A kinesthetic activity using LEGO bricks and buckets for illustrating the regulation of blood sugar

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When first faced with understanding blood sugar regulation, students often resort to simple memorization. Many students would like to get more involved with the conceptual framework but don’t know how to start. We have developed an activity based on the Modell (4) approach, a “view from the inside.” This is to help students understand blood sugar regulation using a kinesthetic approach. Our approach complements the beaver pond analogy of Swain (5) and the kinesthetic activity of Conway and Leonard (2). A summary of our activity is available in the Supplemental Material.

In our activity, students are divided into groups of five. To start, each student needs to convert two proinsulin molecules into insulin and C-peptide, as shown in Fig. 1. Students fold the paper in half and staple it twice to signify the disulfide cross-linking. They then use the scissors to cut out a piece of the paper on the folded side to demonstrate how protease cuts out C-peptide. What is left of the paper is the processed insulin, and the piece cut out is C-peptide.

The role of each person is as follows:

- **Person 1** is the intestine.
- **Person 2** is the pancreas.
- **Person 3** is the liver.
- **Person 4** is the clearance person.
- **Person 5**, for the type I diabetes case, is the insulin syringe.

The different roles of the objects are as follows:

- The red bucket represents the bloodstream.
- Hands represent interactions between the bloodstream and intestine, pancreas, liver, or clearance person, with the left hand sensing the blood levels and the right hand altering blood levels.
- LEGO bricks represent glucose; combined LEGO bricks represent glycogen.
- Folded, stapled, cut paper represents insulin; c-shaped paper represents C-peptide.
- The tennis ball represents glucagon.

In the initial activity, students have their eyes open. For a challenge, they are asked to repeat it with their eyes closed. Students can change roles for each of these variations.

What happens if blood sugar is too high? The first activity is a simplified response to how the body responds to a high sugar meal. Let the LEGO bricks represent glucose and the red bucket represent the bloodstream. Three LEGO bricks are placed in the red bucket to demonstrate normal glucose levels. **Persons 2, 3, and 4** can have their left hands in the blood, so they can sense when glucose changes or when hormones are secreted or removed (Fig. 2). After a high sugar meal, like eating several cupcakes, blood glucose increases; therefore, **person 1** (the intestine) adds three more LEGO bricks to the bloodstream. **Person 2** (the pancreas) senses the extra glucose with his/her left hand and uses his/her right hand to put some insulin and C-peptide into the blood. **Person 3** (the liver) senses the insulin in the blood with his/her left hand and uses the right hand to take some glucose (LEGO bricks) out of the blood. He/she can then use both hands to stack the LEGO bricks (slightly staggered) to show how the liver builds glycogen from glucose. Next, the person returns their left hand to the blood to do more sensing. Now, the blood sugar is back to normal, with just three LEGO bricks in the bucket. **Person 4** (the clearance person) removes the insulin from the blood. While this occurs in the body simultaneously with release, we put in a slight delay to make it easier to see individual steps.

What happens if blood sugar is too low? When someone does not eat, their blood glucose levels decrease, so instead of three LEGO bricks in the bucket, there is only one. The left hand of **person 2** (the pancreas) senses the low glucose. For low glucose, the pancreas secretes glucagon. **Person 2** puts the tennis ball, representing glucagon, into the bucket (blood). The left hand of **person 3** (the liver) senses glucagon (tennis ball) in the blood and breaks down glycogen (the stacked up LEGO bricks) into glucose. **Person 3** then returns the glucose (2 LEGO bricks) to the blood, and blood glucose levels return to normal. **Person 4** (the clearance person) removes glucagon from the blood. While this occurs in the body simultaneously with release, we put in a slight delay to make it easier to see individual steps.

A demonstration of what happens with a person with type 1 diabetes mellitus. This sequence is similar to the first sequence except that the pancreas can’t secrete insulin, so insulin (without C-peptide) is provided by **person 5** (the insulin syringe). After a high sugar meal, like eating several cupcakes, blood glucose increases, so **person 1** (the intestine) adds three more LEGO bricks to the bloodstream. **Person 5** (the insulin syringe) puts some insulin into the blood. **Person 3** (the liver) senses insulin in the blood with his/her left hand and uses their right hand to take some glucose (LEGO bricks) out of the blood. He/she can then use both hands to stack the LEGO bricks (slightly staggered) to show how the liver builds glycogen from glucose. Next, **person 3** returns their left hand to the blood to do more sensing. The blood sugar is then back to normal, with just three LEGO bricks in the bucket. **Person 4** (the clearance person) removes insulin from the blood. While this occurs in the body simultaneously with release, we put in a slight delay to make it easier to see individual steps.
A demonstration of what happens with a person with type II diabetes mellitus. In people with type II diabetes, the body develops insulin resistance. To demonstrate normal insulin sensitivity, use person 3’s (the liver) open hand to signify insulin receptors. Insulin can attach to the receptor as the hand encloses the folded construction paper. However, in type II diabetes, the hand is partly closed. Thus, the hand (the liver) is only sometimes able to sense insulin. Subsequently, normal insulin levels are not high enough to allow the liver to respond and store the LEGO bricks.

