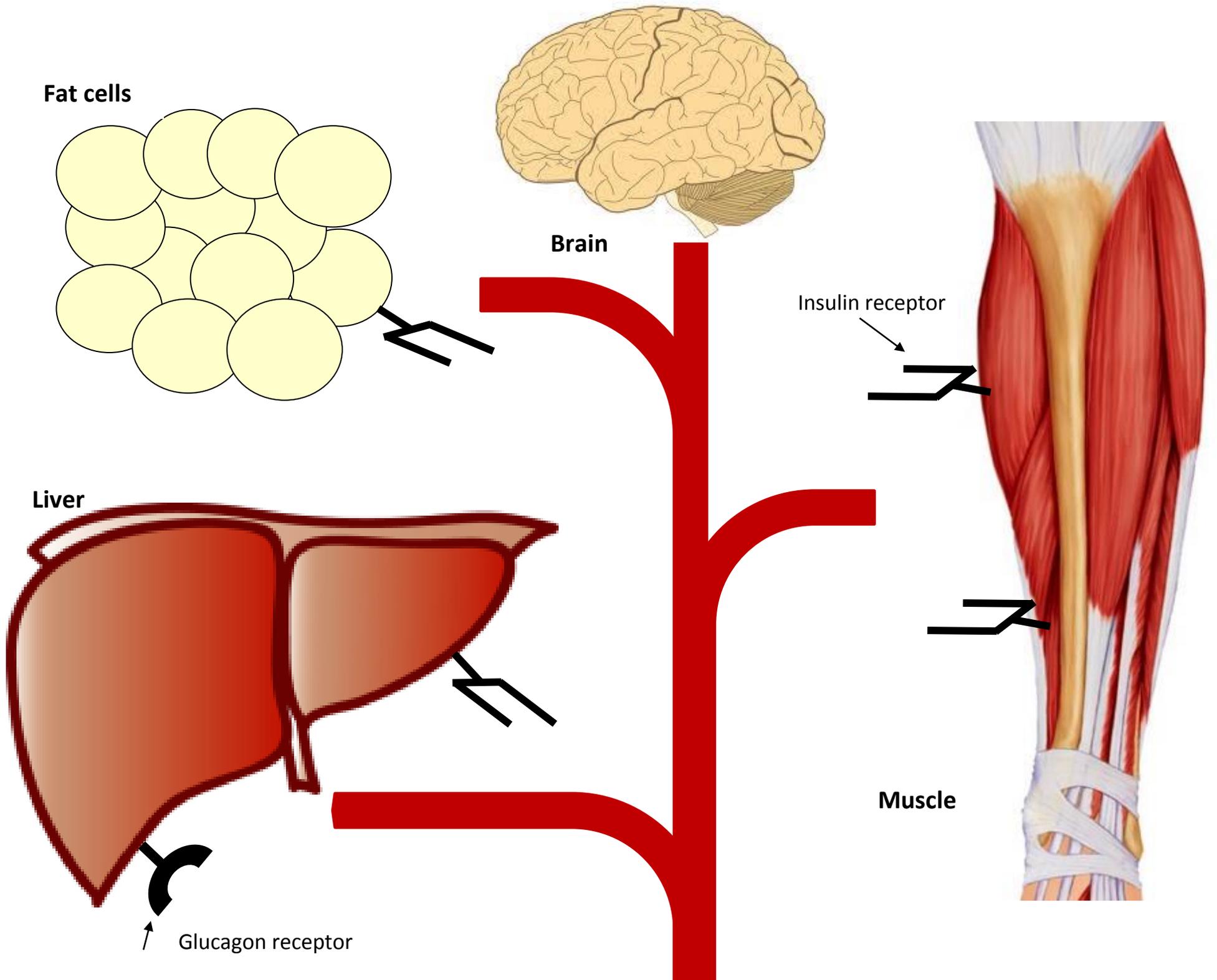
Insulin: A hormone made by the beta cells of the pancreas to regulate the amount of glucose in the blood.

