Glucose-Insulin Model
Student Guide

Glucose is the molecule that the cells of the human body use as an energy source. Cells use glucose to make ATP, which is the primary energy provider in the cell. Maintaining a steady level of glucose in the blood is critical in the human body. If the amount of blood glucose is too much or too little, serious physical problems can occur. In people with diabetes, the body cannot properly control its glucose level. Diabetics must adjust their dietary and exercise styles and often must take medicine.

In this activity you will examine the relationship between glucose and insulin in the human body. You are going to use the STELLA® glucose-insulin models developed for the activity to simulate different types of glucose release into the bloodstream and the insulin secreting response of the pancreas. The models are based on the physiology of glucose metabolism and insulin secretion.

- Double-click Glucose 1.stm to open the first model.
- Read the introduction and scroll around the page to become familiar with its parts. You may wish to read the information section.

The model has three graphs. You will use the small Glucose Release graph to set glucose release rates for the different scenarios in this activity. The two larger graphs record a model's behavior by showing the changing levels of glucose and insulin in the blood for each scenario. The box above each graph is a STELLA® numeric display. It shows the total amount of glucose or insulin in the blood while each simulation progresses. To see all the values for a model run, double-click the Table 1 icon.

Part A. Analyzing the glucose-insulin model

Scenario I. Simulating homeostasis

Homeostasis is the normal, steady internal environment of the human body. You will run the simulation to see and record the behavior of glucose and insulin at homeostatic levels. The values on the graphs and in the numeric displays indicate the total amount of glucose and of insulin in the blood.

- Double-click the small Glucose Release graph to open it. Check the release rate shown by the STELLA® graphical function (also called the input graph). It should be steady at about 200 mg/min, which is the homeostatic level. If the release rate has not been preset, enter in the Output column 200 for each Input step, or click each vertical time line at the 200 mL level (the rate does not have to be exactly 200 mg/min.).
- Click OK when you have checked or set the rate.
- Under the Run pull-down menu, select Run. You should see lines forming on the two larger graphs in the model.

QUESTION 1. How do the model's graphs look? Use the blank graphs on the next page to record what you see on the model's graphs.
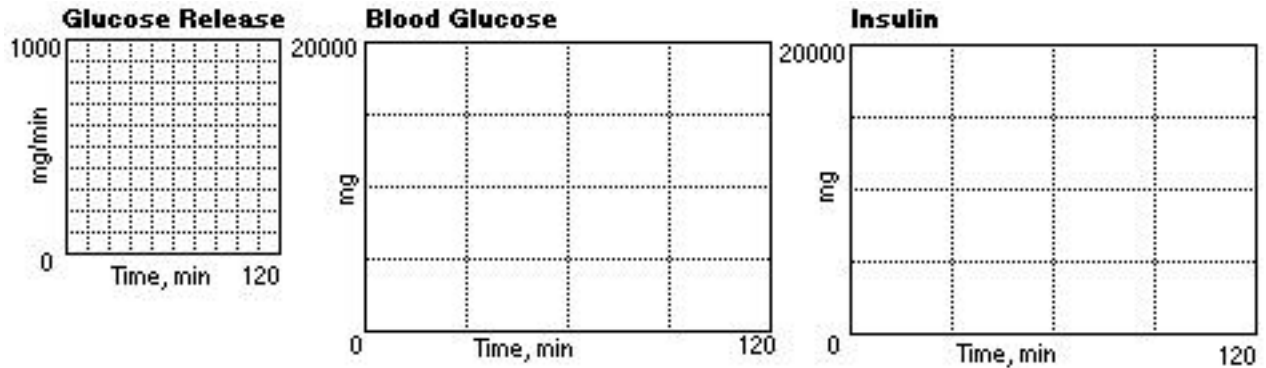
QUESTION 2. What is the homeostatic level of glucose in the blood? HINT: Enlarge the graph for easier reading (click + at lower left), check the numeric display above the graph, or look at the table.

QUESTION 3. What is the homeostatic level of insulin in the blood?

