Grade 9-12 STEM Challenge

Protein Origami

Inspired by Trae, a Pharmaceutical Scientist in the Indiana Uplands.

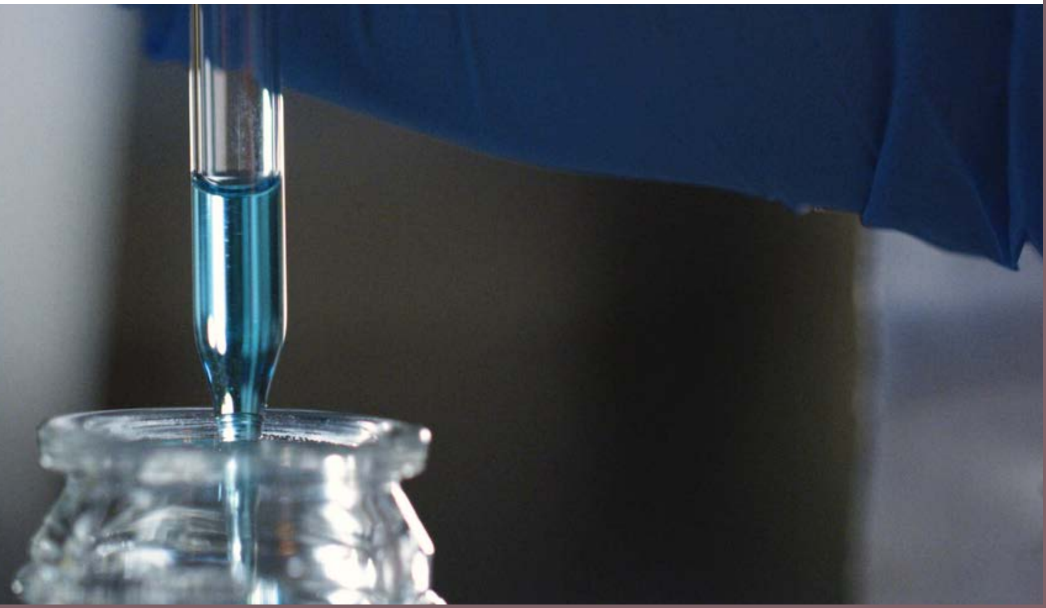
Published by Regional Opportunity Initiatives

GRADE 9-12 STEM CHALLENGE

Protein Origami

Inspired by Trae, a Pharmaceutical Scientist in the Indiana Uplands.

Students will use a paper model to understand how polypeptides are folded into functional proteins.



LESSON TIMELINE

DAY 1

- Show the inspiration video, "Trae - Associate Pharmaceutical Scientist" (5 minutes)
- Introduce the challenge and levels of protein folding (10 minutes)
- Build origami protein models (20 minutes)
- Debreif and discuss (10 minutes)

Recommended Supplies

For each student:

- Long strips of paper cut into 1 cm by 28 cm strips. A printable template is included.
- Tape
- Instruction and Data Sheet

CAREER CONNECTION AND LESSON OVERVIEW

Trae is a pharmaceutical scientist at Singota Solutions in Bloomington, Indiana. Singota Solutions manufactures medical compounds and chemicals for other organizations. Trae's job at the lab is to find the best way to manufacture functional products for the client and to ensure that their products are not contaminated. Most of these products are actually proteins synthesized in the lab and used for medical research. Trae's career focuses heavily on biology, chemistry, and biochemistry but anyone who conducts scientific research to solve a problem can be called a scientist. Trae pursued this career because he was interested in cells—how they grow, how they behave, and how they can be modified to make things humans need.

Proteins play a crucial role in every part of a cell's life. Some proteins, like antibodies, are simple amino acid chains folded up into a three-dimensional structure. Others, like the aquaporins that help let water in and out of your cells, are many individual proteins working together for a single function. In this activity, students will use a simple origami star as a model to help understand the different levels of protein folding and complexity that are required to make a functional protein from a chain of amino acids.