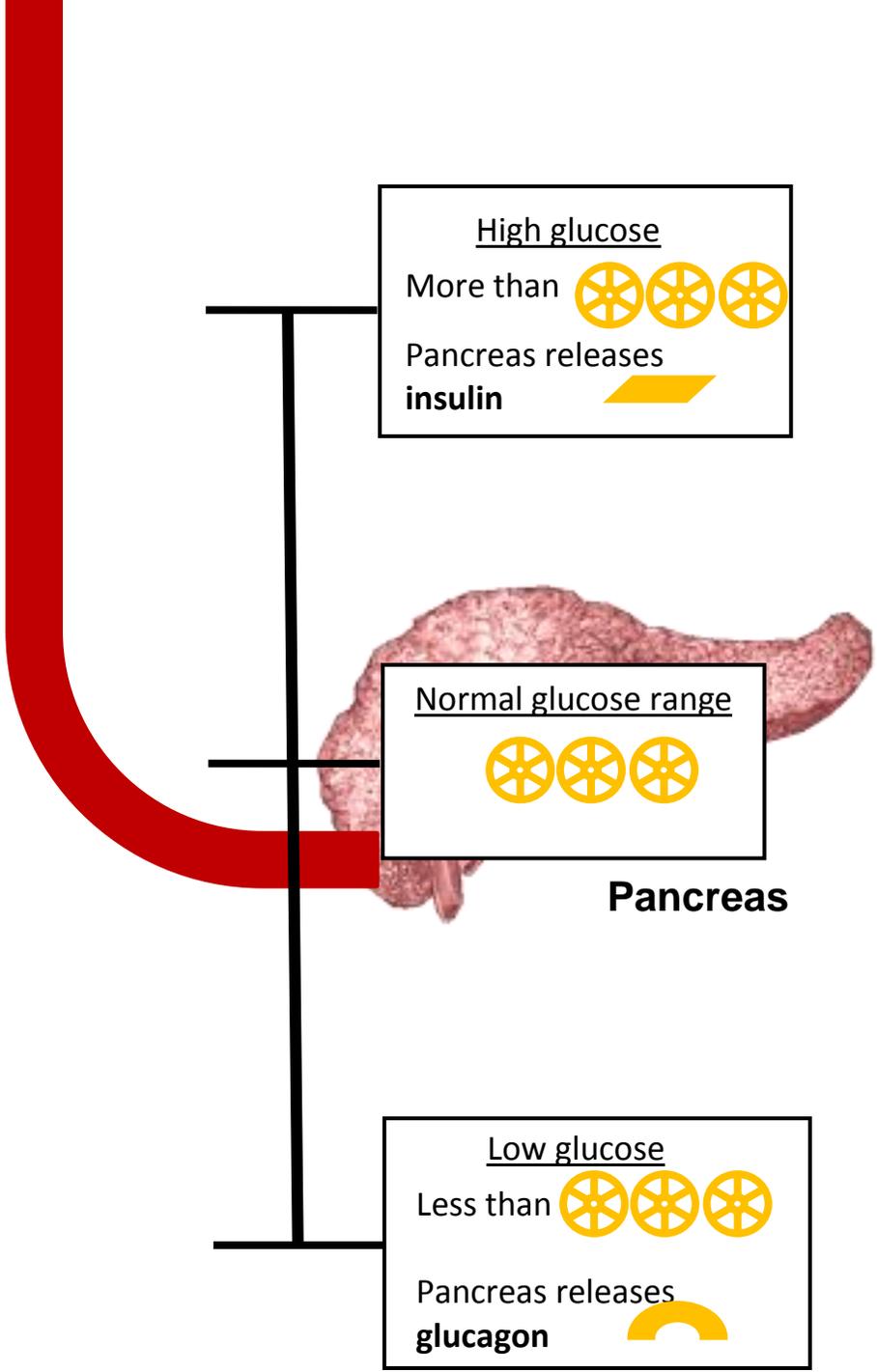
Glycogen: A storage form of glucose produced mainly in the liver and muscle cells.