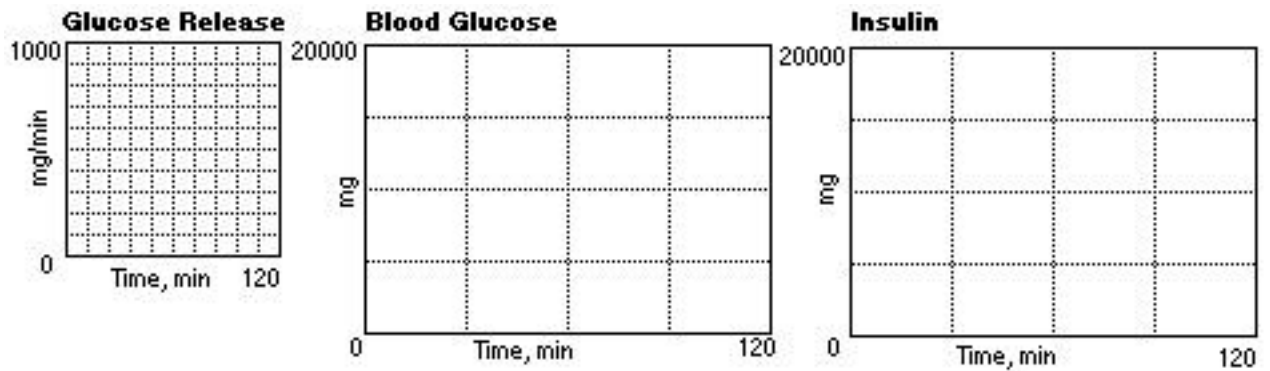QUESTION 4. How do the amounts change in relation to each other?

Scenario II. Eating simple sugars

Eating a candy bar will release a surge of glucose into your bloodstream and give you what is often called a "sugar high." A typical candy bar contains about 30 g (30,000 mg) of simple sugars. A 12-ounce can of regular (not diet) soda contains about 41 g of simple sugars. Simple sugars move rapidly from the digestive system into the bloodstream. The whole candy bar or soda might be absorbed in 20 to 30 minutes.

To simulate eating a candy bar, you are going to change the glucose release input graph to produce a spike of glucose in the blood — a quick rise followed by a quick drop.

 • Open the glucose release input graph.
 • From your knowledge of the amount of sugar in a candy bar and the speed of absorption, choose a glucose release rate that will make a glucose spike. Click the appropriate time (vertical) lines at the value or values of your chosen rate.
 • Click OK when you have set your glucose release rate.
 • Run the simulation. You should see lines forming on the blood glucose and insulin graphs.
 • To close any message box that may appear, click the small box in its upper left corner. Select Run again to continue the simulation. Or simply select Run again; the message will automatically close.

QUESTION 5. How do the model's graphs look? Use the blank graphs below to record the curves the model has generated. NOTE: The red line in the blood glucose graph marks the homeostatic level of 6000 mg.

Glucose Release

1000

mg/min

0

Time, min   120

Blood Glucose

20000

mg

0

Time, min   120

Insulin

20000

mg

0

Time, min   120

QUESTION 6. What glucose release rate or rates did you choose? Which time line or lines did you click?

QUESTION 7. How does the blood level of insulin change as blood glucose increases?

QUESTION 8. How would you describe when the change occurs? How long is the lag interval (the time required for insulin secretion to show a response)?

QUESTION 9. What might cause the change and lag in insulin secretion?

QUESTION 10. How does the blood level of insulin change as blood glucose decreases?

QUESTION 11. What is the lag time?

QUESTION 12. Why does the insulin level decrease?

QUESTION 13. How long after glucose release starts does the blood glucose level return to normal? That is, how long does the glucose spike last?

QUESTION 14. At what glucose release rate in the model does the body begin passing excess glucose into the urine? (You may need to choose a higher glucose release rate to observe the alert.)

QUESTION 15. If you eat 3 candy bars at different times in 2 hours, how do you think your blood glucose and insulin levels would respond?

QUESTION 16. How do you think the model's graphs will look? Use the blank graphs below to sketch your chosen glucose release rate and your predictions of the shape of the blood glucose and insulin curves.
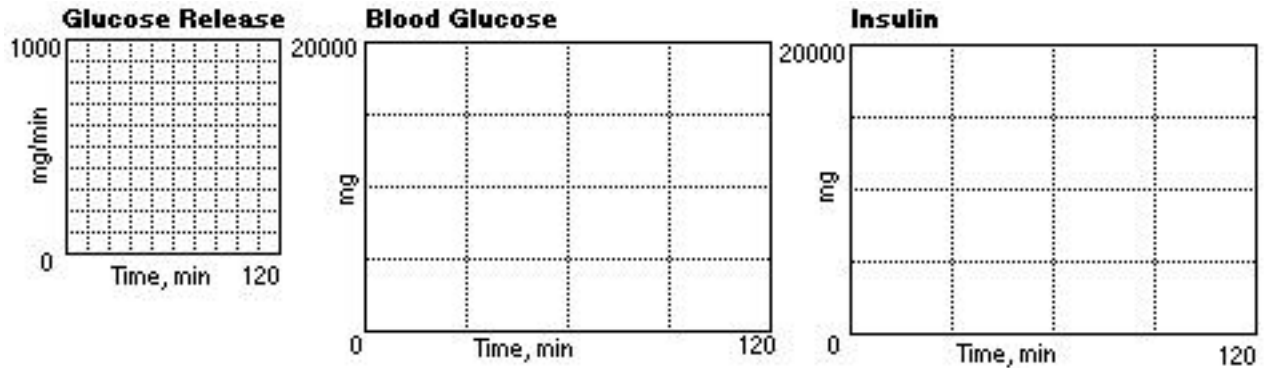
- Open the glucose release input graph.
- Choose three glucose release rates to represent the 3 candy bars and click 3 time lines at those values. Click OK.
- Run the simulation.