IN THIS CHALLENGE, STUDENTS WILL:

- Learn about the four levels of protein structure.
- Use an origami model to understand and explain the four levels of protein organization

Standards

Science & Engineering Process Standards
SEPS.2 Developing and using models and tools

Preparing for College and Careers
PCC-2.1 Determine roles, functions, education, and training requirements of various career options within one or more career clusters and pathways
PCC-2.2 Analyze career trends, options and opportunities for employment and entrepreneurial endeavors for selected career clusters and pathways
PCC-2.3 Evaluate selected careers and pathways for education requirements, working conditions, benefits, and opportunities for growth and change
PCC-2.4 Use appropriate technology and resources to research and organize information about careers

Biology Standards – 9th Grade
B.4.3 Construct a model to explain that the unique shape and function of each protein is determined by the sequence of its amino acids, and thus is determined by the sequence of the DNA that codes for this protein.

Employability Skills, Grade 9-10
9-10.WE.2 Complete tasks or activities with minimal prompting and guidance.
9-10.LS.11 Able to combine concepts in different ways to create new ideas and innovative solutions.

Planning and Implementation

PROTEIN ORIGAMI

Essential Vocabulary

- DNA: Deoxyribonucleic acid, a self-replicating molecule present in nearly all living organisms and makes p chromosomes. It is the carrier of genetic information.
- GENE: A distinct sequence of DNA, the order of which determines which proteins are made in the cell.
- GENOME: The sum total of an organism's entire DNA complement, including all chromosomes and the genes they contain.
- PROTEIN: Large macromolecules consisting of one or more long chains of amino acids bonded together and folded into a three-dimensional shape.
- AMINO ACID: Carbon-based compounds that contain amine (-NH2) and carboxyl (-COOH) functional groups, along with a side chain (R group) specific to each amino acid.
- POLYPEPTIDE: A linear polymer consisting of a large number of amino acids bonded together in a chain. They are folded and sometimes combined with other polypeptides to become proteins.
- SIDE CHAINS: Sometimes called an R group, this is where each amino acid differs from one another. All proteins are made out of some combination of 21 different amino acids.
- ENZYME: A protein that facilitates a specific chemical reaction, usually a catalyst.

In this challenge, students will:

- Learn about the four levels of protein structure
- Use an origami model to understand and explain the four levels of protein organization

Before Class:

- Read the activity outline sheet and leader notes to become familiar with the activity.
- Students should have an understanding of how to use a microscope and prepare a slide before beginning this experiment.
- Students should understand basic lab safety.

Guiding Questions

1. How does information get from a gene on DNA to build a functional protein?
2. What are proteins used for within the cell?
3. What are the levels of protein organization?
4. What happens if a mutation changes the instructions for a polypeptide?

Introduction

Pharmaceutical scientists like Trae spend a lot of their time trying to understand how proteins are made and how they function. What a protein does and how it looks when it's finished is a direct result of the sequence of amino acids in its polypeptide. Trae works in the lab to understand how proteins fold and behave so they can be used in medicines and other treatments.

Proteins are critical to almost every single thing a cell has to do to survive and almost all of the genes in organisms code for proteins. Students probably have some experience with the idea that information is transcribed from DNA to RNA and that the RNA is translated into a polypeptide. However, a polypeptide by itself is not a protein. To be considered a protein, it must fold up into a three-dimensional structure and sometimes form a complex with other three dimensional proteins.

The Activity

In this activity, students will use origami to model the different levels of protein structure. While there aren't really any star-shaped proteins, this is a good metaphor for how a protein goes from a simple chain of amino acids to a complex, functional protein.

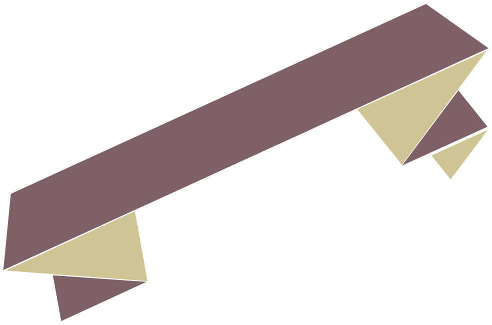
Prompt students to discuss:

What is a protein?

