Taking Computer Models Off Screen: An Art Imbued Twist To An Old Enzyme Lab

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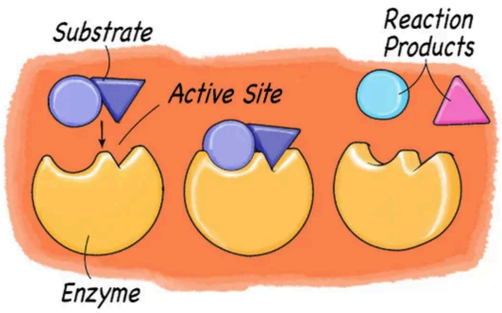
Standards that are addressed by this lesson plan:

The Next Generation Science Standards	
HS-LS1-1	Construct an explanation based on evidence for how the structure of DNA determines the structure of **proteins which carry out the essential functions of life through systems of specialized cells**.
HS-LS1-6	Construct and revise an explanation based on evidence for how carbon, hydrogen, and oxygen from sugar molecules may combine with other elements to form amino acids and/or other large carbon-based molecules.
AP Biology	
ENE-1.D.1	The structure of enzymes includes the active site that specifically interacts with substrate molecules.
ENE-1.D.2	For an enzyme-mediated chemical reaction to occur, the shape and charge of the substrate must be compatible with the active site of the enzyme.
ENE-1.E	Explain how enzymes affect the rate of biological reactions.
ENE-1.E.1	The structure and function of enzymes contribute to the regulation of biological processes— a. Enzymes are biological catalysts that facilitate chemical reactions in cells by lowering the activation energy.
ENE-1.F	Explain how changes to the structure of an enzyme may affect its function.
ENE-1.G	Explain how the cellular environment affects enzyme activity.
ENE-1.F.1	Change to the molecular structure of a component in an enzymatic system may result in a change of the function or efficiency of the system— a. Denaturation of an enzyme occurs when the protein structure is disrupted, eliminating the ability to catalyze reactions. b. Environmental temperatures and pH outside the optimal range for a given enzyme will cause changes to its structure, altering the efficiency with which it catalyzes reactions.
ENE-1.F.2	In some cases, enzyme denaturation is reversible,

	allowing the enzyme to regain activity.
ENE-1.G.1	Environmental pH can alter the efficiency of enzyme activity, including through disruption of hydrogen bonds that provide enzyme structure.
ENE-1.G.2	The relative concentrations of substrates and products determine how efficiently an enzymatic reaction proceeds.
ENE-1.G.3	Higher environmental temperatures increase the speed of movement of molecules in a solution, increasing the frequency of collisions between enzymes and substrates and therefore increasing the rate of reaction.
ENE-1G.4	Competitive inhibitor molecules can bind reversibly or irreversibly to the active site of the enzyme. Noncompetitive inhibitors can bind allosteric sites, changing the activity of the enzyme.