QUESTION 17. How do the model's graphs compare with your predictions?

Scenario III. Eating complex carbohydrates

Foods like beans, rice, oats and other cereal grains, fleshy fruit, vegetables, whole-grain bread, and pasta contain combinations of sugars and starches. Digestion converts these complex carbohydrates into glucose at a much steadier rate than the rapid absorption of simple sugars. You are going to simulate the body's response to eating pasta.

- Under the Map pull-down menu, choose Restore » All Devices. The blood glucose and insulin graphs will clear and the Glucose Release graph will return to the homeostatic rate. Alternatively, on the small Glucose Release graph click the U (in a box in the lower left corner) to reset glucose release to the homeostatic rate. The U appeared in Scenario II when you entered a new glucose release rate. When you next run the simulation, the old curves will vanish, to be replaced by new curves.
- Open the glucose release input graph.
- Click the time lines to set input values for a moderate glucose release of about 400 mg/min that is maintained for the duration of the model run. Click OK when you have set the values.
- Run the simulation.

QUESTION 18. How do the model's graphs look? Use the blank graphs below to record the curves that the model generates.

Glucose Release	Blood Glucose	Insulin
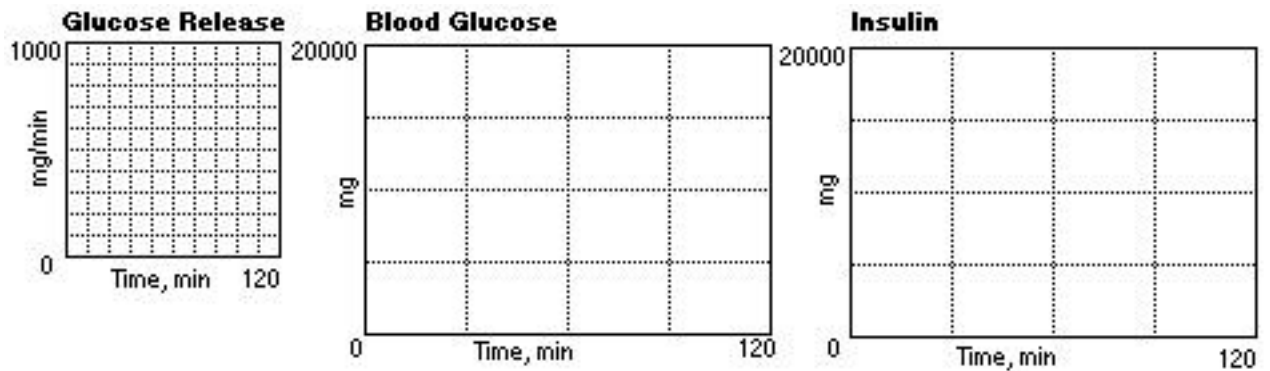
QUESTION 19. How does this blood glucose graph differ from the same graph generated by eating a candy bar (question 5)?

QUESTION 20. What might cause the difference?

QUESTION 21. How is the insulin graph different from the same graph generated by eating a candy bar (question 5)?

QUESTION 22. What might cause the difference?

QUESTION 23. Why do the blood glucose and insulin graphs have a similar shape in a particular simulation?

