BS 03 Optional Activity—Building a Protein

TEACHER GUIDE

All teacher-related instructions appear interspersed with student instructions below. Black text is student-facing (see their handout for comparison). Blue text is teacher-facing and part of the guide.

Learning Objectives:

- Students build a paper protein (10 amino acid starter chain) to reinforce that they are long stands of connected amino acids.
- Ultimately, we'd like the class to recognize:
    - That it takes energy to build proteins from amino acids through a chemical reaction. (We've black boxed the details of the reaction, but students can comment on reactants, products and how energy is involved)
    - That proteins are diverse in their sequence, form, and function. Exactly how deep you go with this secondary objective is up to you. We come around to these ideas again in the genetics (blue) units.

Purpose (as outlined for students)

- Assemble a protein from its base parts while considering what is happening with matter and energy in the process.
- Explore ideas about the diversity of proteins, their sequences and shapes.
- Discuss connections between the form and function of these molecules.

Background Information

We've been studying three types of molecules that are fundamental components of food—carbohydrates, fats, and proteins. We've learned a little about what each is made from, and that proteins are unique among the three in that they contain nitrogen (N) in addition to carbon (C), hydrogen (H), and oxygen (O).

We have recognized that we take these molecules in because they make up our own bodies and the bodies of all living things. But since we don't directly incorporate them into our bodies (eating a piece of corn doesn't put corn in our muscles, for example), we must have some way of breaking down and building these molecules in our cells.

In this activity, we begin to explore how to build proteins. Proteins provide the structure for much of our body and the diversity of proteins in our body also carry out all of the important functions our cells, tissues and organs need to keep us going. Proteins are also the fundamental molecule that actually determine our traits (with the help of something called DNA).

Materials:

- Your group's Amino Acid Sequence
- Paper Amino Acid Molecules (variety, PDFs provided in unit zip file)
- Clear Tape for connecting paper
- Masking Tape for taping to the wall
- Scissors

Prepare photocopies of BS 03 Optional – Amino Acid Sequences and the needed Amino Acid PDFs. (Number of copies for each depend on which proteins you decide to use and how many student groups in your class. Read this whole guide before deciding.) Supply other materials on list to each student work group.

Procedure—Part A: Assembling Your Protein

1. Get together with your group and read over any information your teacher has given you about the protein your team is going to assemble.

   You may use and modify the Optional Student Handouts for each protein as you wish. There are five featured proteins available: rhodopsin, pepsin (pepsinogen), insulin, keratin, and hemoglobin. Each of these proteins is echoed at least once elsewhere in the curriculum. As a collective, they also represent both structural proteins and enzymes. We address this distinction in the genetics (blue) units as well. You can use the discussion of proteins functioning as enzymes as a means to launch into another optional activity, the Enzymes Lab. (See the webpage for Biosynthesis for further details.)

2. Decide which amino acid templates and how many of each you will need to ask for. Then ask your teacher for the needed supplies and make sure you have the materials in the list above ready or nearby.

You will need to calculate the number of copies your class needs based on each amino acid sequence you choose to assemble.

Rhodopsin: Met – Asn – Gly – Thr – Glu – Gly – Pro – Asn – Phe - Tyr

Pepsinogen: Met – Lys – Trp – Leu – Leu – Leu – Leu – Gly – Leu - Val

Insulin: Met – Ala – Leu – Trp – Met – Arg – Leu – Leu – Pro - Leu

Keratin: Met – Thr – Cys – Gly – Ser – Gly – Phe – Gly – Gly - Arg

Hemoglobin: Met – Val – Leu – Ser – Pro – Ala – Asp – Lys – Thr - Asn

Figure out which proteins you want to introduce (if doing part B of the activity, choose some diversity).

Figure out how many of each.

Calculate the number of amino acids you'll need to photocopy for the class (plus some extras for cutting mistakes or lost sheets of paper).

If you are using all five proteins for a standard size class, you will likely run each in duplicate (groups of 3 or 4).

Be sure to add extras to each of these numbers based on your desire to buffer mistakes

Alanine (Ala) = 4	Glycine (Gly) = 14	Serine (Ser) = 4
Arginine (Arg) = 4	Leucine (Leu) = 20	Threonine (Thr) = 6
Asparagine (Asn) = 6	Methionine (Met) = 12	Tryptophan (Trp) = 4
Aspartic Acid (Asp) = 2	Phenylalanine (Phe) = 4	Tyrosine (Tyr) = 2
Cysteine (Cys) = 2	Proline (Pro) = 6	Valine (Val) = 4

3. Look over the individual amino acid molecules and the atoms that make them up. What do they have in common? Do you notice any patterns? (Discuss as a team for a minute.)

