Education Group Meeting

"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

Center for Environmental Health Sciences

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 class-room implementation.

Recruitment Flyer

MASSACHUSETTS SUMMER OF INNOVATION

"Mastering Molecular Biology With LEGO® Molecules"

A NASA and MIT PROFESSIONAL DEVELOPMENT COURSE FOR BOSTON PUBLIC SCHOOL TEACHERS

Students from J. D. O'Byrant HS fold a LEGO protein at the MIT Museum.

On the ribosome, translation is a hands-on experience as well.

Wish you had a better way to teach about DNA and protein synthesis?

- Help pilot the LEGO Molecules Curriculum in your own classroom!
- Sign up for this 15 hour PD course at MIT this fall.
- We have places for only 20 teachers. Register soon.

Who should sign up?

- Teachers teaching DNA and Protein synthesis in spring 2011.

When is the PD offered?

- Sat. October 16th 10:00AM–4:00PM
- Sat. October 30th 8:30 AM – 3:30PM
- Teach with the LEGO sets in your classroom spring semester 2011
- Tuesday May 17th 4:00PM-7:00PM

Where?

- MIT Museum, 265 Massachusetts Ave., Cambridge, MA (MIT Campus)

To preview the agenda or to register

- Go to http://www.mylearningplan.com

WHY is NASA sponsoring LEGO DNA sets and teacher professional development?

This workshop will be brought to you by MIT, a partner in the NASA grant "Massachusetts Summer of Innovation." Besides offering science summer camps for students, this funding supports teacher PD programs.

This course will include basic concepts in protein synthesis with an additional emphasis on DNA damage and repair. Radiation exposure during space travel is of concern to NASA scientists because of the DNA damage it can cause.

So come to the workshops! Gain insight into the DNA-damage connection for cancer as well as the biological challenges inherent in space travel. Find new ways to engage and excite your students in science! NASA is counting on your students to come through the STEM pipeline ….

"Dynamic LEGO models help students learn cellular processes while they complete the steps to building a protein. Their hands do all the work, while their minds are constantly making decisions about what happens next. It's a very active form of learning." Dr. Kathy Vandiver, Outreach Director at MIT and LEGO Life Science inventor

Teacher professional development

October 2010

Teacher professional development

Teacher professional development

Teacher professional development

Teacher professional development

Teacher professional development

Teacher professional development

Teacher professional development

Teacher professional development

MIT Museum Oct 2011

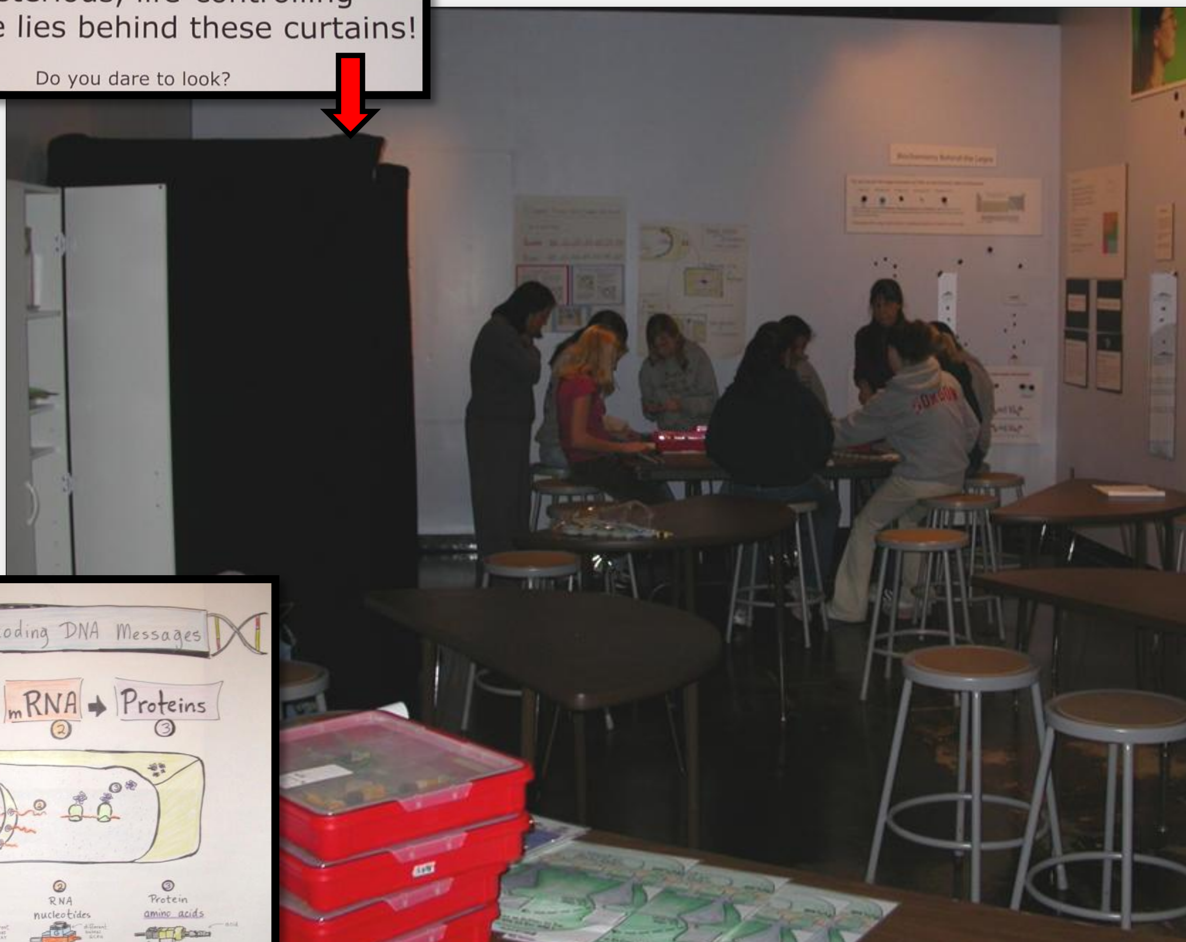
Prototyping the Museum Exhibit

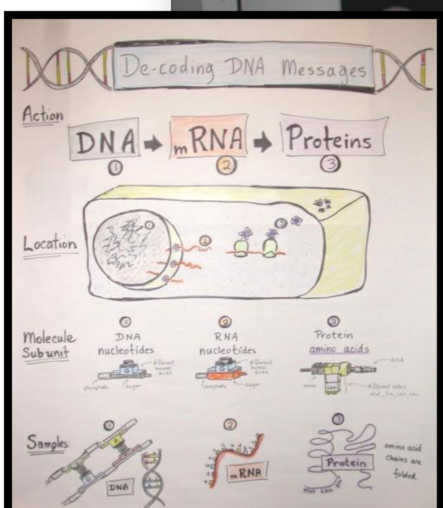
LEGO Protein Synthesis Sets were invented for use in “The Cell“ May 2006

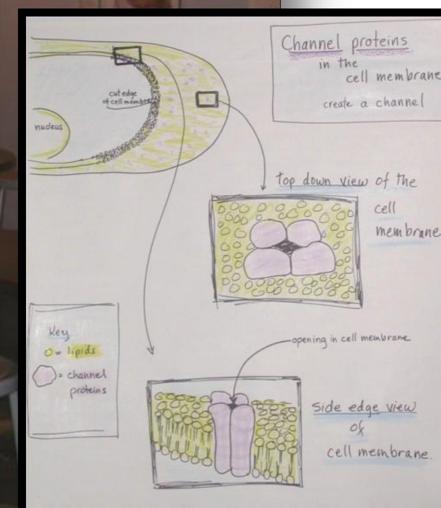
Prototyping the Museum Exhibit

A mysterious, life-controlling substance lies behind these curtains!

Do you dare to look?

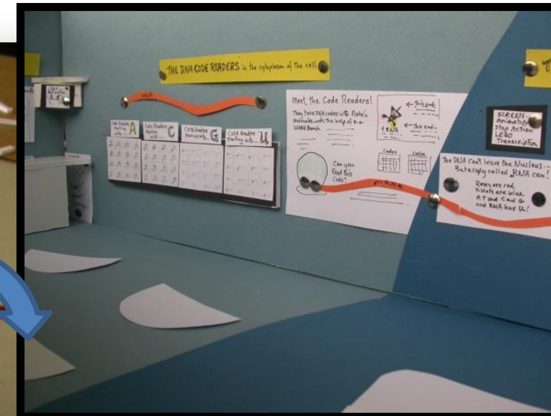


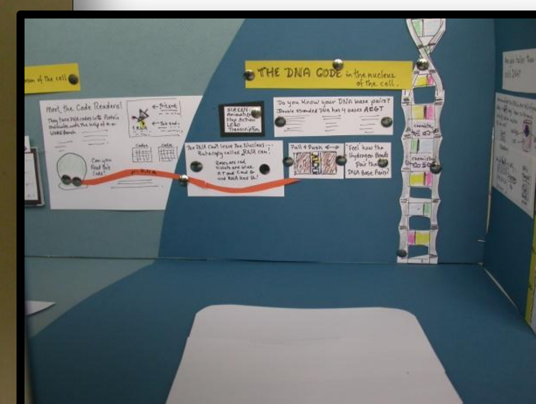




January 2006 prototyping with MIT Terrascope students

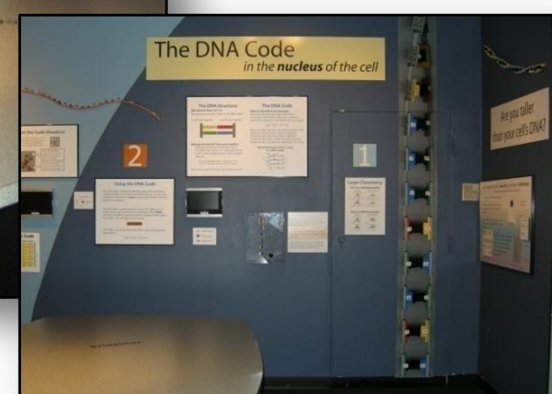
Prototyping the Museum Exhibit





Kathy's scale model of "The Cell"

Prototyping the Museum Exhibit



Dec 2006

Prototyping the Museum Exhibit

MIT museum + MIT CEHS

MIT Center for Environmental Health Sciences

<u>CEHS Pilot Project 2006 Grant Awarded to the Community Outreach & Education Core (COEC) $25,000</u>

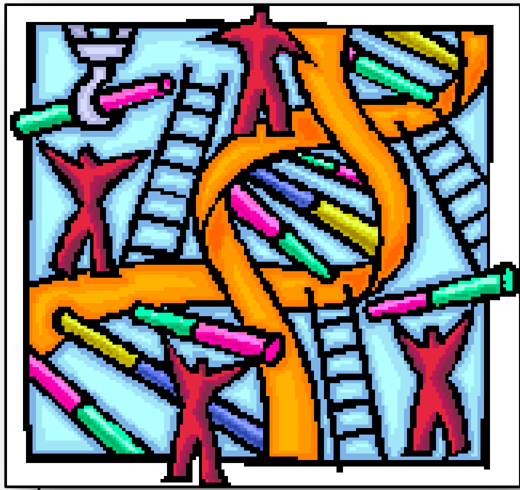
The MIT Museum and the CEHS Community Outreach and Education Program are collaborating in the development of the first of the Museum's Learning Labs. The purpose of this gallery-based experience is to bring middle and high school classes to the museum to help them understand the process of protein synthesis in the cell through the use of manipulatives.