QUESTION 24. How do you think the graphs would look if you extended the model run longer than 120 minutes? Use the blank graphs below to sketch your chosen glucose release rate and your prediction of the shape of the blood glucose and insulin curves. At the lower right corner of each graph, write the number of minutes you would extend the model run.
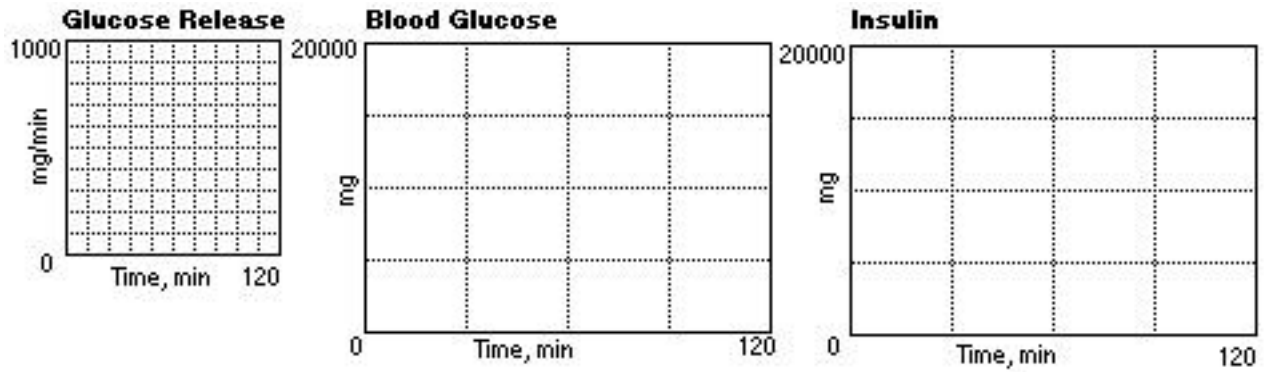
QUESTION 25. What body responses are you showing in your predictions?

Part B. Playing the Part of the Pancreas

The human pancreas secretes chemicals to break down almost all food molecules, buffers against stomach acid, and hormones including insulin. After you eat, glucose enters your bloodstream faster than your cells can use it. Your blood glucose level rises, stimulating the beta cells in the pancreas to secrete insulin. Insulin targets mainly liver, fat and muscle cells to use glucose or store excess as glycogen.

In this part of the activity, you will be simulating pancreatic action by controlling the insulin secretion rate for three glucose release scenarios. For each scenario, you will make a hypothesis about how the pancreas should respond to a particular change in glucose release rate. From your hypothesis, you will try to predict the blood glucose and insulin levels from the insulin secretion rate you have chosen. Each prediction has two parts—the insulin secretion rate you think will work for the scenario, and the response of blood glucose and insulin levels to that rate.

You will be using a second version of the glucose-insulin prebuilt model. It is similar to Glucose 1, but has a STELLA® slider in the lower right of the model box. The slider lets you change the value of the insulin secretion rate, a value that in Glucose 1 was controlled by the model. In Glucose 2, you will control the insulin secretion rate to keep the blood glucose level within a healthy range. To change the insulin secretion rate, move the slider bar with the computer mouse click-and-drag technique, or click in the value box and type a different value.

QUESTION 26. What is a healthy blood glucose range for human adults? (HINT: Read the model's information section.)

**Scenario IV. Simulating steady glucose release**

You will be setting glucose release at a steady, moderate rate and maintaining it for the duration of the model run. (The values are like those in Part C, Eating pasta.)

- Double-click Glucose 2.stm to open the model.
- Open the glucose release input graph.
- Click the time lines or enter values in the Output column to set the glucose release level at 400 mg/min for the length of the model run. Click OK.

QUESTION 27. What is your hypothesis about how the pancreas will respond to an increased glucose release rate?
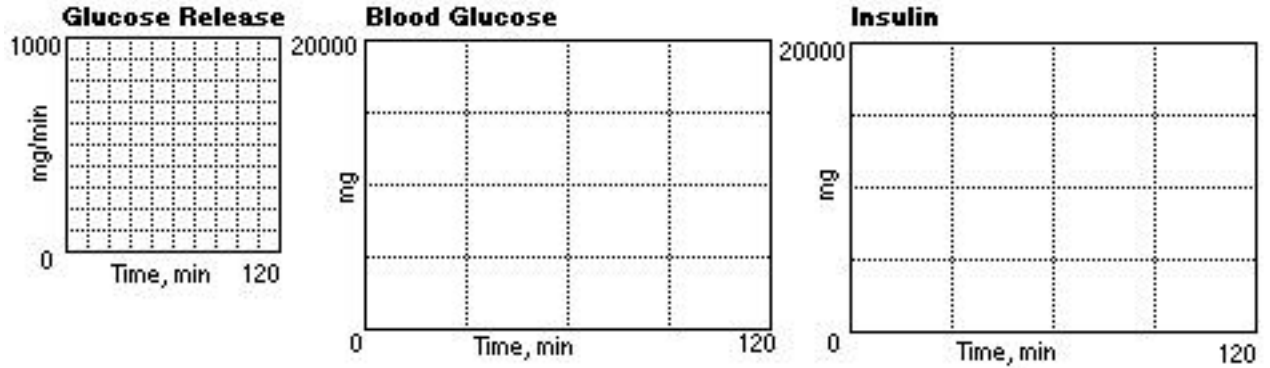
QUESTION 28. How will you, playing the part of the pancreas, change the insulin secretion rate to keep the blood glucose level in a healthy range? This is the first part of your prediction about how the system being modeled should behave as you adjust the slider to control the insulin secretion rate. (NOTE: The replacement of degraded insulin is included in the amount secreted at the homeostatic level.)

