“Boston Public Schools Pilot: Using Tactile and Visual Models to Teach Cellular Processes”

November 7, 2011

Your Presenters:

MIT Center for Environmental Health Science
Kathy Vandiver PhD, Director Community Outreach and Education Core (COEC)
Amanda Gruhl PhD, COEC Coordinator and Edgerton Center Instructor
1. Teacher professional development sessions

2. Create a LEGO DNA Learning Center Set -- Design & Assemble & Deliver:
   - Teacher Guide
   - Student Materials
   - DNA/ RNA Kits
   - Protein Kits
   - tRNA Kits

3. Classroom Support: Provided by BPS, Ms. Susanne Gill and by MIT Kathy Vandiver for classroom implementation.
Teacher professional development
Teacher professional development
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Teacher professional development
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Teacher professional development
Teacher professional development
Teacher professional development
Teacher professional development
Prototyping the Museum Exhibit

LEGO Protein Synthesis Sets were invented for use in “The Cell”  May 2006
Prototyping the Museum Exhibit

A mysterious, life-controlling substance lies behind these curtains!
Do you dare to look?

January 2006 prototyping with MIT Terrascope students
Prototyping the Museum Exhibit

Kathy’s scale model of “The Cell”
Prototyping the Museum Exhibit

Dec 2006
Prototyping the Museum Exhibit

CEHS Pilot Project 2006 Grant Awarded to the Community Outreach & Education Core (COEC) $25,000
The MIT Museum and the CEHS Community Outreach and Education Program are collaborating in the development of the first of the Museum's Learning Labs. The purpose of this gallery-based experience is to bring middle and high school classes to the museum to help them understand the process of protein synthesis in the cell through the use of manipulatives.

Schedule for One Year Pilot Project 2006-2007
1) Jan-April 06: planning & exhibit construction
2) May-June: formative evaluations classes use prototypes
3) July- Aug: rework & create final exhibits
4) Sept- Nov: exhibit opens with summative evaluations
5) Dec 2006: exhibit development completed

ARTHUR VINING DAVIS Foundations
Phase One Award 2007-2011
Phase Two Award 2011-2013
Prototyping the Museum Exhibit

Concepts about DNA Structure

1. DNA is a polymer made from subunits called nucleotides.
2. Nucleotides can pair with one another. One side of the double strand determines the other. Because of this base pairing, DNA can be copied easily. (AT) (CG)
3. DNA separates easily into two strands. They rejoin easily too.
4. DNA replicates in a “semi-conservative” manner. (One side will be new. The other side is the original and it is used as the template.)
5. DNA forms very long molecules!

Museum Exhibit and Programs were designed to meet the following Learning Goals.
**Concepts about DNA Function**

1. DNA contains a nucleotide code that is copied into the mRNA.
2. Nucleotides can be read in groups of 3. Each group codes for a particular amino acid.
3. tRNA molecules carry only specific amino acids. In this way, tRNA molecules translate the DNA code.
4. On the ribosome, the amino acids are joined into a chain.
5. The order of the amino acids in the protein chain is determined by the order of the nucleotides in the DNA.
6. The completed amino acid chain will fold into a shape. It is this shape that gives the protein its function.

**Prototyping the Museum Exhibit**

- Cell processes are more difficult to teach than cell structures which are static.
- More teaching about protein molecules is needed!
DNA can become damaged. Breaks can occur. Extraneous molecules can be come attached to the DNA.

Some molecules from cigarette smoke, for example, cause harm because they adhere to DNA and then the DNA code can not be read properly.

DNA has repair molecules that routinely run up and down the length of the molecule fixing breaks and ripping out the mismatched base pairs.

If a cell cannot repair its DNA, the cell will shut itself down, choosing to die peacefully in a process called apoptosis.

Cancer cells are cells with damaged DNA that have escaped from the peaceful “shut-down program”. Typically the “shut-down program” itself is the portion of the DNA that has become damaged and doesn’t work!
Prototyping the Museum Exhibit

Feb 2008 Combining Fieldtrips: MIT Museum and Broad Institute

Full Day Fieldtrips
Boston Public Schools

MIT Museum
9:00-11:30
LEGO & computer

Broad Institute
11:30-2:00
Lunch & wet lab
Creating LEGO School Sets

Design & Assemble & Deliver LEGO molecules!