We have done this activity with both high school students in a summer prehealth professions camp and with prenursing and prehealth profession students in an undergraduate physiology class. Some students in both groups have a weak science background, which is why we first start with insulin regulating blood sugar and then add in glucagon.

After the activity, students can be asked the following questions: “Suppose you were a pancreatic β-cell: how would you behave?” and “Would you behave differently if you were a pancreatic α-cell?” Students can also discuss how to indicate that a person with longstanding type I diabetes might have a harder time responding to low blood sugar. This is because the autoimmune response that destroys β-cells also begins to destroy α-cells, and α-cells are not able to secrete glucagon.

Given the current obesity epidemic and rise in type II diabetes, a reviewer suggested that the effects of insulin on adipose tissue would be another interesting factor to include. When glucose goes into adipocytes, it is stored as fat. A key point in this storage is that it is not possible to reverse the steps and convert fats back glucose (except for a small fraction). This can be illustrated by including an adipocyte person. The conversion of glucose to fat can be shown by having the person smash some LEGO bricks as an analogy for the breakdown of glucose to pyruvate. The steps to form fats can then be represented by taping together the smashed LEGO brick pieces. When the fats are broken down, fatty acids, not glucose molecules, are generated.

If students understand the concepts of the control process for blood glucose and would like a challenge, they can modify this activity so that it applies to the regulation of blood calcium, where bone is the storage location.

In preliminary attempts at this activity, we also had a skeletal muscle person and emphasized how insulin alters glucose transport in skeletal muscle. In the liver, insulin alters an enzymatic step that follows glucose uptake in liver cells. To include the muscle steps versus liver steps, the group is expanded, where the liver has two people (persons 2A and 2B) and the skeletal muscle has two people (persons 2C and 2D). The role of each person is as follows:

- **Person 2A** represents glucose transporter (GLUT)2 (transport from blood to the liver).
- **Person 2B** represents the rate limiting enzyme(s) from glucose to glycogen in the liver.
- **Person 2C** represents GLUT4 (transport from blood to skeletal muscle).
- **Person 2D** represents the rate-limiting enzyme(s) from glucose to glycogen in skeletal muscle.

Fig. 1. Draw two lines on a piece of paper to divide it into three sections. Label the sections as “A,” “C,” and “B” to mimic the order that the insulin prohormone is made (top). Fold the paper within section C so that sections A and B touch (middle). Staple the paper in two places mimicking the disulfide bonds that form between the A and B chains. Cut out the bent section C to create the C-peptide (bottom left) and leave the mature insulin as cross-linked sections A and B (bottom right).

Fig. 2. The red bucket represents blood and contains three LEGO bricks, which represent resting blood glucose levels. The left hands of the people representing the pancreas, the liver, and clearance are in the bucket to sense the blood glucose levels.
Insulin increases the rate at which person 2B can assemble glycogen and increases the rate of both persons 2C and 2D. However, we found that this extra detail often confused the students and took away from their ability to appreciate the overall picture. We are not sure how often most health professionals need to remember this subtle difference in the cells’ response to insulin in the two cell types; nevertheless, it is of great interest to physiologists. We certainly agree that these details make for an interesting story. Furthermore, how scientists figured out these two different pathways is a great way to learn about the scientific process (1, 3). Overall, in a one-semester class for prenursing students, there is a clear trade off of stressing information that is clinically relevant versus providing a more complete scientific story.

We have found that many of our students enjoy doing this kinesthetic activity and that it improves their understanding and appreciation of how blood glucose is regulated as well as what can go wrong in diabetes mellitus.

DISCLOSURES
No conflicts of interest, financial or otherwise, are declared by the author(s).

AUTHOR CONTRIBUTIONS

REFERENCES