<u>Schedule for One Year Pilot Project 2006-2007</u>

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

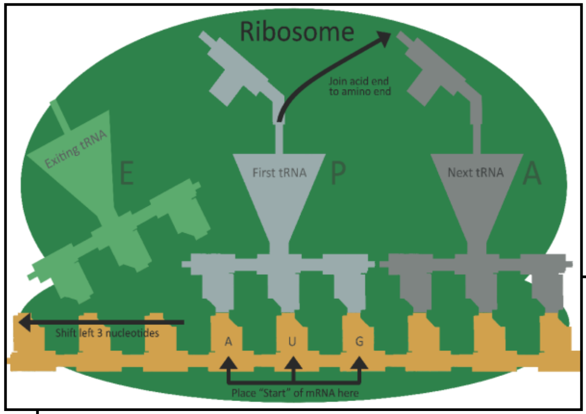


Museum Exhibit and Programs were designed to meet the following Learning Goals.

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!

Prototyping the Museum Exhibit

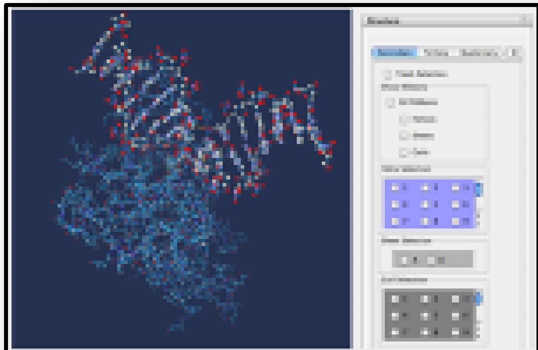


- Cell processes are more difficult to teach than cell structures which are static.
- More teaching about protein molecules is needed!

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



Office of Educational Innovation and Technology

Concepts about DNA Damage & Repair

1. DNA can become damaged. Breaks can occur. Extraneous molecules can be come attached to the DNA.
2. Some molecules from cigarette smoke, for example, cause harm because they adhere to DNA and then the DNA code can not be read properly.
3. DNA has repair molecules that routinely run up and down the length of the molecule fixing breaks and ripping out the mismatched base pairs.
4. If a cell cannot repair its DNA, the cell will shut itself down, choosing to die peacefully in a process called apoptosis.
5. 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

Full Day Fieldtrips
Boston Public Schools

BROAD INSTITUTE

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

Broad Institute
11:30-2:00
Lunch & wet lab

Feb 2008 Combining Fieldtrips: MIT Museum and Broad Institute

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 150^{th} 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

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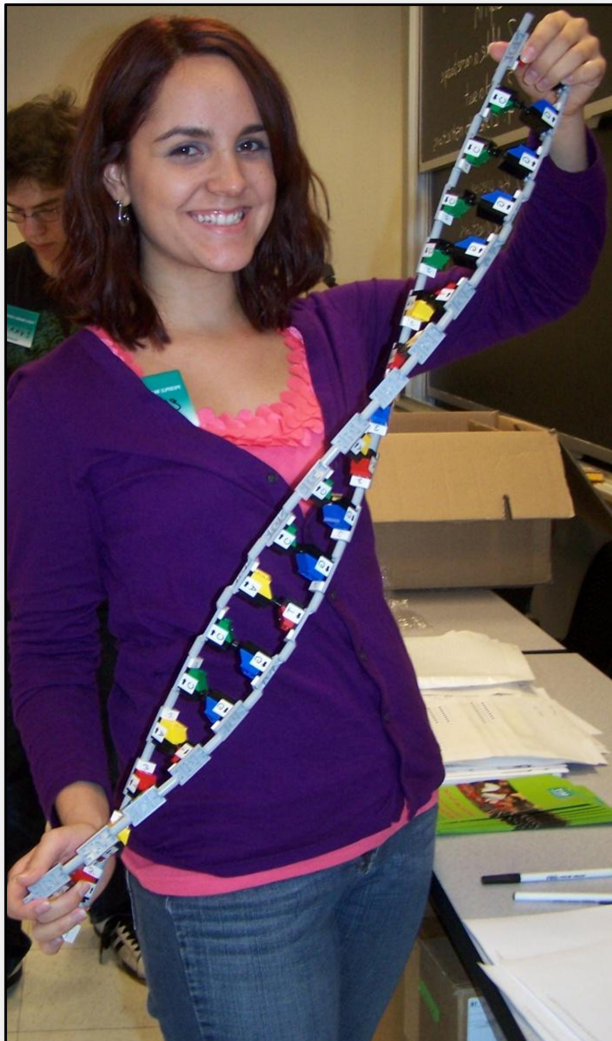
Creating LEGO School Sets



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

Creating LEGO School Sets

Novartis Community Day

Creating LEGO School Sets

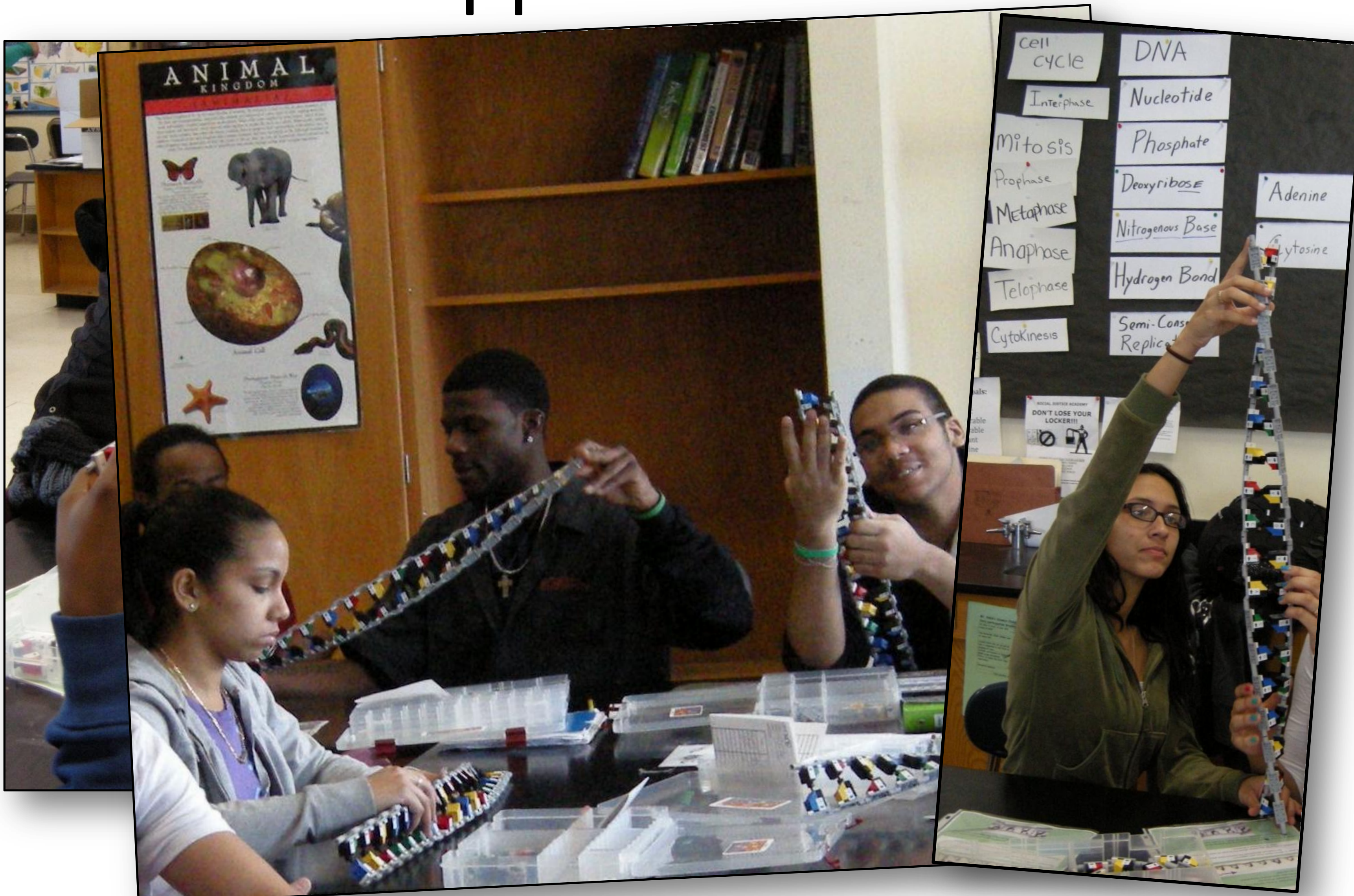
Creating LEGO School Sets

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 .....

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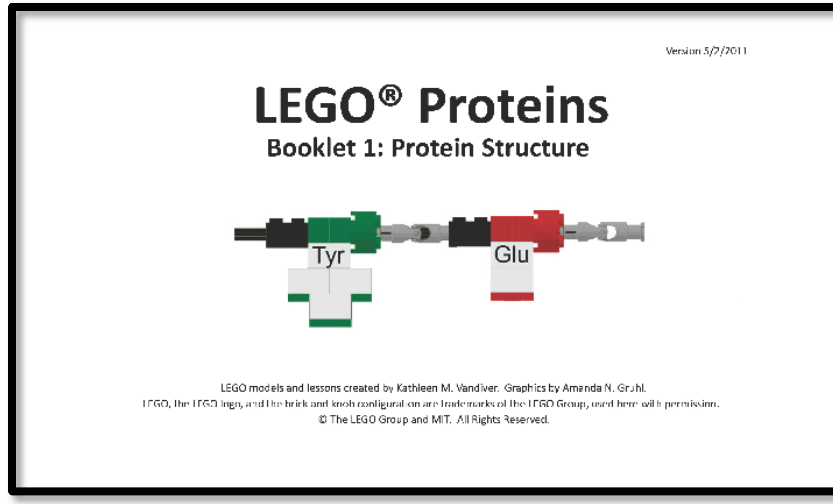


Version 5/2/2011

LEGO® Proteins

Booklet 1: Protein Structure

LEGO models and lessons created by Kathleen M. Vandiver. Graphics by Amanda N. Gruhl.

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!