**People Making a Difference®**
Non-profit corporation, directed by Lori Tsuruda, MIT alum
Jan 2011- March 2011 more than 1000 man hours of effort!

**TASK description: (22 classroom sets- 10 for BPS)**

- Order 440,000 LEGO pieces (~ half million LEGO components!)
- Estimate work hours to build the DNA, Protein and tRNA kits
  - 140 hours per classroom set
- Create the INSTRUCTIONS FOR BUILDING all LEGO molecules
- Organize and recruit volunteers
- Host LEGO building events at different sites, on and off campus
  - Corporate volunteer events during the work day
  - MIT 150th celebration community volunteering – Bush Room
- Track LEGO production of individual molecules (e.g. Nucleotides)
- Re-associate all LEGO molecules into the correct classroom sets
Creating LEGO School Sets
Creating LEGO School Sets
Creating LEGO School Sets
Creating LEGO School Sets

MIT Grad Students very important! Needed for upper level biochemistry tasks in LEGO
Creating LEGO School Sets

Novartis Community Day
Creating LEGO School Sets
Creating LEGO School Sets
Teacher Support in the Classroom

Social Justice Academy, Hyde Park High School – Biology teacher Andrew Rabin
Teacher Support in the Classroom
Teacher Support in the Classroom
Teacher Support in the Classroom

The classroom of the Lead Biology Leader in Boston Public Schools, Johanna Waldman
Teacher Support in the Classroom

The classroom of Juliet Parry, Brighton, with 14 (ESL) English as a Second Language Students
Seven different languages in one room! The most enjoyable class! I co-taught with Juliet.
Next it is your turn to try .....
Boston Public Schools Pilot  
May 2010 – April 2012

1. Teacher professional development sessions

2. Create a LEGO DNA Learning Center Set -- Design & Assemble & Deliver:
   - Teacher Guide
   - Student Materials
   - DNA/ RNA Kits
   - Protein Kits
   - tRNA Kits

3. Classroom Support:
   Provided by BPS, Ms. Susanne Gill and by MIT Kathy Vandiver for classroom implementation.

Many thanks to Amanda Gruhl for contributing her many professional talents to this project! 
And to the Edgerton Center Staff
Your LEGO Learning Time....

Thank you!
Hands-on LEGO® DNA:
An Introduction to DNA Structure and Replication
Kathy Vandiver, Ph.D. and Amanda Gruhl, Ph.D.
Community Outreach and Engagement Core,
Center for Environmental Health Sciences (CEHS),
MIT, Cambridge MA
2009 ©MIT and the LEGO Group
Nucleotides

DNA is a molecule made from subunits called nucleotides.
Introduction to Nucleotides

1. Take 1 of each color nucleotide. Hold a nucleotide in your hand and study the picture to identify the parts (phosphate group, sugar, base).

2. Look at the bases of all nucleotides. Which bases are bigger?
Building DNA

1. DNA contains messages. **Build the bottom strand of DNA: ATG CCC TAG.** Make sure all the arrows point to the right (in the direction you read).

2. DNA is double stranded. **Create the top strand of DNA using these rules:**
   - DNA strands go in opposite directions
   - Bigger nucleotides pair with smaller nucleotides
   - Top and bottom DNA strands are parallel

Notice the direction of the arrows.
Which bases pair together? You have just discovered the famous base pairing rule!

Notice the direction of the arrows on each side of the DNA. DNA strands have a direction.

3. Unsnap the DNA by pinching and pulling up on the sides of the DNA ladder. The two DNA strands will snap apart. In a cell, the two DNA strands must separate to create new DNA.

This symbol means pinch the DNA as shown in this photo.
A long molecule of DNA is called a chromosome.
Overview of DNA, Genes, and Chromosomes

These three terms are often confusing: DNA, genes, and chromosomes. Let’s use the diagram below. The diagram represents a double stranded DNA molecule, which has been untwisted and laid flat. It looks like a ladder.

- DNA is made of two strands, Strand A (top) and Strand B (bottom), as shown here. The strands can be easily separated where they meet in the middle, like the LEGO DNA.
- Note that both strands contain coded messages of DNA nucleotides, called genes.
- The strands are like one-way streets. Molecules reading the codes can only read in one direction.
- DNA is an abbreviation for DeoxyriboNucleic Acid, the chemical name for the molecule. Both genes and chromosomes are made of DNA. Find the words in red below. Review the picture definitions.