Students should have a basic understanding of the flow of biological information from DNA to RNA to protein. Specifically, they should know that amino acids are assembled into long chains, called polypeptides, by the cell's ribosomes using messenger RNA as a blueprint.

Primary Structure

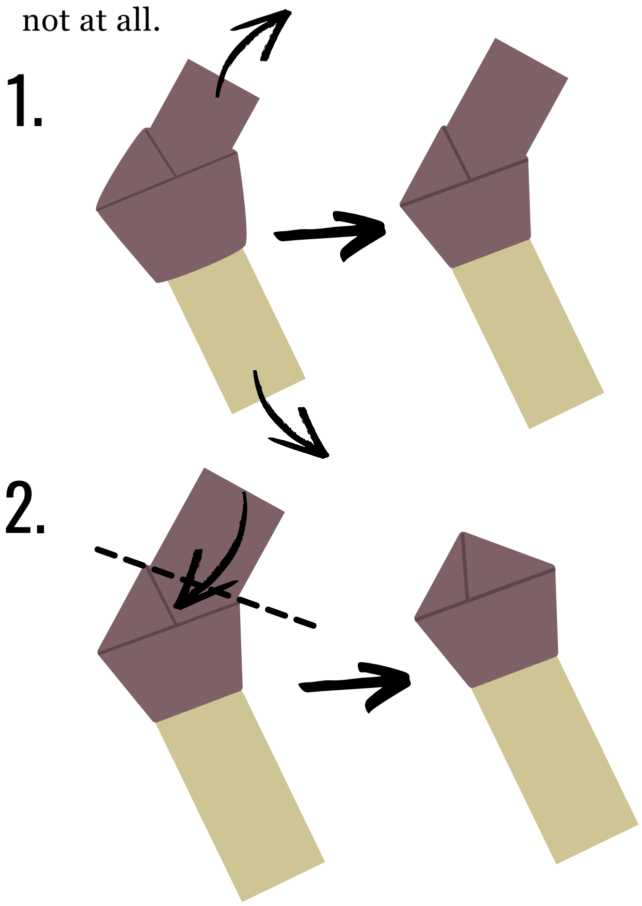
The primary structure (sometimes shorted to 1°) is the simplest level of protein structure, a chain of amino acids assembled by the ribosome and released. As the ribosome translates the information in the messenger RNA, each new amino acid is bonded to the last with a peptide bond. When translation stops this polypeptide is released. It's tempting to call this a protein, but it isn't yet!



In our model, this is represented by the unfolded strip of paper. The potential to be a protein is there, but it isn't functional yet. Hydrophobic parts of a protein tend to end up on the inside of the structure. Here, the lighter (or patterned) side of each strip will be the water-hating side and the blank will be the hydrophilic, water-loving side. As you fold, make sure your lighter or patterned side ends up on the INSIDE of your protein structure!

Secondary Structure

The secondary protein structure (abbreviated 2°) is where things start to fold and twist. The initial folds are largely governed by the chemistry of the side chains of the amino acids in the polypeptide. These side chains can be oily and non-polar or polar, acidic or basic, bulky or small. The final structure is dependent on these early interactions between the side chains. This is also why small changes, or mutations, to the DNA, can have drastic effects on how well the protein works. If the ribosome adds the wrong amino acid, one with a very different side chain, the protein may fold up differently or not at all.

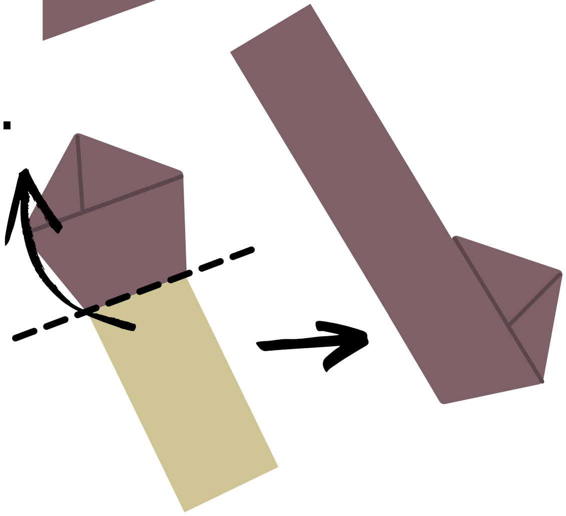


Let's fold!