QUESTION 29. How do you think the blood glucose and insulin graphs will look after you change the insulin secretion rate? This is the second part of your prediction of the system's behavior at the insulin secretion rate you have chosen. Use the blank graphs below to sketch the glucose release rate and the curves you predict the model will generate.
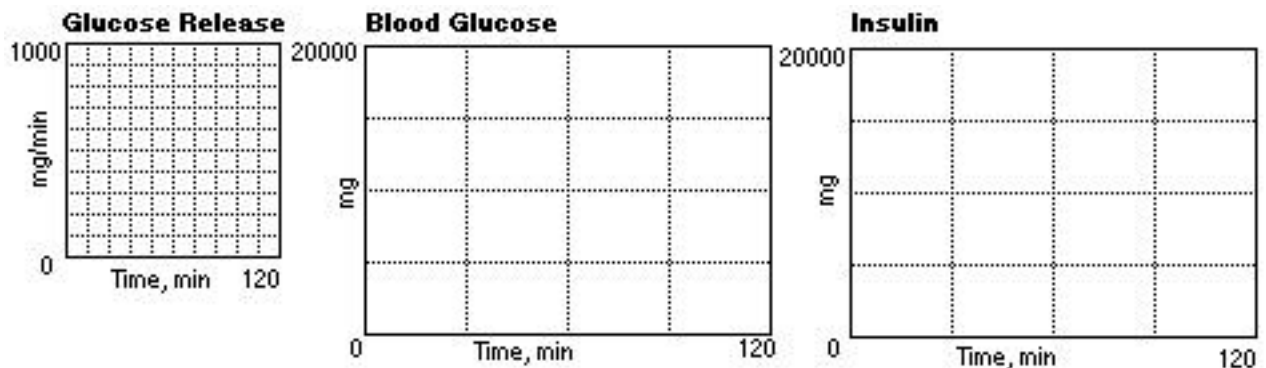
• Run the simulation. Remember to control the insulin secretion rate as you have planned, to bring the blood glucose level as close to normal (the red line) as possible.

QUESTION 30. How did the model behave? Use the blank graphs below to record the curves you see on the model's graphs.

Glucose Release

mg/min

1000

0

Time, min   120

Blood Glucose

mg

20000

0

0   Time, min   120

Insulin

mg

20000

0   Time, min   120

QUESTION 31. What does the shape of the blood glucose curve tell you about the amount of glucose in the blood?

QUESTION 32. What does the shape of the insulin curve tell you about the amount of insulin in the bloodstream?

QUESTION 33. How can you tell how successful you were at maintaining a healthy level of blood glucose?

Scenario V. Simulating moderate, then low glucose release

For this scenario, you will be simulating a drop on the body's glucose release rate. You need a moderate glucose release of 400 mg/min for a short time, followed by very low glucose release of 100 mg/min for the rest of the model run.

- Open the glucose release input graph.
- Click the time lines to enter starting values of 400 mg/min for a short time, then 100 mg/min for the duration of the model run. Click OK.

QUESTION 34. What is your hypothesis about how the pancreas should respond in this scenario?

QUESTION 35. What insulin secretion rate do you predict will keep the blood glucose level in a healthy range?
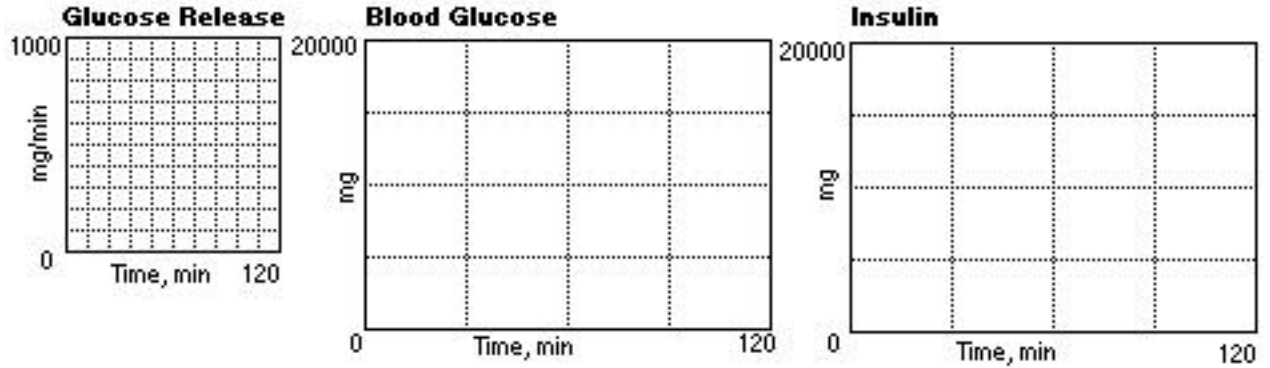
QUESTION 36. What changes in blood glucose and insulin levels do you predict will occur when you change the insulin secretion rate?