Gene codes for Protein "X"/"Y"
Gene codes for Protein "W"
Gene codes for Protein "O"/"Q"
Gene codes for Protein "M"

Chromosome

This is a very short example. The shortest human chromosome has 17 million base pairs (17 millions steps on the DNA ladder) and is made of hundreds of genes.
DNA replication has already occurred in this photograph. Each rod-shaped chromosome is actually two DNA molecules side-by-side (exact copies).

**DNA Replication**

Before a cell splits into two cells, it must make enough DNA for the additional cell.
DNA Replication

The process of copying a DNA molecule is called DNA replication. Let’s try it!

1. **Build this strand of DNA:** GCA TGC ACA TTG. (The gaps between every three letters will help you build the sequence correctly.) Add a white marker to the G on the GCA end.

   ![Image of a DNA strand with markers]

2. **Make a complementary DNA strand on top using the base pairing rules.** Add a white marker to the second strand. Both strands of the original DNA are now marked so we can follow what happens to them.

   ![Image of a complementary DNA strand with markers]

   Notice the white markers on the original strands.
3. Now we begin the process of DNA replication! **Unsnap** your DNA strands from one end, as shown below. In real DNA, weak hydrogen bonds (represented by the LEGO black joint) allow the two DNA strands to separate from each other easily.
4. Make base pairs following along after the opening as shown below.
5. Continue unsnapping the DNA strands and adding nucleotides until you have two complete DNA molecules.

Notice the white markers on the original strands.

Congratulations! DNA replication is complete.

Look carefully at your two molecules of DNA. Are both molecules identical? Was the copying perfect? Notice the markers on the molecules. Remember you marked the original DNA strands before the copying process began. Where did the original strands end up?

DNA replication is called a semi-conservative process. One strand is conserved (or kept) in the copying process. In other words, there is one original strand in each new molecule.
Major DNA Concepts

• DNA is a molecule made from smaller molecules called nucleotides.
• DNA’s two sides separate easily and rejoin easily.
• DNA forms long molecules called chromosomes, which are comprised of genes joined end to end.
• Genes are lengths of DNA which code for proteins or RNA products.
• Nucleotides can pair with one another. Because of this base pairing, DNA can be copied easily. One side of the double strand determines the other.
• DNA replication (doubling) occurs in a semi-conservative manner. One side of the DNA is conserved (saved) in this process.
Hands-on LEGO® Proteins:
An Introduction to Protein Structure and Synthesis

Kathy Vandiver, Ph.D. and Amanda Gruhl, Ph.D.
Community Outreach and Engagement Core,
Center for Environmental Health Sciences (CEHS),
MIT, Cambridge MA

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Major Concepts for Proteins

Protein structure and function
• Proteins are made from subunits called **amino acids**.
• The amino acids form long chains that fold up into different working shapes to perform their functions. The order of the amino acids is key.

Proteins and some genetic (Mendelian) terms
• Genes code for proteins. A protein can be the **trait** on the molecular level.
• Genes coding for non-functional proteins can appear to be **recessive traits**. For example, the cystic fibrosis gene produces a non-functional channel protein. Thus, this gene produces a trait we call recessive.

Protein coding
• The order of the DNA nucleotides determines the order of the the amino acids in the protein.
• Every three nucleotides, a **codon**, codes a particular amino acid (or indicates a stop signal).
• Changes in the DNA sequence can cause changes in a protein’s shape and function.
Where can you find proteins?

- Keratin is a protein.
- Actin and myosin are proteins.
Look at a Red Blood Cell -- Close up!

Cut through the red blood cell

Cell membrane

Blood Liquid

Proteins are the worker molecules
Proteins molecules can be found everywhere in the cell-- How we depict them.

Protein Molecules in the Cell

- This is a protein in its folded shape.
- Proteins are made of tightly folded chains like the LEGO model below.
- Lots of proteins are present in the cytoplasm of the cell.

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What does this model tell us already about proteins?
What does this model tell us already about proteins?

Proteins ..... 
1. Are made of subunits (amino acids) joined into chains 
2. Have flexible chains which can be folded up into different shapes 
3. Are comprised of four types of amino acids (4 colors) and 20 different ones.
Each person picks up one amino acid. Find the 3 parts of an amino acid.