1. Take your strip of paper and tie a "knot" in one end. This is a little tricky, but you should be able to gently flatten it out into a pentagon. Make sure the outside of your knot does NOT have a pattern showing—remember, those hydrophobic residues like to be on the INSIDE!

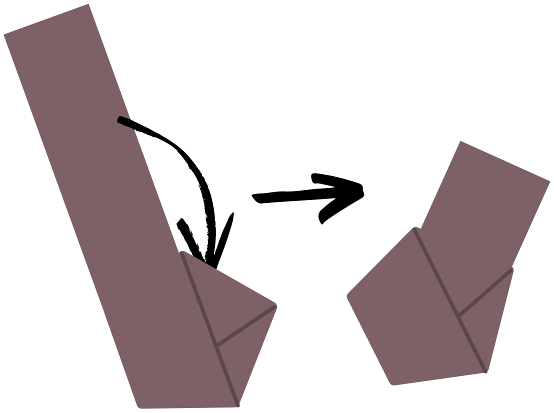
2. Next: fold the short end of the strip down and and tuck it neatly into the knot.

3.



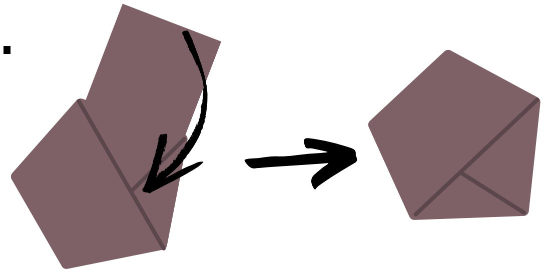
3. Wrap the other end of the strip around the pentagon, lining it up along one of the five sides each time. Gently crease these folds down but it isn't necessary to make them sharp. As you wrap, the patterned hydrophobic side of the amino acid chain should end up on the inside of the protein, away from the environment!

4.



4. Keep wrapping around and around the pentagon until you run out of paper.

5.



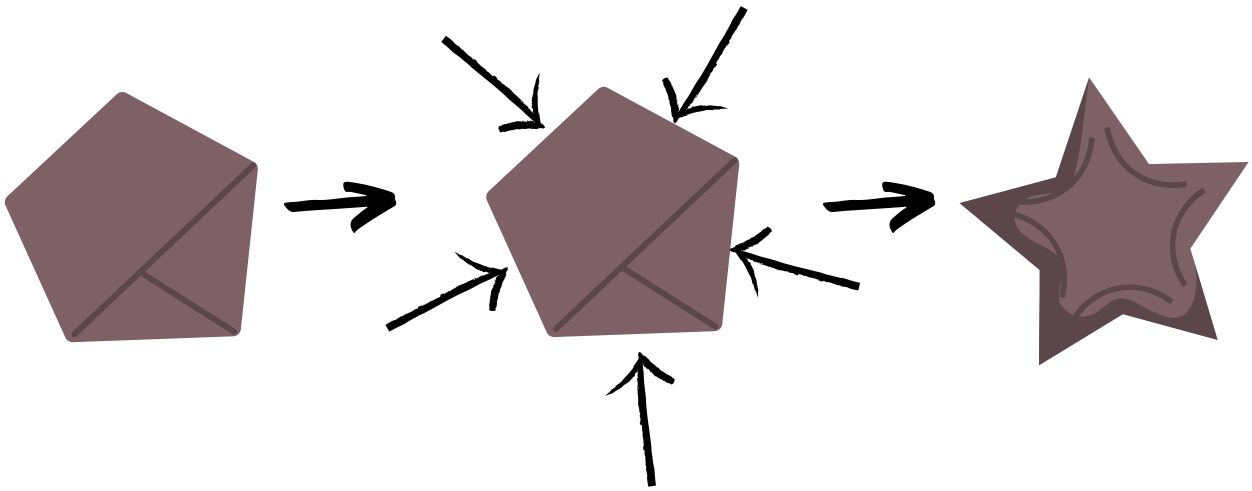
5. Tuck the last leftover bit of the strip into the pouch formed by the wrapping. You should have a neat little pentagon!