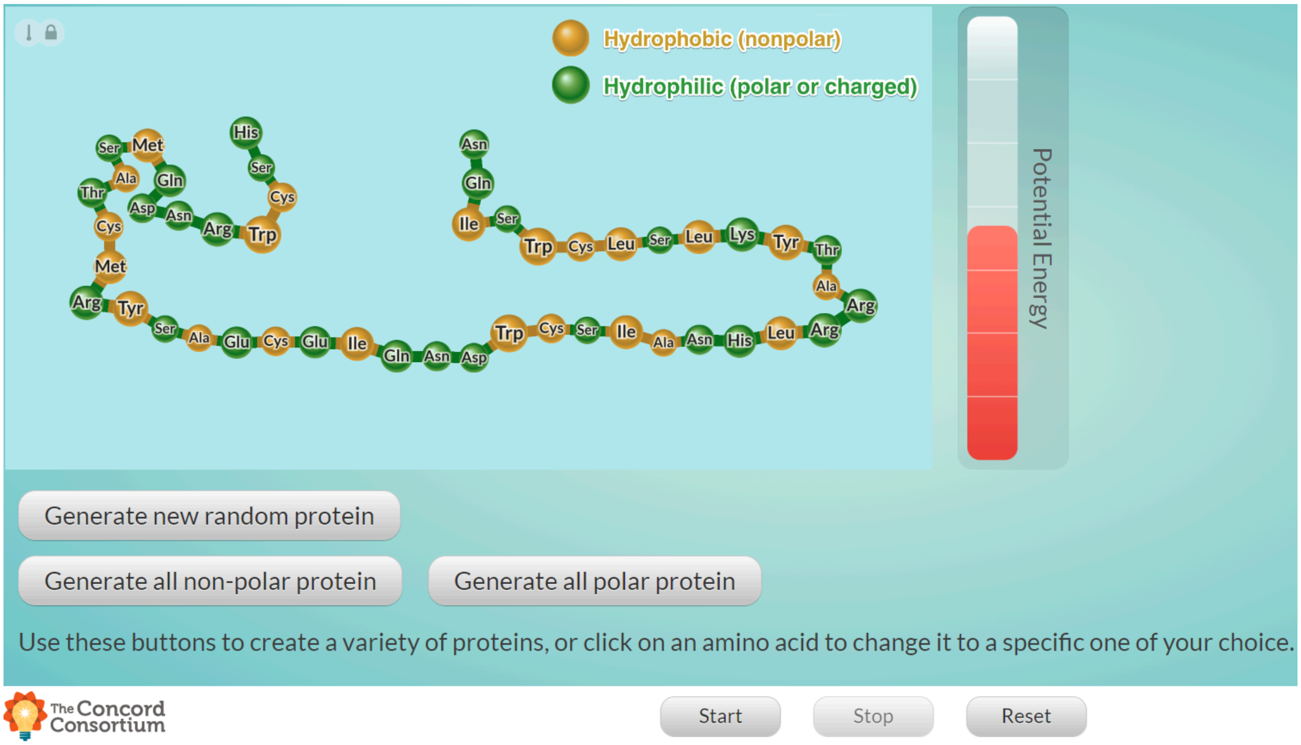
BSCS 5E lesson framework

1. (Engage) Introduce the lesson series with the chicken liver and hydrogen peroxide phenomenon.
    a. Inform students that the chicken liver has an enzyme (specialized protein) that causes a chemical reaction to happen quicker.
    b. (optional) Instructor can take a match, light it, blow it out, and then reignite the match using the bubbles from the reaction. After this demo, you can have students reflect on what bubbles mean in a reaction, and what the gas might consist of given the reignition of the match (example question: what gas might be involved in creating fire?).
2. (Explore)(optional) If you don't tell students that the clear liquid you added during the demonstration was hydrogen peroxide you can have students design a lab with an appropriate negative control group to identify which clear liquid was added to the chicken liver in the original demo (vinegar, hydrogen peroxide, salt water, and isopropyl alcohol (70%)). This can give students practice with designing experiments, and can prove that enzymes are specific to certain molecules.