Education Group Meeting
November 7, 2011

Hands-on LEGO® DNA:

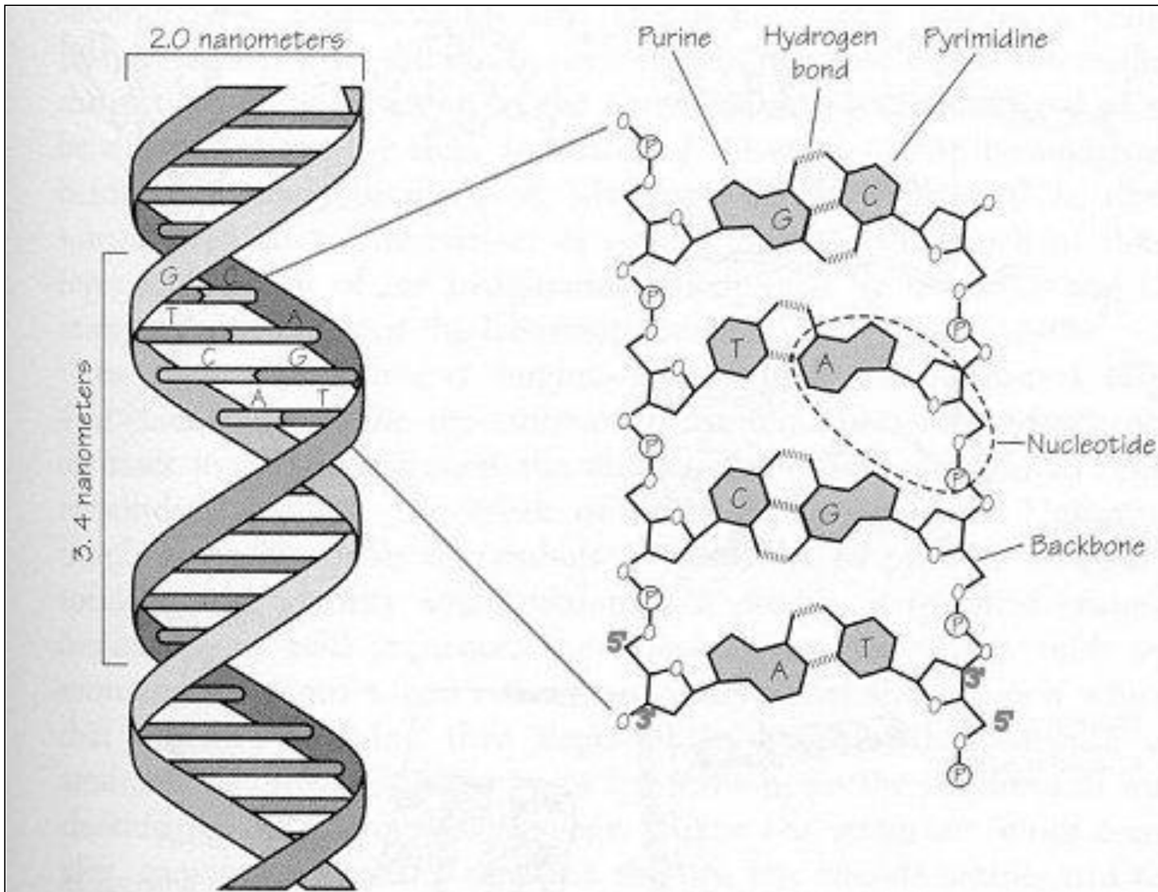
An Introduction to DNA Structure and Replication

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

Nucleotides

DNA is a molecule made from subunits called <u>nucleotides</u>.

Chemical Structure

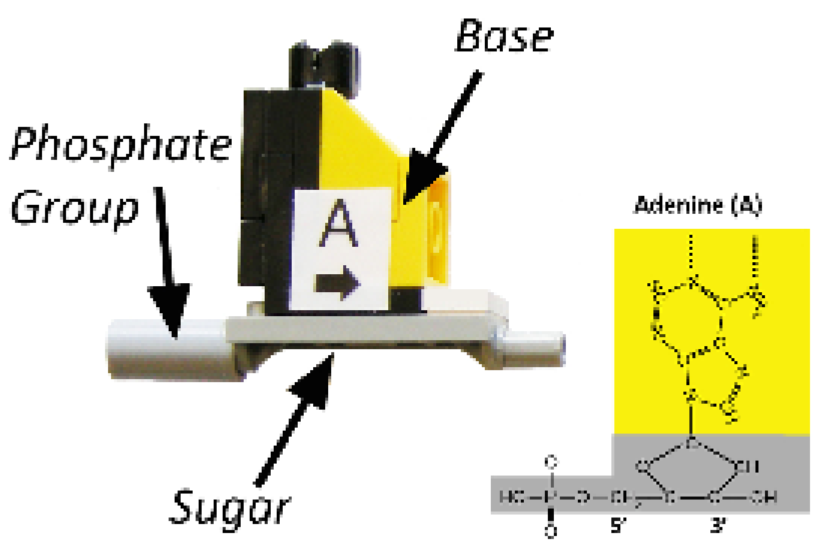


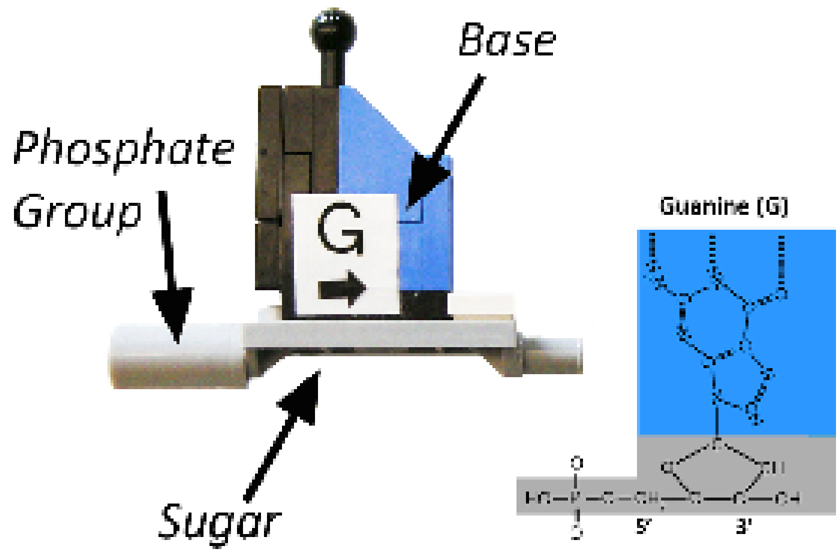
LEGO Structure

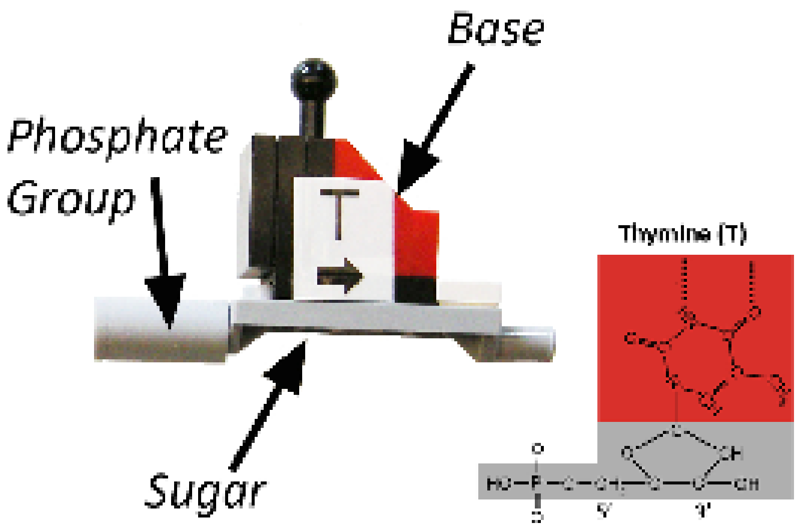
Introduction to Nucleotides

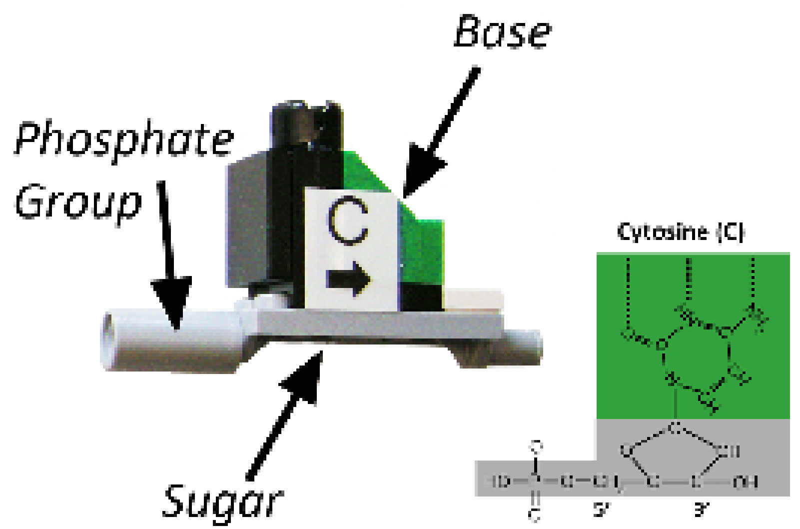
1. Take 1 of each color nucleotide. Hold a nucleotide in your hand and study the picture to identify the parts (phosphate group, sugar, base).

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






Base
Phosphate Group
T
Sugar
Thymine (T)
5'
3'

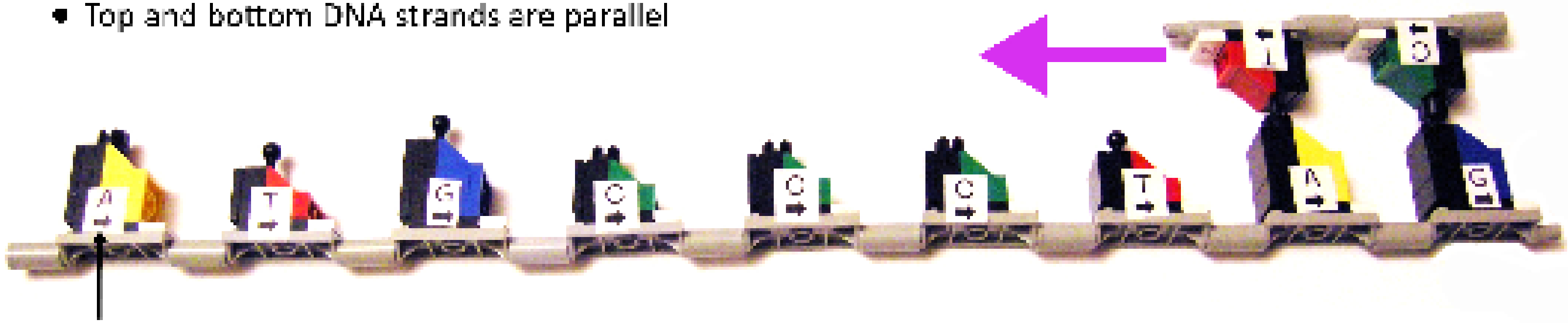

Base
Phosphate Group
C
Sugar
Cytosine (C)
5'
3'

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



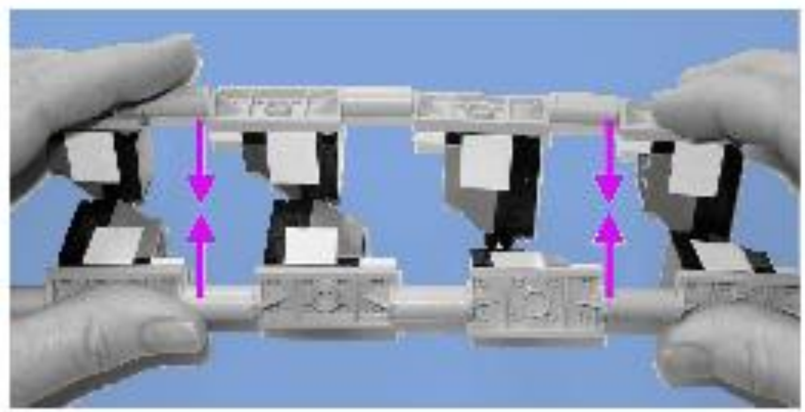
Notice the direction of the arrows.