How to Build LEGO Proteins

Proteins are long chains of amino acids. Let’s look at an amino acid! Each teammate should:
1. Choose any one amino acid from your LEGO kit.
2. Find these 3 parts on your model.

- Amino group \((\text{NH}_2)\)
- Acid group \((\text{COOH})\)
- Side chain

An amino acid is a small molecule with different groups of atoms.
- The amino group \((\text{NH}_2)\) is black.
- The acid group \((\text{COOH})\) is gray.
- Twenty different kinds of amino acids are created by varying side chains.
- The side chains on amino acids can rotate freely.
### Amino Acid Chemistry Reference

**Hydrophobic (water-fearing)**

<table>
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<tr>
<th>Alanine (Ala) or (A)</th>
<th>Cysteine (Cys) or (C)</th>
<th>Glycine (Gly) or (G)</th>
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Page 32

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# Amino Acid Chemistry Reference

**Hydrophilic (water-loving)**

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<td>CH₂-NH-NH₂</td>
<td>CH₂-NH-NH₂</td>
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</table>
Disconnecting amino acids is easy

1) Hold the large flat bricks of the side chain.
2) Pull.

See how to correctly pull them apart.
Could millions of **different** proteins be made?

**Experiment:** Each person should build a chain:

1) Connect any 4 amino acids together
2) **Keep the amino end (black brick end) to the left.** This rule helps keep them in order.
3) When asked, hold up your protein so everyone can see it.
4) How many people made the same protein? Compare #1-2-3-4

Which amino acid is #1? The amino acid with the Free black end is #1!

Protein chains always have two ends. No circles - please!
Proteins? Most people think of food.....

Where can you find proteins?

Watch Demo! Instructor eats, then rebuilds muscle from the same amino acids.
Team Building Task #1. Build this practice protein together. See page 13.

**Experiment and Discover #2**
[Work through the steps to find the answers.]

Can each amino acid’s attraction for water or dislike for water, help create the protein’s shape? Teammates should work together on this activity:

1. **Assemble the 12 amino acid protein chain below.** Remember to keep the amino end (black brick end) towards the left. Your team can share the job, if each person builds a section of the chain. Join the sections and check your work.

   ![](image)

   1 | 2 | 3 | 4 | 5 | 6 | 7 | 8 | 9 | 10 | 11 | 12
   --|---|---|---|---|---|---|---|---|----|----|----
   Asn | Val | Met | Ile | His | Ser | Thr | Glu | Val | Trp | Met | Val

2. **The protein is surrounded by water molecules.** Water molecules have an electrical charge that can attract and repel amino acids. Molecules are always in motion, so the amino acid chain can move around to fit in with its surroundings.

3. Some amino acids are hydrophobic (water-fearing). **Gently fold the chain so that the hydrophobic (yellow) amino acids are located mostly inside of the protein, away from the water.**

4. Some amino acids are hydrophilic (water-loving). **Adjust the chain so that the hydrophilic (red, blue, green) amino acids are located mostly on the outside, facing the water molecules.**

Keep the black ends to the left. Show your instructor your folded chain!
We are going to build a LEGO channel protein next. See how the proteins work?

Channel Protein in the Cell

Proteins have many important jobs to do in cells. Some proteins are important because they form cell structures. For example, proteins are needed to make the pores in the cell membrane. These proteins regulate the entry and exit of many molecules. You will build a channel protein and see how its specialized shape helps it fit into the cell membrane.

1. Study the cell membrane below.
Here is a finished LEGO channel protein.

Channel Protein Modeled with LEGO

2. Look for the pore in the center that is formed by 4 protein chains. Find 2 alpha chains and 2 beta chains.

The protein chains form helices. The LEGO helices look like they have holes in the center, but real protein helices are more tightly coiled.

Also in the real protein, the helices are longer. It takes 9 or 10 full turns to go through the membrane. (Look at the side-view diagram on page 25.)
Listen for which chain your team should build. Is it an alpha or beta chain?