   We want students to at least notice the repetition of the amino and carboxylic acid groups, and that the "R" group (as it is often referred to) is variable.

4. How will you connect them? Decide as a group. Then talk to a neighboring group in the presence of your teacher.

   ➔ *While you are waiting, you may begin to cut out your amino acids, being careful to NOT cut off any of the parts (the atoms).*

You will need to check in with students about how to assemble the amino acids into a chain before you let them go wild. Decide if you'll check in with individual groups, pairs of groups or if you'll just provide instructions from the front of the room as a slide. Keep in mind the time it will take for each of these options and the trade-offs.

5. Once you've decided on how to assemble the protein and have checked in with your teacher, you can begin the process of linking the amino acids to one another. Be sure to save any scraps that may be removed in the process. (Just place them aside for now.) Begin by cutting on the dotted lines.

We do want the students to see that water is produced from the assembly of the amino acid chain.

6. Next connect the molecules together with clear tape where the other elements where removed. Keep connecting all the molecules until you have a long chain of amino acid molecules.
7. Pause here to answer the reflection questions below. Answer them to the best of your ability, discussing your ideas with your group and other classmates. We're trying to figure some things out and may not always have complete answers during the activity.

What did your group notice about the differences among the amino acids in your chain?

Here we would like them to record some ideas they discussed (during the procedure above) about the amino group, carboxylic acid group, and the variable region. Do not introduce this vocabulary here. Just let kids use their own words to describe the patterns they observed. (That's the intent—for the students to practice noticing and describing patterns, not for them to learn the detailed structure of an amino acid. You'll have plenty of opportunity to engage them with the variability, which is perhaps the more important piece in the long term.)

How many amino acids did you assemble? ______ (10)

How many amino acids does your protein actually contain? ______

Variable – if you do not give them the info sheet on their protein, you'll have to at least direct them to the table on their activity handout. (See table below.)

When you put your amino acids together, which atoms were left over (the scraps)?

Again, we're trying to get to leftover H_2O here. They may only see it as Hs and Os, so it may be productive to ask them to do some counting.

Was this assembly of amino acids into a protein a chemical reaction? (circle one) Yes / No

If so, what were the reactants? What were the products? Was energy released as we saw in cellular respiration? What do you think? Could you draw a diagram for this reaction? (Discuss with your group and record some of your thoughts here or make a drawing.)

This may be more than they are ready to do, but it will prime them for the conversation about energy and biosynthesis, a key model idea we develop in this learning segment (unit) when we return to the PowerPoint.

Procedure—Part B: Considering Protein Diversity, Form and Function

1. Look over this summary information table for all of the proteins in your class below, plus any extra information your group was given on your particular protein. Reminder: you were given only the first 10 amino acids of a much longer chain needed to make your protein.

Protein Name	Function	Length (# of amino acids)
Rhodopsin	detects light in the eye	348
Pepsin	breaks down other proteins in the stomach	388
Insulin*	helps cells pull glucose from the blood	110*
Keratin*	builds skin, nails, and hair	505*
Hemoglobin*	transports oxygen in the blood	142*

*each of these individual protein chains combines with others before it can function

What is your protein's function?

Students just read from the table for this answer.

2. Next, take a tour of what other groups have been working on as instructed by your teacher.

Are there any patterns you notice when looking at the starter sequence of amino acids that your classmates have assembled? Discuss briefly with your group and record any ideas in the space provided below.

Have your students check in with another group or do some kind of a quick gallery walk. However you choose to structure this, it should be quick.

We are trying to see if they will notice:

- All the sequences are different.
- All the sequences begin with Methionine.

3. Follow your teacher's instructions for finding the 3-D structure of your completed protein.

You'll need to motivate this next portion of the investigation into protein folding.

After a brief discussion of some of the similarities and differences students notices in comparing their sequence to other groups, you might say something to the whole class like, "Your amino acid sequence is very, very short and incomplete. It does not form a complete protein yet – it is called a polypeptide."

Then remind students of the 3-D structures we've been using in the PowerPoint slides or go to one of the Wikipedia or UnitProt pages below to show the structure of one of the proteins the class is building.

Say something like, "Does the polypeptide you have at your table look like this or the proteins we have seen so far?" When students say no, respond, "OK then, we're missing part of the process."

Give the students access to the internet and the URLs below. (Or just have them use a search engine to find images of their protein folded as a 3-S structure.)

The teacher-facing PowerPoint slides for this activity contain a link for each protein to the UniProt website where students can actually rotate a 3-D representation of their protein's structure. You are welcome of course to find other resources. Wikipedia links for each are also included here.