Which bases pair together? You have just discovered the famous base pairing rule!

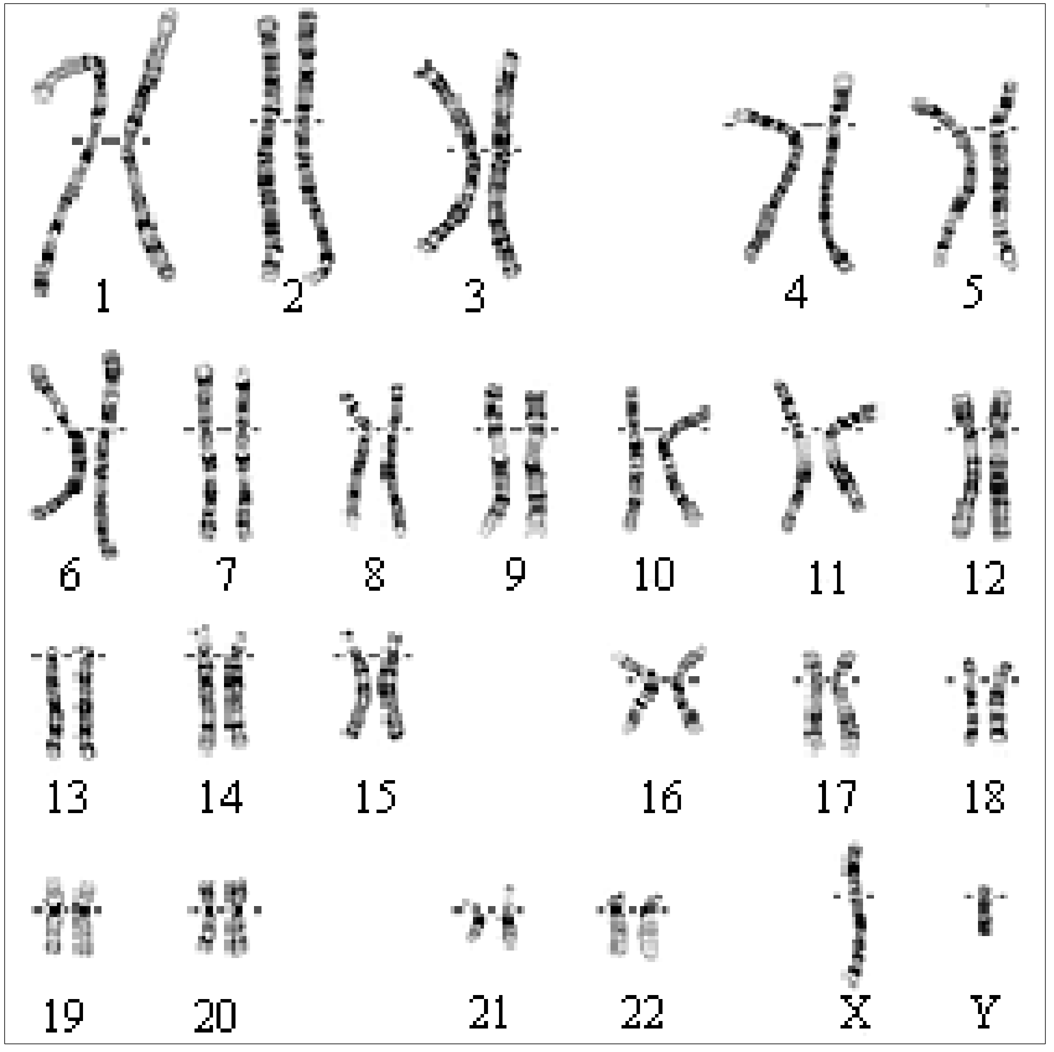
Notice the direction of the arrows on each side of the DNA. DNA strands have a direction.

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.



Chromosomes



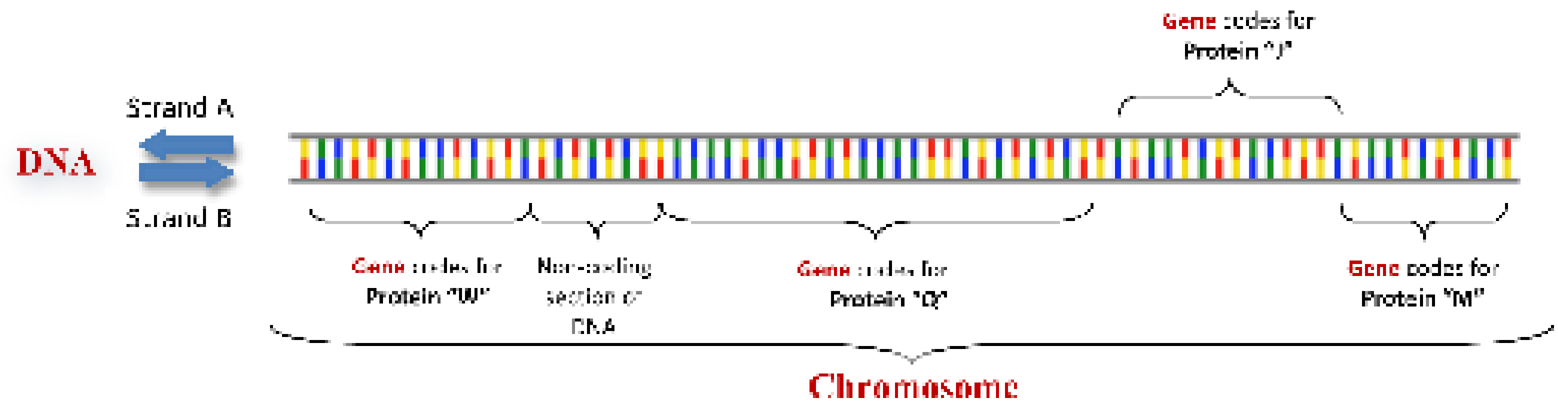
Human Chromosomes

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.

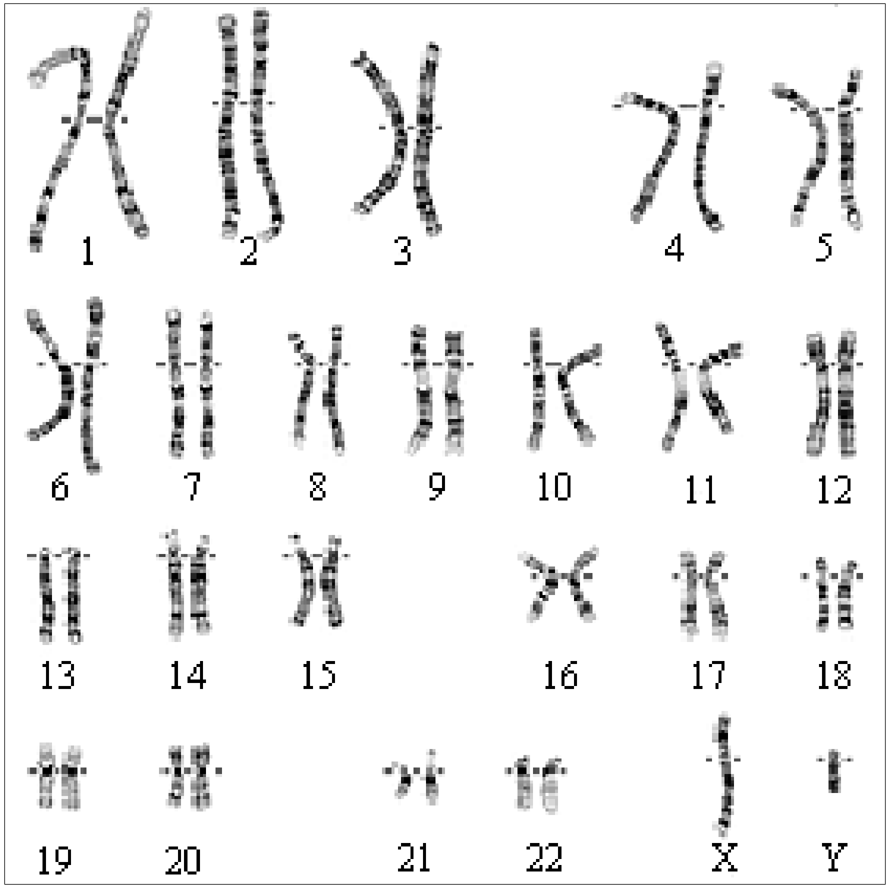
- DNA is made of two strands, Strand A (top) and Strand B (bottom), as shown here. The strands can be easily separated where they meet in the middle, like the LEGO DNA.
- Note that both strands contain coded messages of DNA nucleotides, called genes.
- The strands are like one-way streets. Molecules 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.

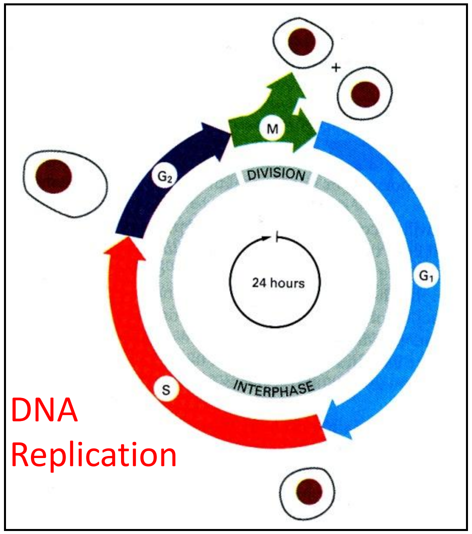


This is a very short example. The shortest human chromosome has 47 million base pairs (47 millions steps on the DNA ladder) and is made of hundreds of genes.