QUESTION 37. How do you think the blood glucose and insulin graphs will look after you change the insulin secretion rate? This is part of your prediction of the system's behavior at the insulin secretion rate you have chosen. Use the blank graphs below to sketch the glucose release rate for Scenario V and the curves you predict the model will generate.
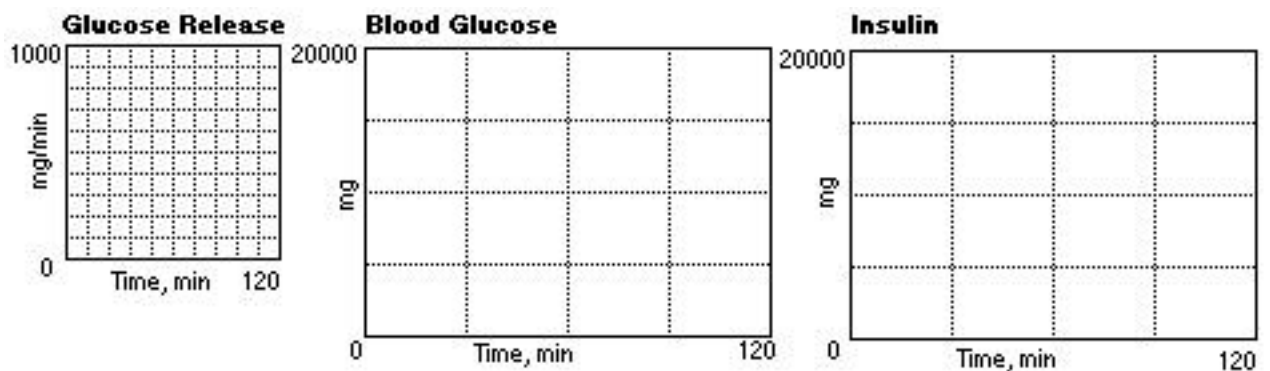
- Run the simulation. Remember to control the insulin secretion rate as you have planned, to bring the blood glucose level as close to normal (the red line) as possible.

QUESTION 38. How did the model behave? Use the blank graphs below to record the curves you see on the model's graphs.

| Glucose Release | Blood Glucose | Insulin |

Graphs:
- Glucose Release: y-axis mg/min (0 to 1000), x-axis Time, min (0 to 120)
- Blood Glucose: y-axis mg (0 to 20000), x-axis Time, min (0 to 120)
- Insulin: y-axis mg (0 to 20000), x-axis Time, min (0 to 120)

QUESTION 39. What does the shape of the blood glucose curve tell you about the amount of glucose in the blood?

QUESTION 40. What does the shape of the insulin curve tell you about the amount of insulin in circulation?

QUESTION 41. What evidence tells you how successful you were at maintaining a healthy level of blood glucose?

**Scenario VI. Simulating your choice of glucose release rate**

Now, you will create your own scenario, using glucose release rates that you choose. You will need to explain the scenario you have decided to test, state your hypothesis about how the pancreas should respond, and predict the blood glucose and insulin levels that will result.

QUESTION 42. What pattern of glucose release are you going to try?

QUESTION 43. What does this pattern represent?

QUESTION 44. What is your hypothesis about how the pancreas should respond?