At this point, you've done a lot of the hard work! You've folded your polypeptide, but it is still not quite a finished protein.

Tertiary Structure

The three-dimensional structure of a polypeptide, once it has completed all of its preliminary folds and twists, is called is tertiary structure (3°). This third level of organization is also heavlily depending on what kinds of R groups are on the amino acids in the polypeptides. Disulfide bonds between the different parts of the polypeptide form and pull things together. Sometimes popping the polypeptide into a three-dimensional structure requires other specialized proteins, called chaperonins (they literally chaperone the new protein and help it fold correctly.) In our model, your role is very much like the chaperonins in the cell!

To give your folded polypeptide a three-dimensional structure, gently and slowly use a fingernail to press in the center of each edge. The star should puff out.

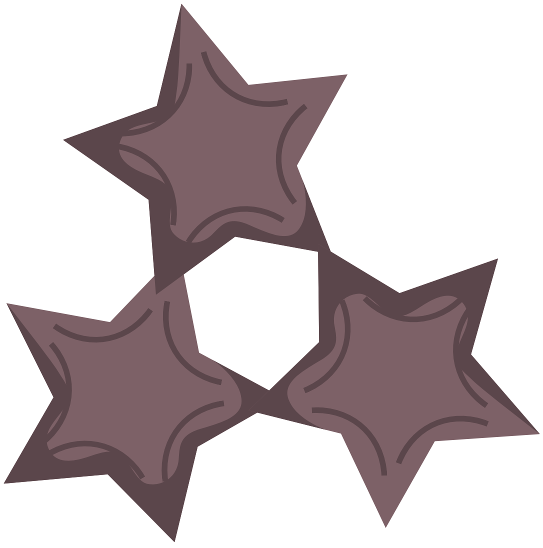


Congratulations! Your protein is done! Many proteins are made of just one polypeptide and once they are 3D, they're finished and ready to do their jobs. However, some functional proteins require several subunits to function. Which brings us to...

Quaternary Structure

When more than one polypeptide comes together to make a functional protein it's called having quaternary structure (4°). Many proteins are fully functional with just one correctly folded polypeptide chain. However, some proteins require multiple polypeptide chains to do their jobs. Each of these pieces is called a subunit. A good example of this is hemoglobin, a protein that requires many subunits as well as an iron atom, to be able to grab and hold on to oxygen.

Encourage students to find at least three other classmates and use tape to connect their individual protein subunits (stars) together. Prompt them to give their new protein a name!



Discuss and Report

Once students have completed their models, discuss the following:

- *What would happen if your initial polypeptide chain (the strip of paper) had a chunk cut out? What if it had a large piece hanging off?*
  The star wouldn't fold up correctly or it wouldn't puff up the way it is supposed to.
- *How is this similar to what happens when mutations change an amino acid sequence?*
  A polypeptide with the wrong amino acids might have bulky side chains in the wrong place or be missing something that is needed for bonding.

Career Exploration and Extension

Prompt students to think about and research what a career as a pharmaceutical scientist might entail.

- What does a scientist do all day? What does Trae do?
- What kind of training would a student need to become a pharmaceutical scientist? What other types of scientists are there?
- Are jobs like Trae's in high demand? Will more people be hired to develop and manufacture new medicines in the future?
- What kind of education is needed to be a scientist? Where could a student be trained locally for this career? What types of classes are important?

Encourage students to research how small changes to DNA sequences can have large effects on people's health. Examples of disorders to research include:

- Sickle Cell Anemia
- Alpha1 Antitrypsin Deficiency
- Hemophilia

Name: ______________

Protein Origami

Student Instruction Sheet

Pharmaceutical scientists, like Trae at Singota Solutions, use cells to make proteins and other gene products for medical use. Remember that generally, information for how to build the molecules a cell needs flows in one direction:

DNA ⟶ RNA ⟶ Protein

That is, the information stored in DNA as genes is transcribed into an RNA message, which is then sent out into the cell to be translated by the ribosome into a chain of amino acids. Once these amino acids are folded correctly, they become a functional protein.