DNA Replication

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



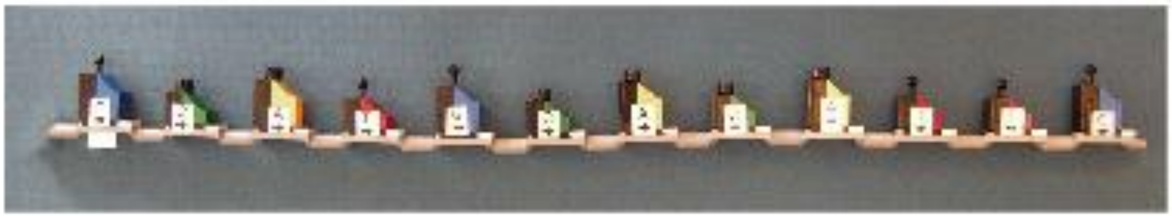


DNA replication has already occurred in this photograph. Each rod-shaped chromosome is actually two DNA molecules side-by-side (exact copies).

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.

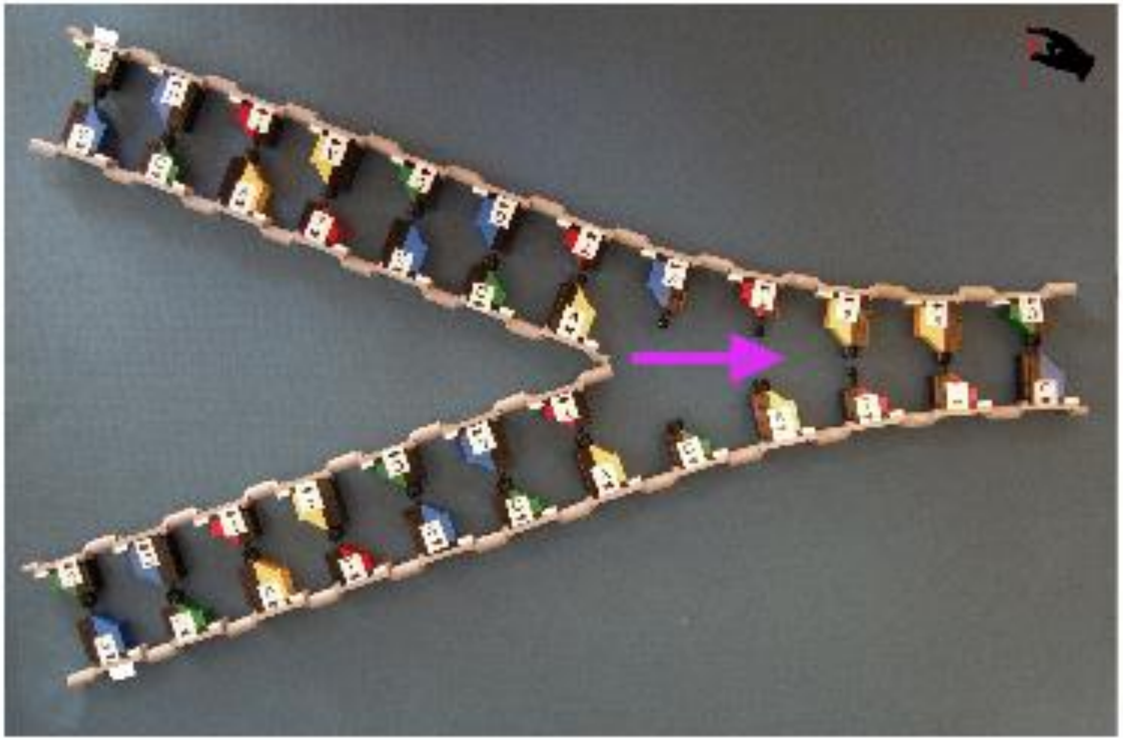


2. Make a complementary DNA strand on top using the base pairing rules. Add a white marker to the second strand. Both strands of the original DNA are now marked so we can follow what happens to them.

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.

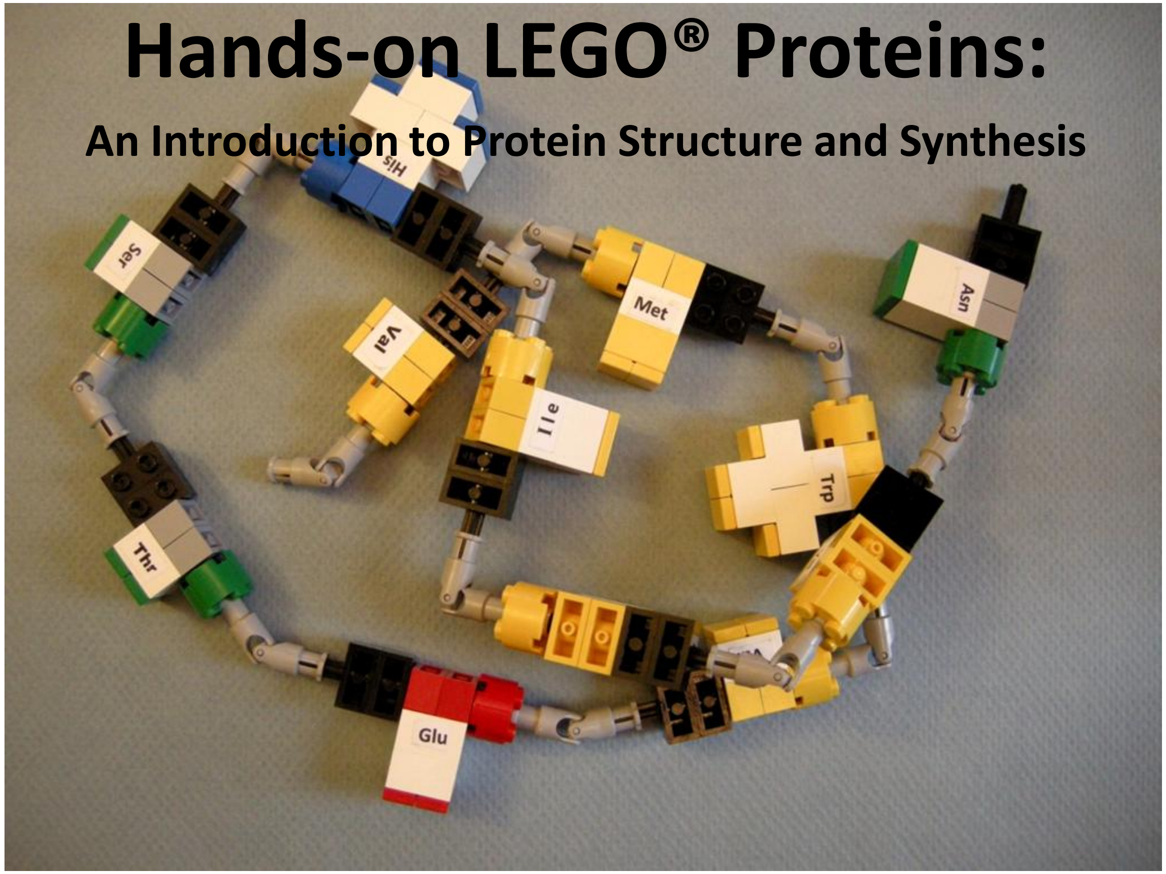
Major DNA Concepts

- 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.

Education Group Meeting, MIT Biology
November 7 , 2011

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,
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MIT, Cambridge MA

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

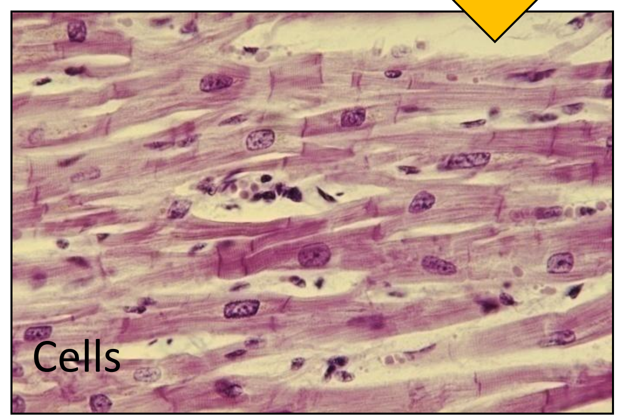
- Genes code for proteins. A protein can be the trait on the molecular level.
- Genes coding for non-functional proteins can appear to be recessive traits. For example, the cystic fibrosis gene produces a non-functional channel protein. Thus, this gene produces a trait we call recessive.

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.



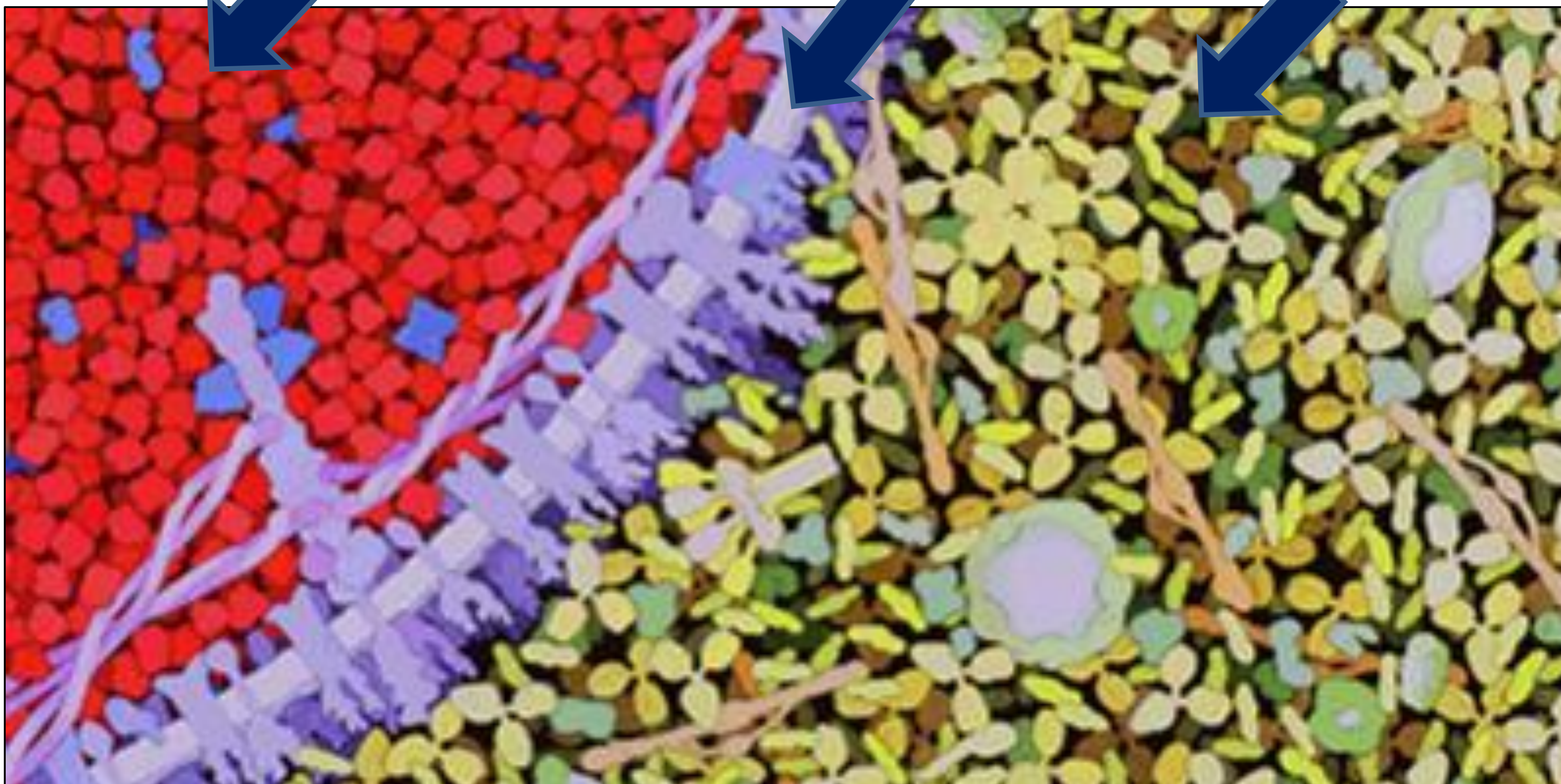
Actin and myosin are proteins.