Protein	UniProt	Wikipedia
Rhodopsin	UniProtKB - P08100 (OPSD_HUMAN) *https://www.uniprot.org/uniprot/P08100*	Article, "Rhodopsin" https://en.wikipedia.org/wiki/Rhodopsin
Pepsinogen A	UniProtKB - P0DJD9 (PEPA5_HUMAN) *https://www.uniprot.org/uniprot/P0DJD9*	Article, "Pepsin" https://en.wikipedia.org/wiki/Pepsin
Insulin	UniProtKB - P01308 (INS_HUMAN) *https://www.uniprot.org/uniprot/P01308*	Article, "Insulin" https://en.wikipedia.org/wiki/Insulin

Keratin, type II cuticular Hb1	UniProtKB - Q14533 (KRT81_HUMAN) *https://www.uniprot.org/uniprot/Q14533*	Article, "Keratin" https://en.wikipedia.org/wiki/Keratin Article, "Alpha-keratin" https://en.wikipedia.org/wiki/Alpha-keratin
Hemoglobin subunit alpha	UniProtKB - P69905 (HBA_HUMAN) *https://www.uniprot.org/uniprot/P69905*	Article, "Hemoglobin" https://en.wikipedia.org/wiki/Hemoglobin

4. Then look at other the shapes of the other proteins your classmates are studying.
5. Pause to answer the questions below before having a class discussion.

How do you think a protein figures out how to fold into a 3-D shape considering your starter sequence seems more like a chain?

This is a rather complex model, certainly well beyond the scope of what the NGSS requires our students explore. Be judicious in the amount of time you spend here, but you are welcome to go down this "rabbit hole" as much as you like. In the context of this question, we just want to surface some student ideas.

You can explore this further with your students using a video. One of the suggested videos in the PowerPoint provides them with some information about the chemistry of the amino acid R groups. You might choose to go in depth even further. Amino acids can be characterized as acidic, basic, or neutral; hydrophilic or hydrophobic; and some amino acids have the ability to bind R groups, forming "bridges" between distant portions of the chain.

Again, there are a couple of good suggestions in the PowerPoint. However, they do review aspects of protein building that your students just engaged in. If you want something more directly pertinent to the moment, here's one video that might be a helpful starting point:

Protein Folding Explained (on YouTube from user "Deep Mind")

https://www.youtube.com/watch?v=KpedmJdrTpY

As with the videos suggested in the PowerPoint, we like this one because it does not include anything about the translation of protein from DNA/RNA—concepts you do NOT need to introduce at this time. (Of course, if you've already talked about DNA, you might select a video that does also review the processes of transcription and translation.)

Why do you think proteins have complex forms? How might their form and function be related?

This is a broader discussion engaging one of the NGSS Cross-Cutting Concepts: the relationship between form and function. This may be more than you want to take on, so edit the student-facing materials accordingly. Of course the function of both structural and enzymatic proteins is intimately tied to their structure. It may be that you want to highlight a couple of examples and leave a bigger discussion for later in the term.

Some ideas using the five proteins provided in this activity:

Protein	Form and Function
Rhodopsin	Highly folded protein whose chemistry allows it to embed itself in cellular membranes where it can position itself to be hit by light and also trigger a set of chemical reactions inside the cellular membrane.
Pepsinogen	Enzyme that breaks down other proteins. The protein is folded to alternatively expose and “hide” the active site that cleaves other proteins. Pepsin is the active form after a portion of the pepsinogen is itself cleaved in a chemical reaction with stomach acid.
Insulin	Acts as a hormone with exposed portions or “domains” that trigger other cellular proteins (insulin receptors embedded in the cellular membrane, akin to what happens to rhodopsin).
Keratin, type II cuticular Hb1	Complex sub-unit of the larger twisting of keratins into helices. The super helices provide a lot of strength to cells and tissues.
Hemoglobin subunit alpha	The layout of each subunit of hemoglobin allows for the positioning of the heme unit (the oxygen carrying piece) in a protected pocket. This allows for all sorts of complexity in how the oxygen is held onto or released to cells under differing conditions. For example, hemoglobin needs to acquire oxygen in the lungs but needs to release it in the cells (but not before it reaches the cells that need oxygen)! There are of course complex and interesting interactions between types of hemoglobins in mammals during pregnancy (fetal versus maternal hemoglobin in the placenta).

Be sure to follow any further instructions from your teacher about folding and displaying your group’s amino acid chain / starter protein sequence. Clean up your work stations and return supplies before ending the activity.