QUESTION 45. How should the glucose release, blood glucose and insulin graphs look in your scenario? Use the blank graphs below to sketch your prediction.
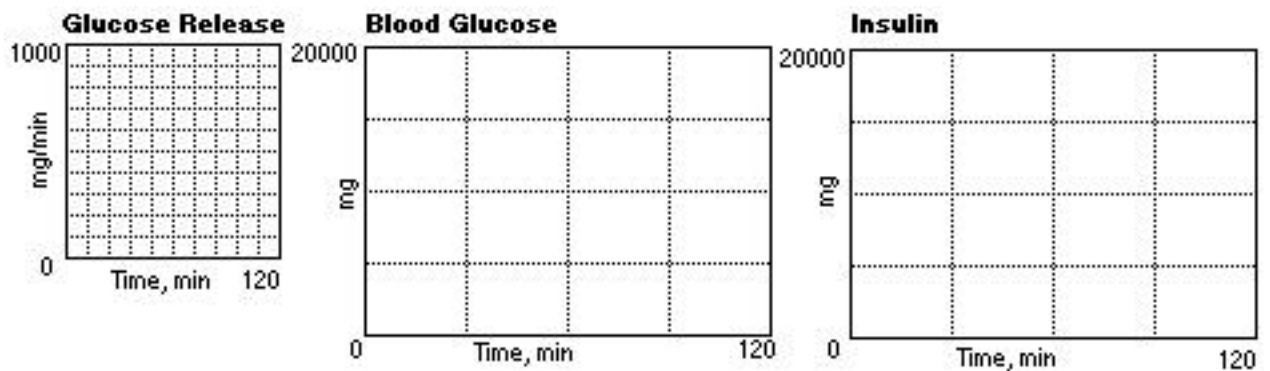
- Set your glucose release rate.
- Run the simulation.

QUESTION 46. Using your scenario, how did the model behave? Use the blank graphs below to record the model-generated curves.

Glucose Release **Blood Glucose** **Insulin**
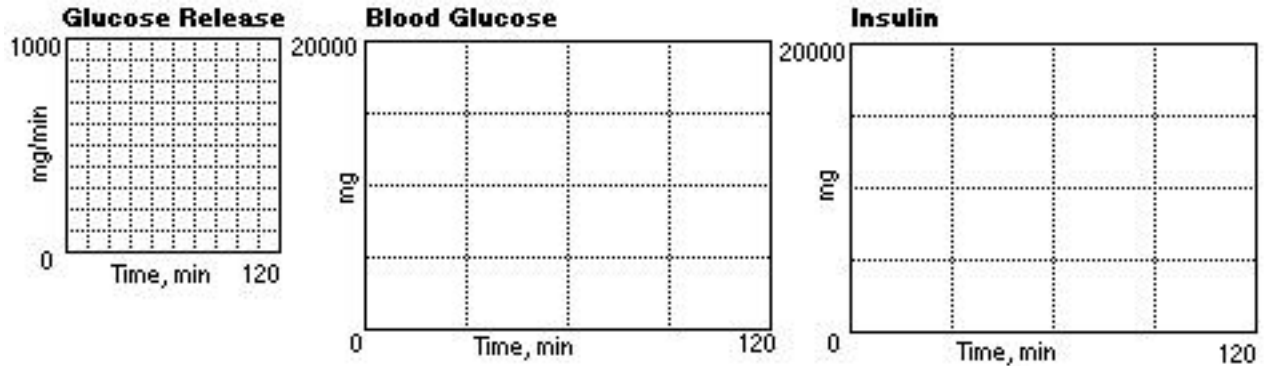
QUESTION 47. What evidence can you use to tell if the behavior of the model supports your hypothesis?

Part C. Thinking about glucose and insulin

The normal relationship between glucose release and insulin secretion is a feedback mechanism governed by chemical signals carried in the bloodstream. The STELLA® models you have been using to simulate glucose release scenarios are based on the physiology of the average, healthy human. Individual healthy humans are not necessarily average.

QUESTION 48. What similarities in the glucose-insulin relationship would you expect all healthy humans to share?

QUESTION 49. What differences in healthy humans do you think would make differences in how their bodies respond to glucose release?

QUESTION 50. How does the glucose-insulin feedback mechanism keep the healthy human body in homeostasis in spite of glucose fluctuations?

Part D. Thinking about diabetes

In people with diabetes, the body can't control the blood glucose level. The glucose-insulin feedback mechanism does not work. In Type I diabetes, the beta cells secrete little or no insulin. Type I is often called juvenile diabetes because it occurs most often in young people. In Type II diabetes, the pancreas secretes insulin at healthy rates but the body's cells do not take in glucose because they do not respond well when insulin tries to help them take in glucose. Type II is often called adult-onset diabetes or insulin-resistant diabetes.

A glucose tolerance test is often used to diagnose diabetes. The test gauges the body's ability to use glucose. The person taking the test fasts for 8 to 12 hours, then drinks a solution containing 75 g of glucose. During the next 3 hours, 4 blood samples are taken at equal time intervals. For a healthy person, the blood glucose concentration should be less than 195 mg/dL after 1 hour, less than 160 mg/dL after 1.5 hours, and less than 140 mg/dL after 2 hours.