Look at a Red Blood Cell -- Close up!

Cut through the red blood cell

Cell membrane

Blood Liquid

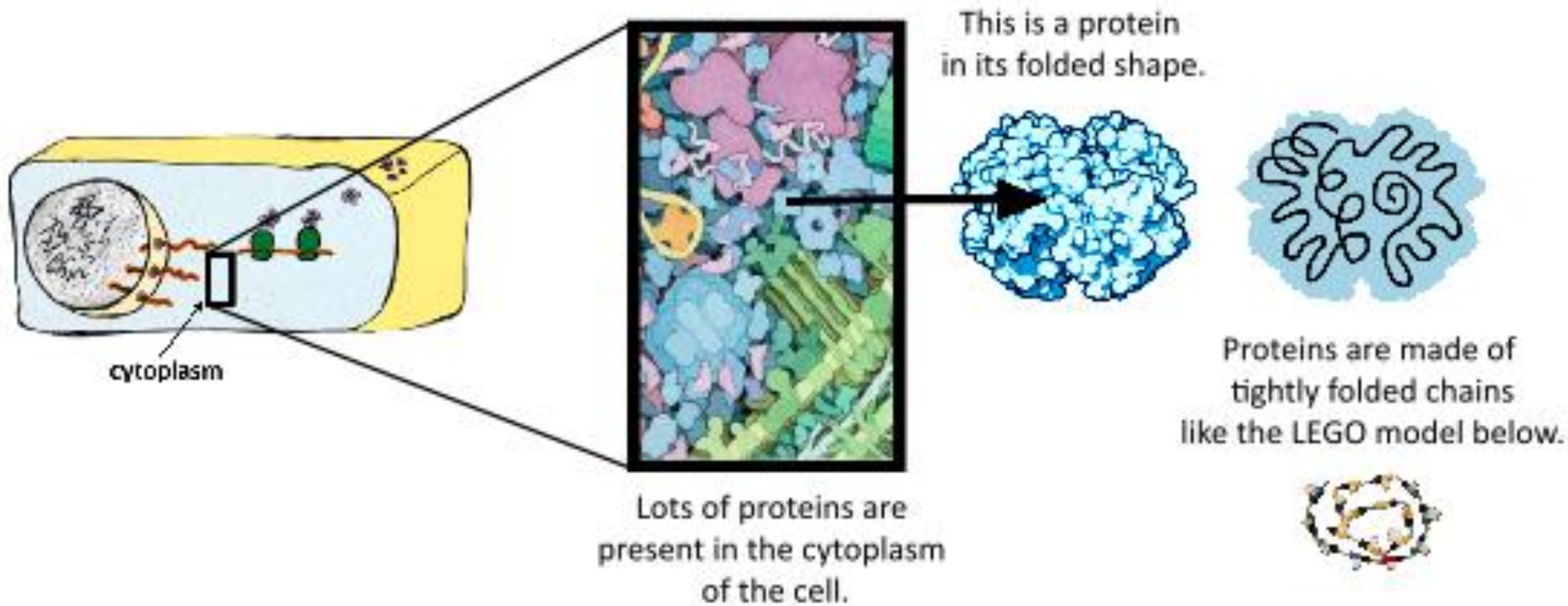


Proteins are the worker molecules

David S. Goodsell

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

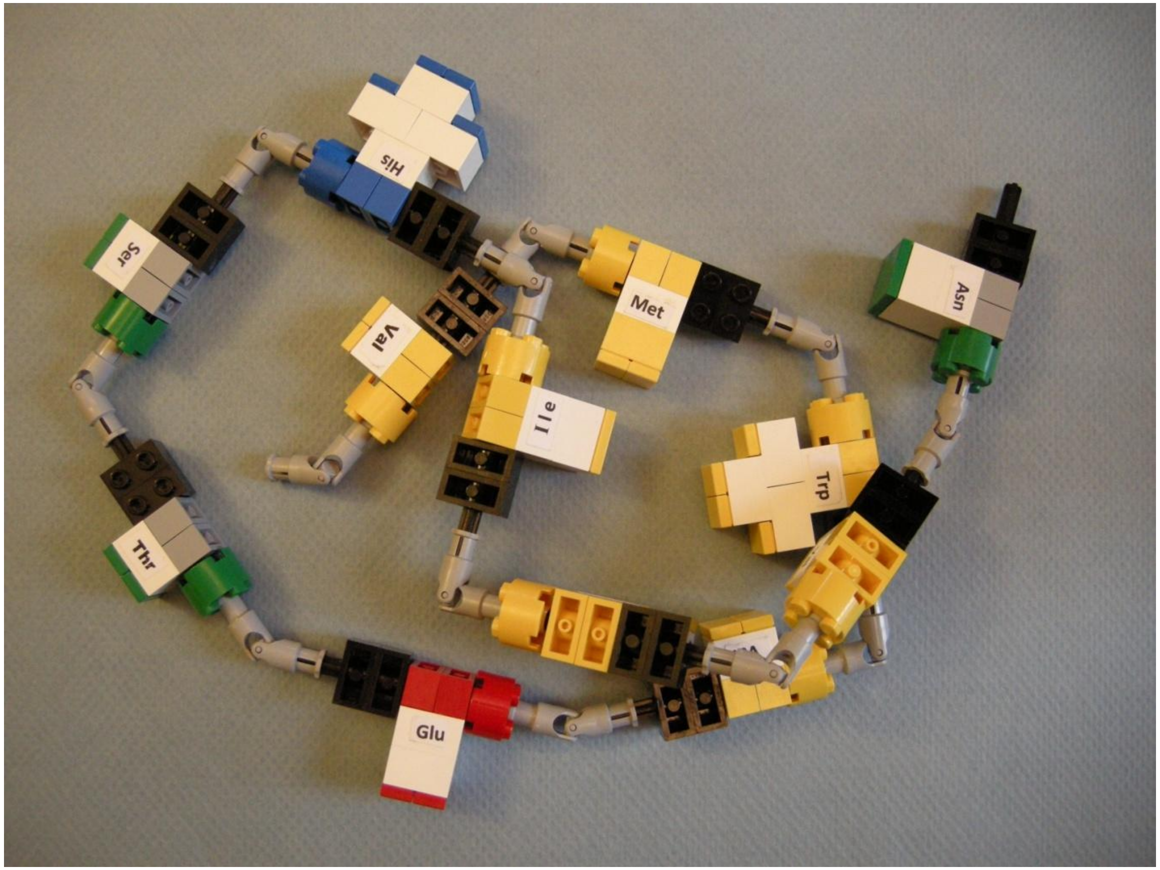
Protein Molecules in the Cell



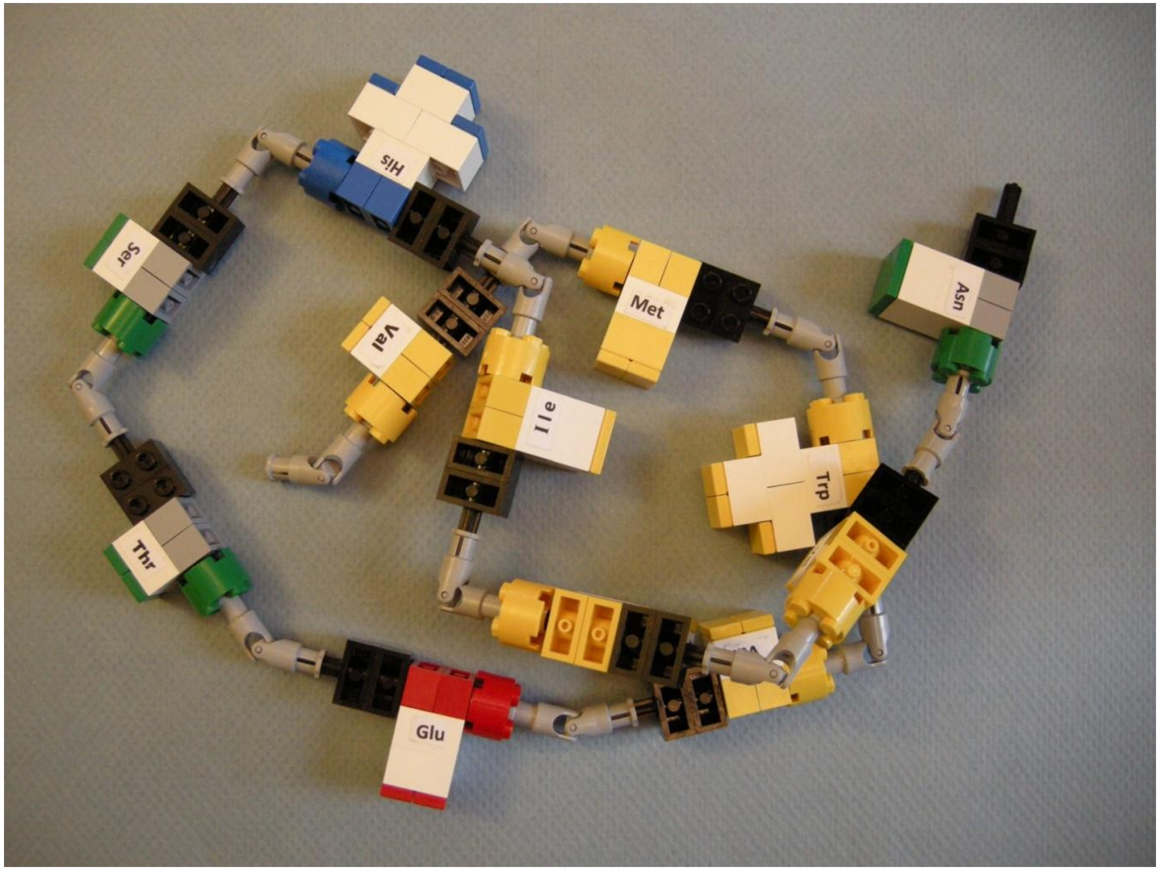
Protein Data Bank Website

Page 6

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 (NH_2)

Acid group ($COOH$)

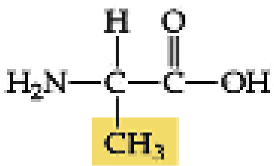
Side chain

An amino acid is a small molecule with different groups of atoms.