Your Mission

You will use origami to model the four different levels of protein structure. While there aren't really any star-shaped proteins, this is a good metaphor for how a protein goes from a simple chain of amino acids to a complex, functional protein. The four levels of protein folding are:

Primary Structure

The primary structure (sometimes shorted as 1°) is the simplest level of protein structure, a chain of amino acids assembled by the ribosome and released. As the ribosome translates the information in the messenger RNA, each new amino acid is bonded to the last with a peptide bond. When translation stops this polypeptide is released. It's tempting to call this a protein, but it isn't yet!

Secondary Structure

The secondary protein structure (abbreviated 2°) is where things start to fold and twist. The initial folds are largely governed by the chemistry of the side chains of the amino acids in the polypeptide. These side chains can be oily and non-polar or polar, acidic or basic, bulky or small. The final structure is dependent on these early interactions between the side chains. This is also why small changes, or mutations, to the DNA can have drastic effects on how well the protein works. If the ribosome add the wrong amino acid, one with a very different side chain, the protein may fold up differently or not at all.

Name: ____________

Tertiary Structure

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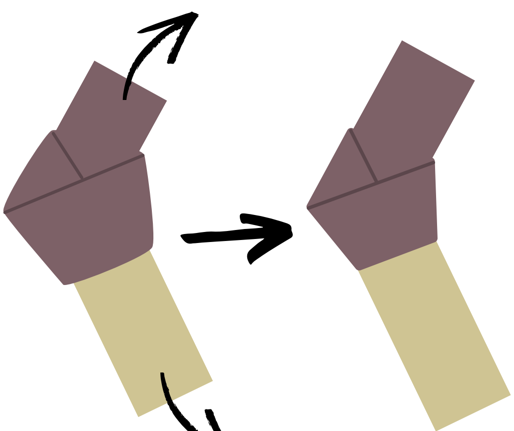
Quaternary Structure

When more than one polypeptide comes together to make a functional protein it's called having quaternary structure (4°). Many proteins are fully functional with just one correctly folded polypeptide chain. However, some proteins require multiple polypeptide chains to do their jobs. Each of these pieces is called a subunit. A good example of this is hemoglobin, a protein that requires many subunits as well as an iron atom, to be able to grab and hold on to oxygen.

1.



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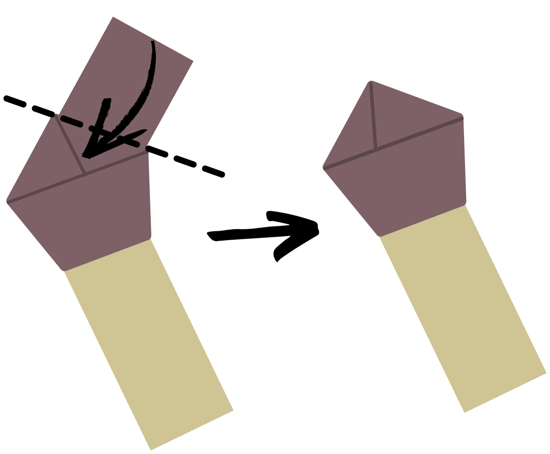
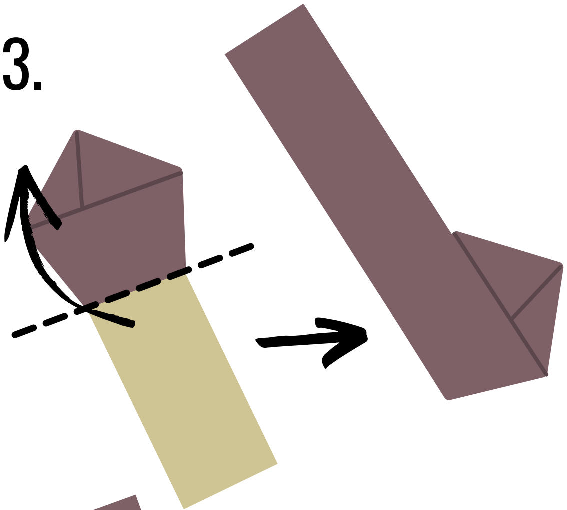


Let's get folding!