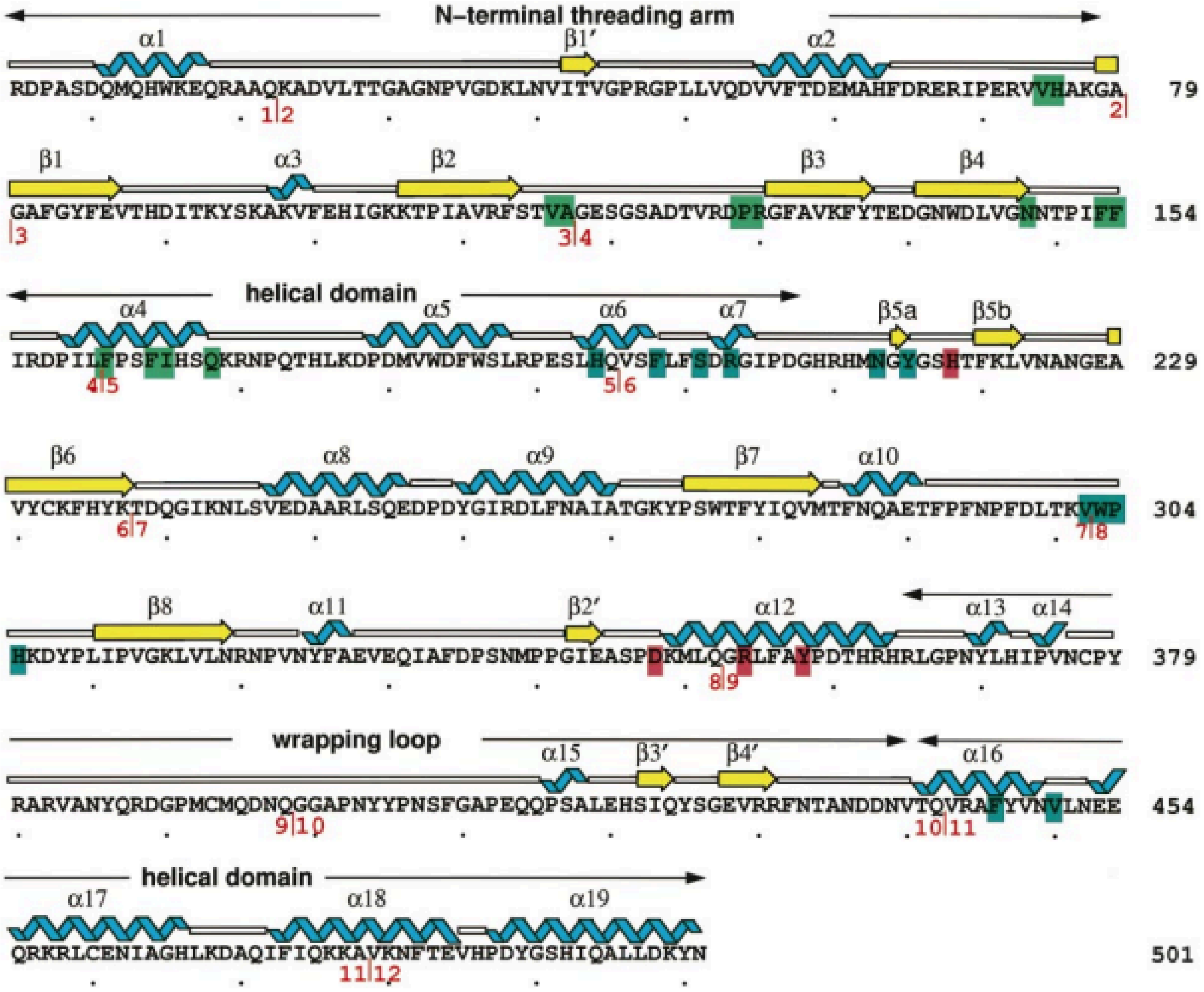
3. (Explore)Show students an image like: Image credit: George Retseck (1)
    a. Give students a minute to discuss with partners what they notice is happening in this picture. After the minute, have each partner group share one thing they notice (it is ok for students to agree with another group, but they should repeat the statement that they agree with).
    b. Most students should get to the understanding that some enzymes help to facilitate a breakdown of molecules and that this might be happening with the chicken liver and hydrogen peroxide.
    c. Explain to students that this is a very simplistic version of what is happening at the active site, and that their goal is to describe exactly how complex this process is. "We will do this by utilizing art".