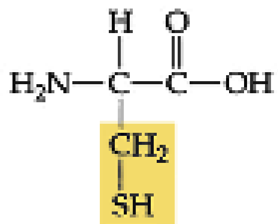
- The amino group (NH_2) is black.
- The acid group ($COOH$) is gray.
- Twenty different kinds of amino acids are created by varying side chains.
- The side chains on amino acids can rotate freely.

Amino Acid Chemistry Reference

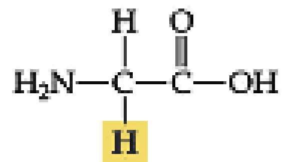
Hydrophobic (water-fearing)



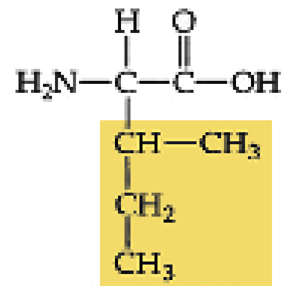
Alanine
(Ala) or (A)



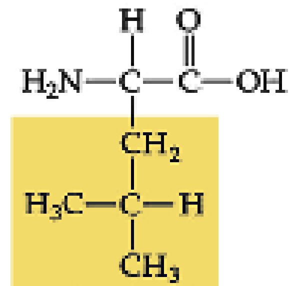
Cysteine
(Cys) or (C)



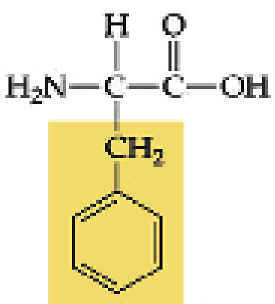
Glycine
(Gly) or (G)



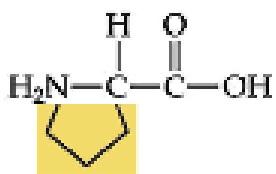
Isoleucine
(Ile) or (I)



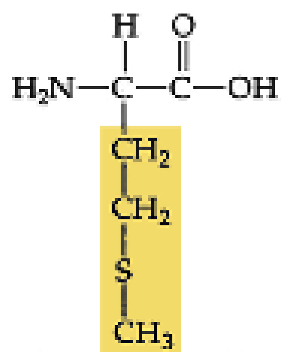
Leucine
(Leu) or (L)



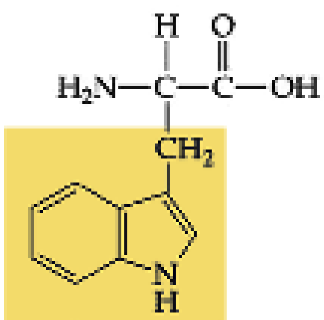
Phenylalanine
(Phe) or (F)



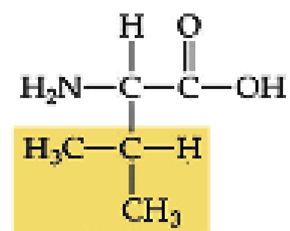
Proline
(Pro) or (P)



Methionine
(Met) or (M)



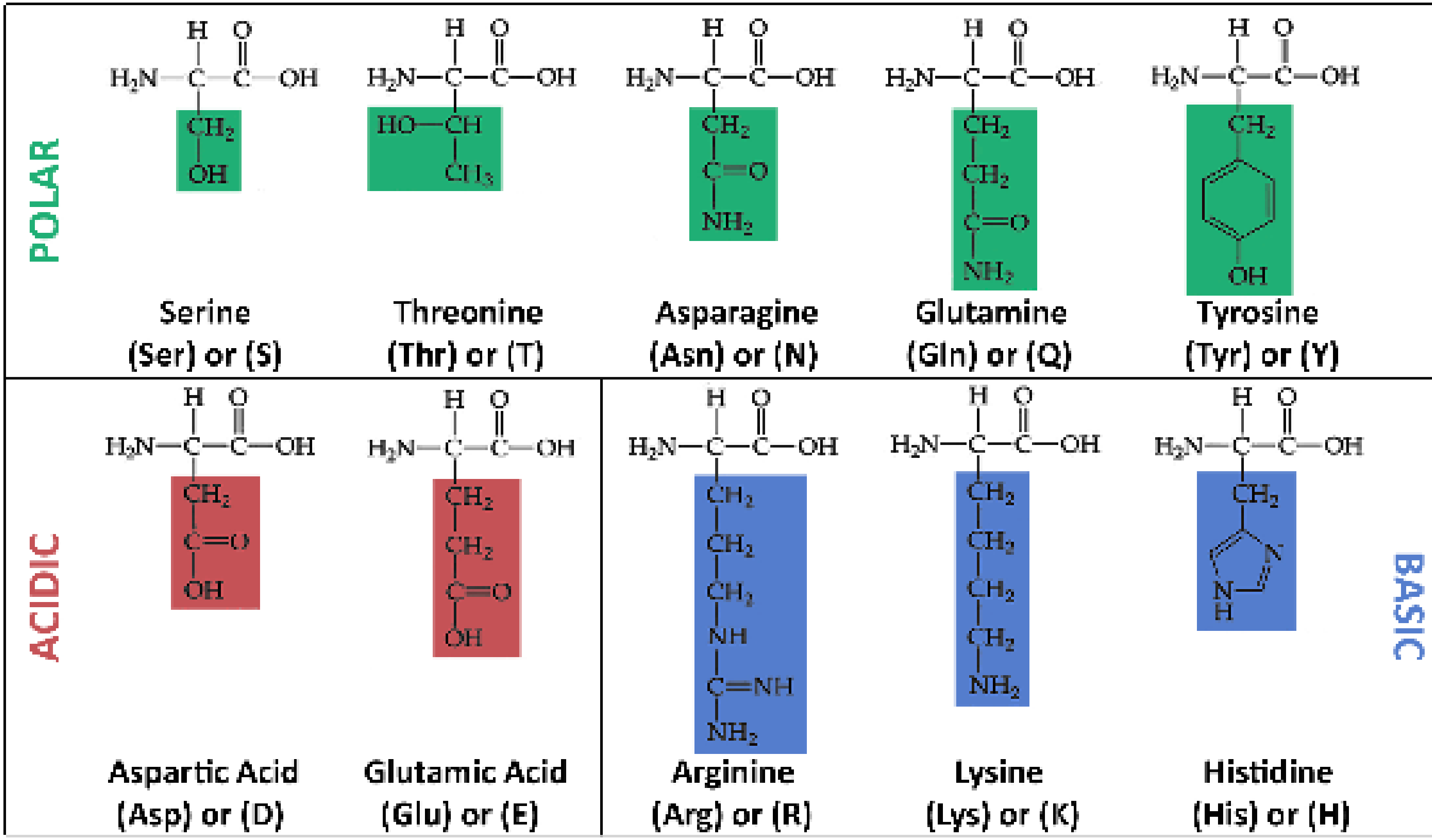
Tryptophan
(Trp) or (W)



Valine
(Val) or (V)

Amino Acid Chemistry Reference

Hydrophilic (water-loving)



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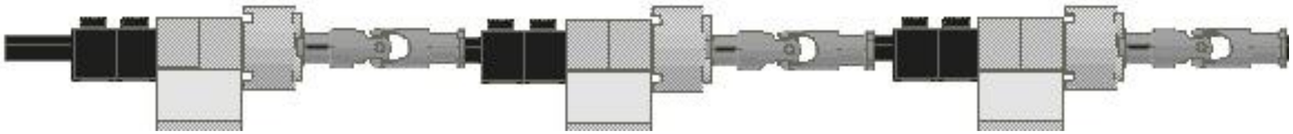
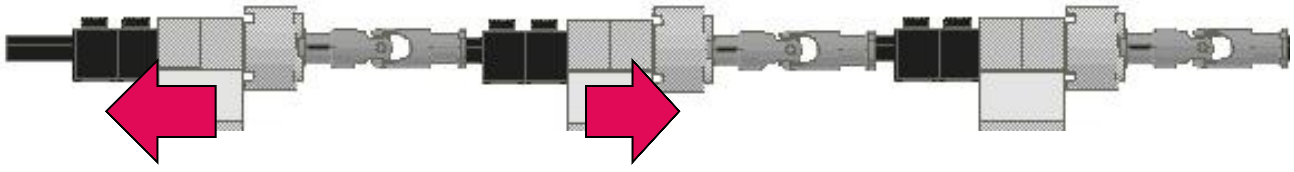
Connecting amino acids is easy



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 <u>different</u> proteins be made?

Experiment: Each person should build a chain:

1) Connect any 4 amino acids together
2) <u>Keep the amino end (black brick end) to the left.</u>
   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.

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.**

Page 13

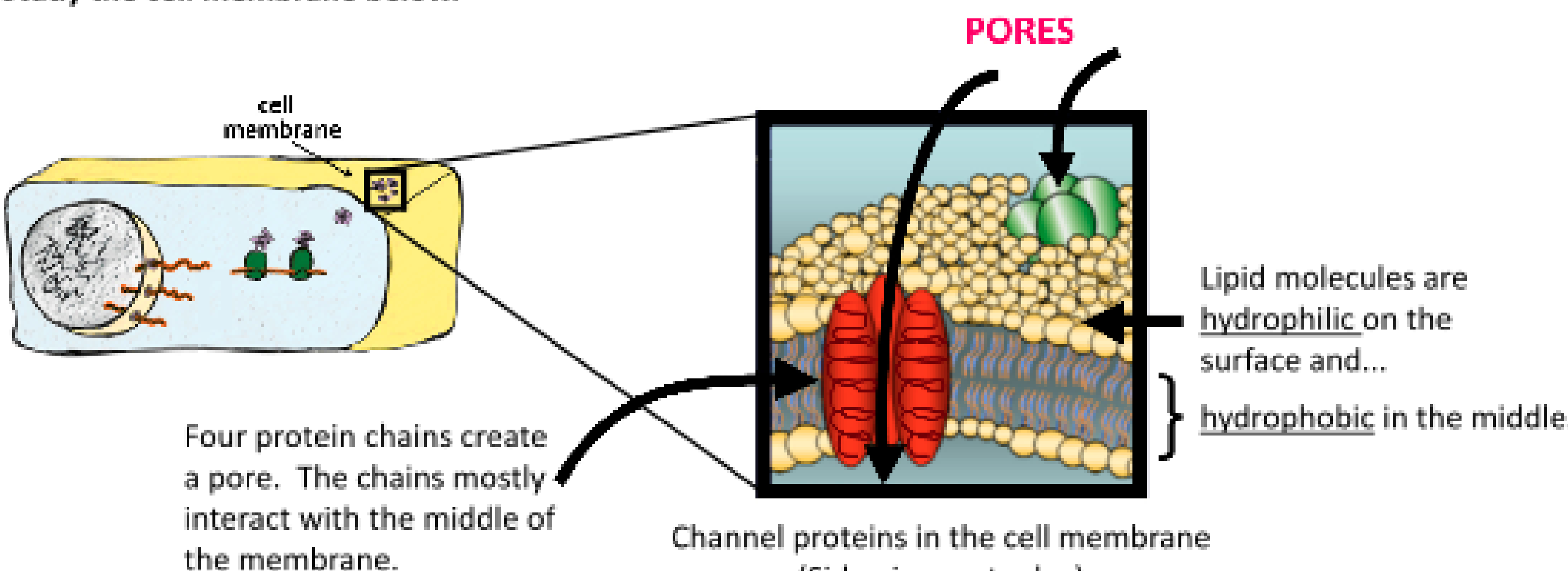
Keep the black ends to the left. Show your instructor your folded chain!