Build the Channel Protein

3. Build one of these protein chains as your teacher directs. Will Met have its amino group or its acid group free?

The **alpha chain** has this sequence of amino acids:

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The **beta chain** has this sequence of amino acids:

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<td>Ser</td>
<td>Glu</td>
<td>Ala</td>
<td>Cys</td>
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</table>

We will need 2 alpha chains and 2 beta chains (4 chains) to make a channel protein.
Follow the steps.

Fold and Place Protein Chains in the Cell Membrane

4. Fold the channel protein chains into helices and place them on the LEGO membrane mat.

Alpha chain:

<table>
<thead>
<tr>
<th>Met</th>
<th>Pro</th>
<th>Arg</th>
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</table>

Step 1

Step 2

Step 3

Beta chain:

<table>
<thead>
<tr>
<th>Met</th>
<th>Pro</th>
<th>Ser</th>
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<th>Ala</th>
<th>Cys</th>
</tr>
</thead>
</table>

Step 1

Step 2

Step 3
The completed protein. Look at the effects of the mutations.

Channel Protein Modeled with LEGO

2. Look for the pore in the center that is formed by 4 protein chains. Find 2 alpha chains and 2 beta chains.

The protein chains form helices. The LEGO helices look like they have holes in the center, but real protein helices are more tightly coiled.

Also in the real protein, the helices are longer. It takes 9 or 10 full turns to go through the membrane. (Look at the side-view diagram on page 25.)
Review Protein Structure for the Computer Activity

1) **Primary** structure – the order of the amino acids
2) **Secondary** structure – the folding of the chains into helices or a beta pleated sheets. These structures utilize hydrogen bonding.
3) **Tertiary** structure – the folding of the chains caused by hydrophobic or hydrophilic principles
4) **Quaternary** structure – the association of a protein with another protein chain
Major Concepts for Proteins

Protein structure and function
• Proteins are made from subunits called amino acids.
• The amino acids form long chains that fold up into different working shapes to perform their functions. The order of the amino acids is key.

Proteins and some genetic (Mendelian) terms
• Genes code for proteins. A protein can be the trait on the molecular level.
• Genes coding for non-functional proteins can appear to be recessive traits. For example, the cystic fibrosis gene produces a non-functional channel protein. Thus, this gene produces a trait we call recessive.

Protein coding
• The order of the DNA nucleotides determines the order of the the amino acids in the protein.
• Every three nucleotides, a codon, codes a particular amino acid (or indicates a stop signal).
• Changes in the DNA sequence can cause changes in a protein’s shape and function.
Three nucleotides in a line means a certain amino acid.

Examine the LEGO gene strips for the membrane protein

1) The alpha gene:

```
ATG CCC CCG GAG CTA TAG
1 2 3 4 5 6 7
```

2) The mutated alpha gene:

```
ATG CCT CCG GAG CTA TAG
1 2 3 4 5 6 7
```

3) The beta gene:

```
ATG CCC TCT GAA GCA TGT TAG
1 2 3 4 5 6 7
```

4) The mutated beta gene:

```
ATG CCC TCT GAA ACA TGT TAG
1 2 3 4 5 6 7
```

1. Build the gene from DNA nucleotides exactly in the order shown above. Add a LEGO white marker to the A of the ATG end. Then add the correct base pairs to make the DNA double stranded.
Decoding the Messages in DNA

DNA can be decoded by reading in the direction of the arrows. Each arrow points towards the 3’ end of the nucleotide. In the picture, the bottom strand of DNA reads: ATG. What will the top strand read?

Three nucleotides in a row, called a codon, indicate a particular amino acid. For instance, the DNA sequence ATG (shown below) codes for the amino acid, Methionine (Met). Decode your DNA with the following steps:

1. Obtain the pack of cards for your gene (alpha, alpha mutated, beta, or beta mutated).

2. Look up the nucleotides in groups of 3. Use the table on pages 16-17 to find the correct amino acid.

3. Select the correct amino acid card. Slide the amino acid card under the DNA strand as shown in the photo.

4. Continue decoding the DNA nucleotides, in groups of 3, until the end.

Now, look at the order of the amino acids. Imagine they are joined together in a chain. Notice this sequence of amino acids seems familiar. You can now see how the DNA nucleotides can determine the order of the amino acids in a protein.
## Amino Acid DNA Code

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<th>DNA Code</th>
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RNA nucleotides. The sugar is different. But the molecules work the same way.
Photo of the ribosome with mRNA and tRNA molecules and the forming protein.