1. Lay your strip of paper out flat. This is your PRIMARY STRUCTURE model—it's like a fresh new polypeptide ready to become a protein! Take your strip of paper and tie a "knot" in one end. This is a little tricky, but you should be able to gently flatten it out into a pentagon. Make sure the outside of your knot does NOT have a pattern showing—remember, those hydrophobic residues like to be on the INSIDE!
2. Fold the short end of the strip down and tuck it into the knot.

Name: ________________

3.



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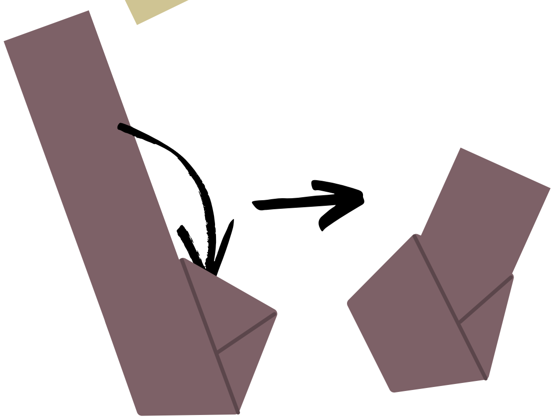

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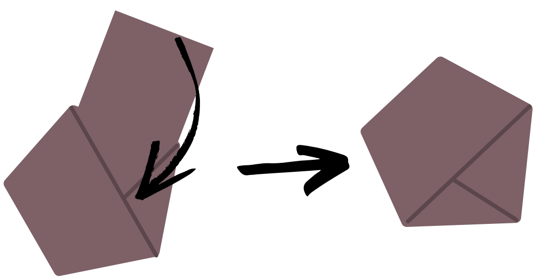

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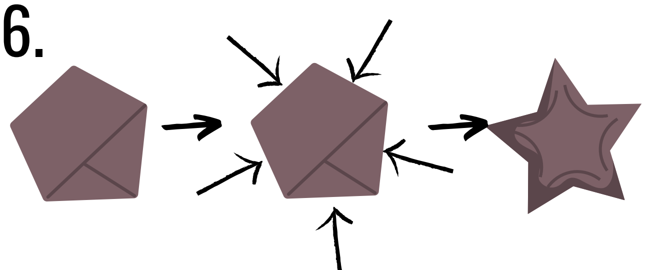

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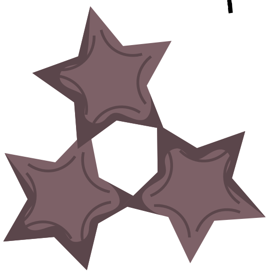

3. Next: wrap the other end of the strip around the pentagon, lining it up along one of the five sides each time. Gently crease these folds down but it isn't necessary to make them sharp. As you wrap, the patterned hydrophobic side of the amino acid chain should end up on the inside of the protein, away from the environment!
4. Keep wrapping around and around the pentagon until you run out of paper.
5. Tuck the last leftover bit of the strip into the pouch formed by the wrapping. You should have a neat little pentagon! You've completed the SECONDARY STRUCTURE of this protein!
6. Let's give this protein some TERTIARY STRUCTURE. To pop the star into a three-dimensional structure, gently and slowly use a fingernail to press in the center of each edge. The star should puff out.
7. Some proteins are ready to go and finished at the tertiary level. Our protein, though, needs a QUATERNARY STRUCTURE. We'll need to bond a few subunits together before it is finished and functional. Find at least three other classmates and use tape to connect your protein subunits (stars) together. What will you name your new protein?

ACKNOWLEDGEMENTS

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ROI would like to thank the following members of our Educator Advisory Group for their gracious support and review of this curriculum:

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IMAGE AND CONTENT CREDITS

Images

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Still video images from "Trae - Associate Pharmaceutical Scientist," available at https://regionalopportunityinc.org/trae/

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