Glucose conditions after 8 to 12 hours of fasting followed by a glucose tolerance test are in the table below.

Condition	Glucose concentration	Amount of blood	Total blood glucose
Normal blood glucose	80 110 mg/dL	60 dL	4800 6600 mg
Hypoglycemia	<40 mg/dL	60 dL	<2400 mg
Renal threshold	160 180 mg/dL	60 dL	9600 10,800 mg
Hyperglycemia	>210 mg/dL	60 dL	>12,600 mg

QUESTION 51. Which part of this activity would the glucose tolerance test resemble?

QUESTION 52. How do you think the blood glucose and insulin curves will look for a person with Type I diabetes who takes the glucose tolerance test? Use the blank graphs below to sketch your estimates.
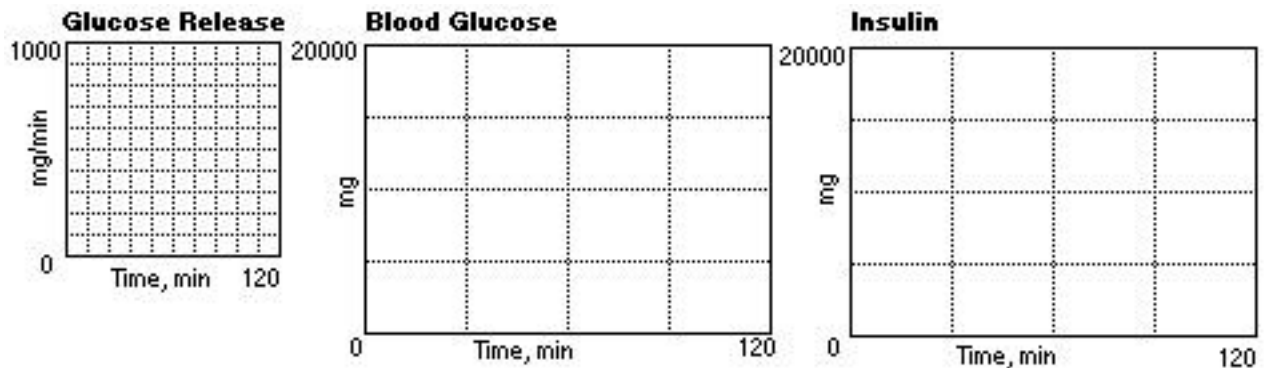
QUESTION 53. How do you think the blood glucose and insulin curves will look for a person with Type II diabetes who takes the glucose tolerance test? Use the blank graphs below to sketch your estimates.
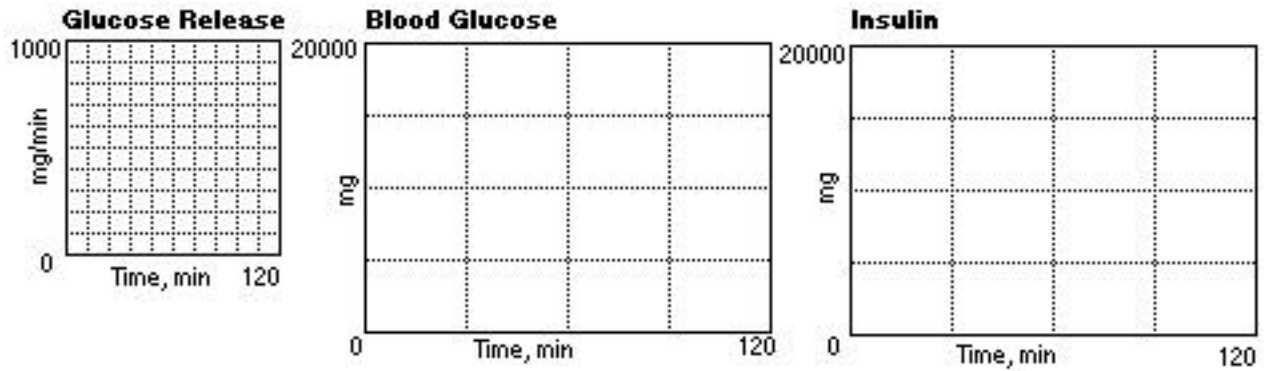
QUESTION 54. Based on your estimates about the behavior of the glucose-insulin system for Type I diabetes (question 52), how might you adjust glucose release and insulin secretion in the Glucose 2 model to simulate Type I diabetes?

QUESTION 55. Based on your estimates about the behavior of the glucose-insulin system for Type II diabetes (question 53), how might you adjust the Glucose 2 model to simulate Type II diabetes?