Glucagon: A hormone made by the pancreas in response to a fall in blood glucose levels.

Beta cell (β cell): A type of cell in the pancreas that makes and secretes insulin.

Homeostasis: The ability to maintain a living system's internal conditions within certain limits even as external conditions change within some range, often involving feedback mechanisms.





Lesson Four: *Glucose in balance*

POSSIBLE ANSWERS to Student Sheet 4

Meet the Players:

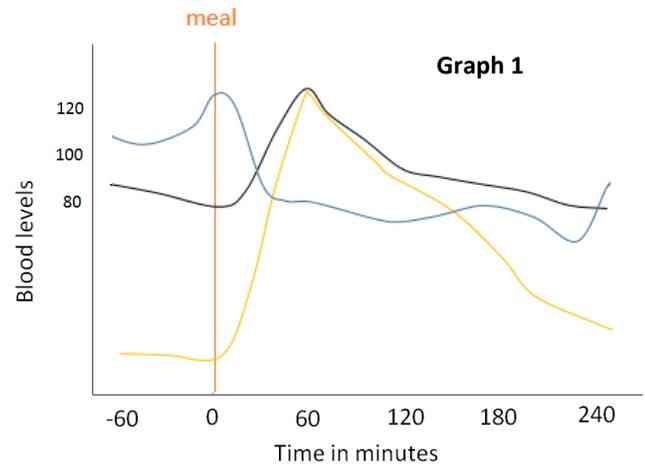
Player	Game piece	Function
Glucose		Blood sugar, used as energy
Glycogen		Stored glucose, made of many units of glucose
Insulin		Hormone allows glucose storage
Glucagon		Hormone allows glucose to be released
Organ	Role	
Pancreas	Makes and releases insulin and glucagon. Has β cells, which make insulin.	
Liver	Regulates glucose levels in blood by both taking up and releasing glucose	
Muscles	Can take up lots of glucose from the blood, use glucose, and store glucose	
Fat cells	Can take glucose into the fat cell when glucose is present	
Brain	Uses glucose for fuel; does not need insulin	

Glucose in Balance

- When our blood glucose is high, the pancreas releases insulin.
- When our blood glucose is low, the pancreas releases glucagon.
- Define homeostasis:
The ability of the body to maintain balance and regulate internal conditions.
- Summarize what happens in the body in scenario **one** (after a meal).
Digestion releases glucose into the blood stream. Glucose levels become high, so the pancreas releases insulin. Insulin in receptors allows muscle, liver and fat to take up and store glucose.
- Summarize what happens in scenario **two** (after not eating).
Low blood glucose levels trigger the release of glucagon from the pancreas. The liver receives the glucagon message and releases stored glucose into the blood.

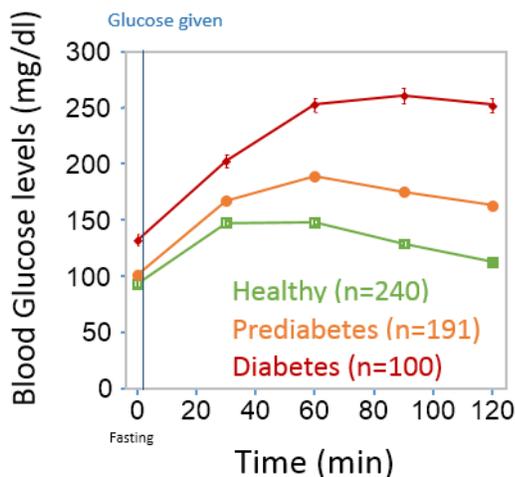
Lesson Four: Glucose in balance

6. On the **Graph 1** to the right, blood glucose levels are shown.
- Draw in the line you think will best represent **insulin** levels
 - Draw in the line you think will best represent **glucagon** levels for a healthy person.



Glucose out of balance

7. Why does one develop type 2 diabetes?
Insulin resistance (body requires higher levels of insulin to trigger receptors to take up glucose) and beta cell damage (the pancreas cannot produce adequate levels of insulin).