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.

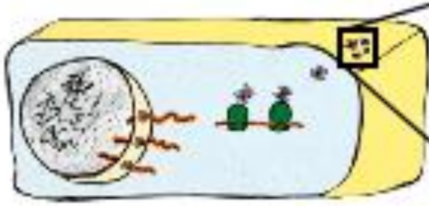


Channel proteins in the cell membrane (Side-view, cut edge)

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.



Channel protein in the cell membrane
(Top-down, membrane view)

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:

1	2	3	4	5	6
Met	Pro	Arg	Ser	Val	Leu

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

1	2	3	4	5	6
Met	Pro	Ser	Glu	Ala	Cys

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:

Met	Pro	Arg	Ser	Val	Leu

Step 1

Step 2

Step 3

Beta chain:

Met	Pro	Ser	Glu	Ala	Cys

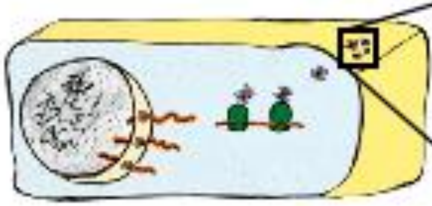
Step 1

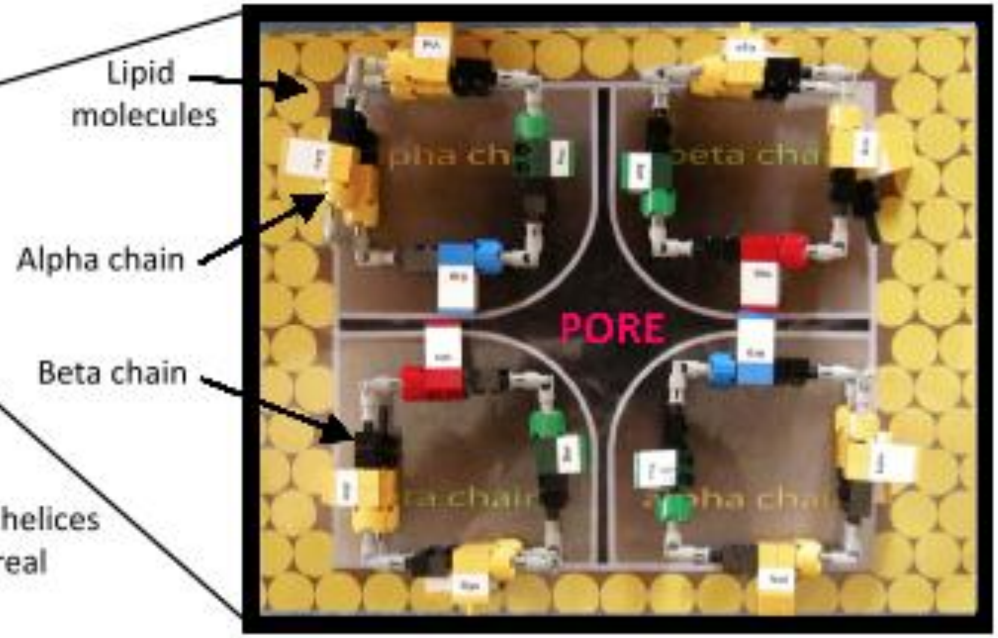
Step 2

Step 3

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.





Channel protein in the cell membrane
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Review Protein Structure for the Computer Activity

1) **<u>Primary</u>** structure– the order of the amino acids
2) **<u>Secondary</u>** structure – the folding of the chains into helices or a beta pleated sheets. These structures utilize hydrogen bonding.
3) **<u>Tertiary</u>** structure – the folding of the chains caused by hydrophobic or hydrophilic principles
4) **<u>Quaternary</u>** 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

Alpha and Beta Channel Protein Genes

1) The alpha gene:

A T G	C C C	C G G	A G C	G T A	C T A	T A G
1	2	3	4	5	6	7

2) The mutated alpha gene:

A T G	C C T	C G G	A G C	G T A	C T A	T A G
1	2	3	4	5	6	7

$\}$ Two Alpha Chains

3) The beta gene:

A T G	C C C	T C T	G A A	G C A	T G T	T A G
1	2	3	4	5	6	7

4) The mutated beta gene:

A T G	C C C	T C T	G A A	A C A	T G T	T A G
1	2	3	4	5	6	7

$\}$ Two Beta Chains

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.

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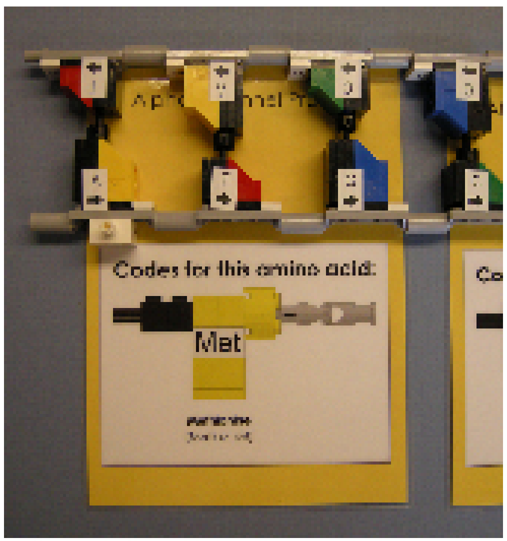
Three nucleotides means a amino acid. Decode the protein message here !

Look up the DNA codons on page 16 & 17. Place the cards under the codon

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 A T G (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.

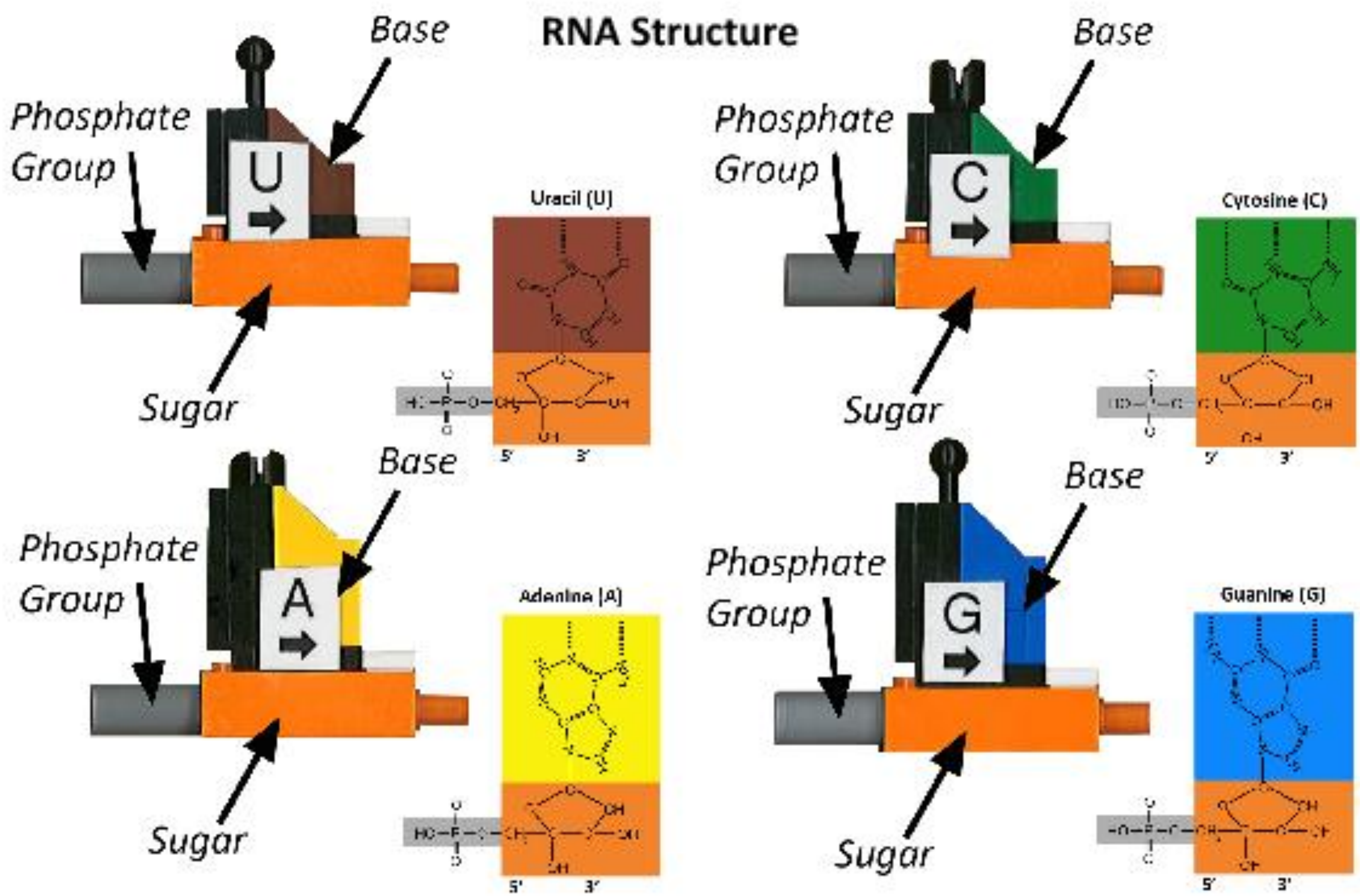
Now, look at the order of the amino acids. Imagine they are joined together in a chain. Notice this sequence of amino acids seems familiar. You can now see how the DNA nucleotides can determine the order of the amino acids in a protein.

Amino Acid DNA Code

Lysine	AAA AAG
Asparagine	AAT AAC
Isoleucine	ATT ATC ATA
Methionine	ATG
Threonine	ACT ACC ACA ACG
Serine	TCT TCC TCA TCG AGT AGC
Tyrosine	TAT TAC
Stop	TAA TAG TGA
Tryptophan	TGG
Cysteine	TGT TGC

Phenylalanine	TTT TTC
Leucine	CTT CTC CTA CTG TTA TTG
Proline	CCT CCC CCA CCG
Glutamine	CAA CAG
Histidine	CAT CAC
Arginine	CGT CGC CGA CGG AGA AGG
Alanine	GCT GCC GCA GCG
Glycine	GGT GGC GGA GGG
Valine	GTT GTC GTA GTG
Glutamic acid	GAA GAG
Aspartic acid	GAT GAC

RNA nucleotides. The sugar is different. But the molecules work the same way.



Booklet last page

Photo of the ribosome with mRNA and tRNA molecules and the forming protein.