8. On the **Graph 2** to the left, draw the line that best represents **blood glucose** levels after eating for:

- a person who is healthy
- a person who is prediabetic
- a person who is diabetic.

Graph 2

9. What happens if...
- ONE:** The β cells in the pancreas can only produce a very small amount of insulin.
Blood glucose stays high, which leads to complications like blindness, heart disease, amputations, and constant thirst and urination.
 - TWO:** You go from a sedentary lifestyle to one that includes daily exercise.
Exercise decreases blood glucose levels because muscles use blood glucose to work, plus muscles can store lots of glucose so building muscle builds places for glucose storage. Exercise also helps burn calories which can control weight.
 - THREE:** You have been diagnosed with type 2 diabetes and have been prescribed the drug Metformin
Metformin controls blood sugar by not allowing as much stored glucose to be released by the liver. It also allows muscles to take up more glucose.

Lesson Four: *Glucose in balance*

Name: _____ Date: _____ Period: _____

Meet the Players:

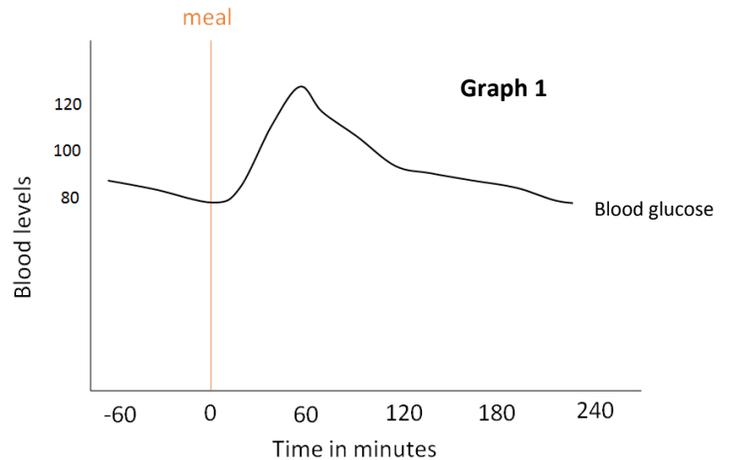
Player	Game piece	Function
Glucose		
Glycogen		
Insulin		
Glucagon		
Organ	Role	
Pancreas		
Liver		
Muscles		
Fat cells		
Brain		

Glucose in Balance

1. When our blood glucose is high, the _____ releases _____.
2. When our blood glucose is low, the _____ releases _____.
3. Define homeostasis:
4. Summarize what happens in the body in scenario **one** (after a meal).
5. Summarize what happens in scenario **two** (after not eating).

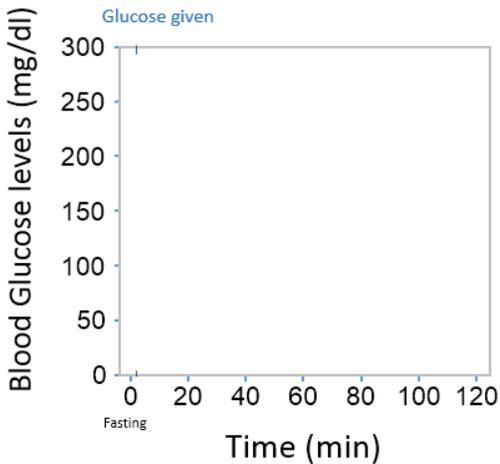
Lesson Four: Glucose in balance

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Glucose out of balance

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8. On the **Graph 2** to the left, draw the line that best represents **blood glucose** levels after eating for:

- a person who is healthy
- a person who is prediabetic
- a person who is diabetic.

9. What happens if...
- ONE:** The β cells in the pancreas can only produce a very small amount of insulin.
 - TWO:** You go from a sedentary lifestyle to one that includes daily exercise.
 - THREE:** You have been diagnosed with type 2 diabetes and have been prescribed the drug Metformin

Continue on another sheet of paper, if needed