4. (Explore/Explain)Have students investigate [PDB-101 molecule of the month - catalase]() (2) with the goal of writing down anything that they think is important in reconstructing where the active site is of the protein and what is occurring to cause the breakdown of hydrogen peroxide. After students have read through the article with their teams and written down a few key pieces of information, have a class discussion.
    a. The key pieces of information are:
        i. A heme group is crucial for the function of the active site
        ii. This heme group is associated with two amino acids (histidine and asparagine)
        iii. There are two hydrogen peroxide molecules broken down in each cycle of the enzyme's activity
            1. Nice to know information:
                a. The hydrogen peroxide molecules in our bodies are derived from the fact that oxygen is being used to accept electrons after atp synthesis and that as they are shuttled around the cell they may interact with other molecules that cause them to turn into H2O2.
                b. A single catalase can degrade millions of H2O2 molecules per second
                c. The quaternary structure is incredibly stable
                d. Due to the fact that catalases are found in a lot of organisms, there is an evolutionary story to be discussed.
5. (Optional) Some students prefer to learn the basics before engaging in a project-based learning sequence. If your students are in this mindset, the instructor might choose to lecture on monomers, polymers, dehydration synthesis, polypeptide chains, primary, secondary, tertiary, quaternary structures, and how polarity affects hydrophobicity and hydrophilicity. There are many freely available google slide decks or powerpoints available for this.
    a. The instructor can also use a simulator ([Protein Folding Exploring by The Concord Consortium is licensed under CC BY 4.0]()) to demonstrate how hydrophobic and hydrophilic interactions can impact overall protein shape.



Use these buttons to create a variety of proteins, or click on an amino acid to change it to a specific one of your choice.

6. (Explore) If students prefer to learn by doing, they can begin by investigating Figure 1 from Putnam et. al. (3).



The instructor can describe how this image represents the primary and secondary structures of the catalase enzyme from the demonstration. A **helpful tip** would be to display the hydrophilic, hydrophobic, and charged amino acid chart and have students identify all of the amino acids in the image above as one of those three. This could be considered a quiz on the aforementioned chemical properties of each amino acid because the instructor could walk around asking why the amino acids are either hydrophobic, hydrophilic, or charged. This would be a great segway into why these secondary and ultimately tertiary structures emerge.

7. (Explore) After the students have shown proficiency in understanding how the monomers of this enzyme are involved in its overall structure, you can move on to having students build their pipe cleaner model. Have students identify an appropriate scale first (e.g. one pipe cleaner represents 10 amino acids). The instructor could also have students color code beads on the pipe cleaners to represent the different hydro -philic or -phobic natures of the amino acids (however, this is unnecessary for the end product).
8. (Explore) Once the scale has been decided, the students can move on to demonstrating their attention to detail by making every bend of their model exactly like they see it in the AlphaFold digital modeler (4,5). The alpha helix and beta sheet lengths should be marked prior to making bends to avoid errors. Then the students will either spiral the structure (alpha helix) or make sequential 45 degree bends (one bend for each amino acid in the beta sheet). Students have the greatest success when they use the highlighting feature in AlphaFold and add a black background contrast:

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MNGYGSHTFKLVNANGEAVYCKFHYKTDQGIKNLSVEDAARLSQEDPDYGIRDLFNAIATGKYPSWTFYIQVMTFNQ
         361              371              381              391              401              411              421              431
FAYPDTHRHRLGPNYLHIPVNCPYRARVANYQRDGPMCMQDNQGGAPNYYPNSFGAPEQQPSALEHSIQYSGEVRRF
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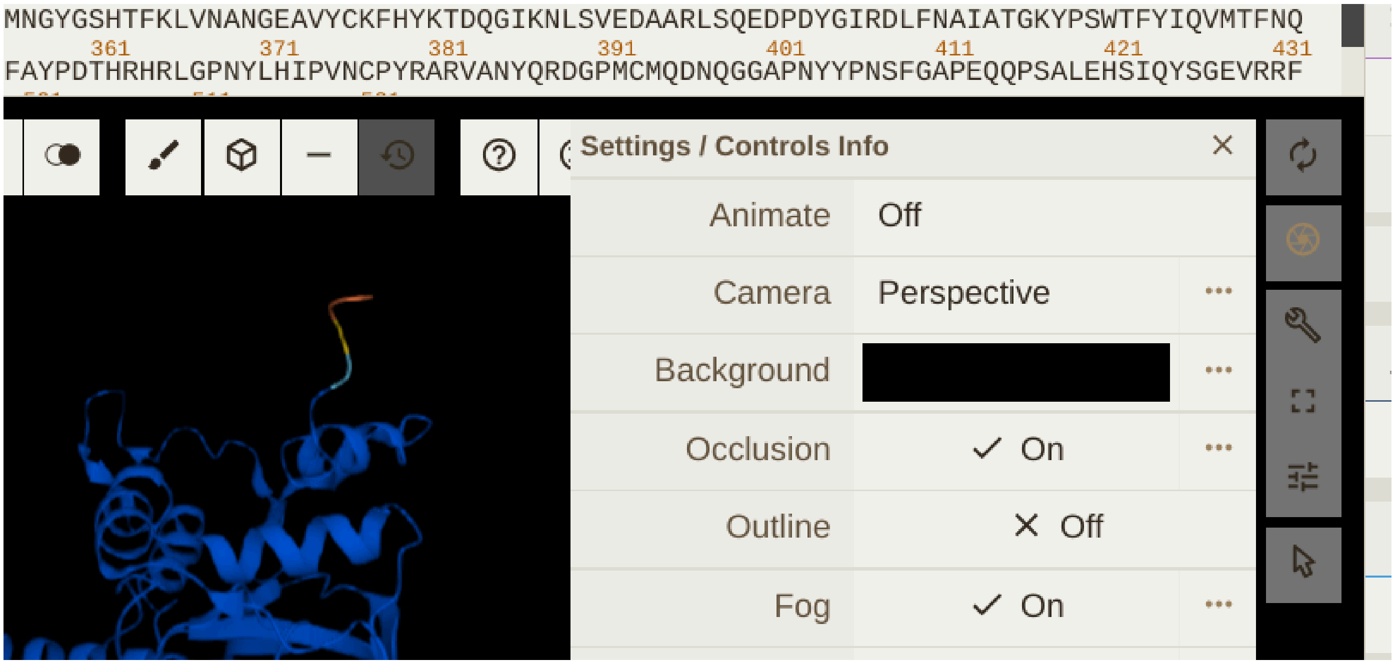

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MNGYGSHTFKLVNANGEAVYCKFHYKTDQGIKNLSVEDAARLSQEDPDYGIRDLFNAIATGKYPSWTFYIQVMTFNQ
         361              371              381              391              401              411              421              431
FAYPDTHRHRLGPNYLHIPVNCPYRARVANYQRDGPMCMQDNQGGAPNYYPNSFGAPEQQPSALEHSIQYSGEVRRF
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Settings / Controls Info

Animate: Off

Camera: Perspective

Background: ■

Occlusion: ✓ On

Outline: ✕ Off

Fog: ✓ On

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1           11          21          31          41          51          61          71          81          91          101
MADSRDPASDQMQHWKEQRAAQKADVLTTGAGNPVGDKLNVITVGPRGPLLVQDVVFTDEMAHFDRERIPERVVHAKGAGAFGYFEVTHDITKYSKAKVFEHIGKK
     151         161         171         181         191         201         211         221         231         241
LVGNNTPIFFIRDPILFPSFIHSQKRNPQTHLKDPDMVWDFWSLRPESLHQVSFLFSDRGIPDGHRHMNGYGSHTFKLVNANGEAVYCKFHYKTDQGIKNLSVEDA
  291         301         311         321         331         341         351         361         371         381         391
AETFPFNPFDLTKVWPHKDYPLIPVGKLVLNRNPVNYFAEVEQIAFDPSNMPPGIEASPDKMLQGRLFAYPDTHRHRLGPNYLHIPVNCPYRARVANYQRDGPMCM
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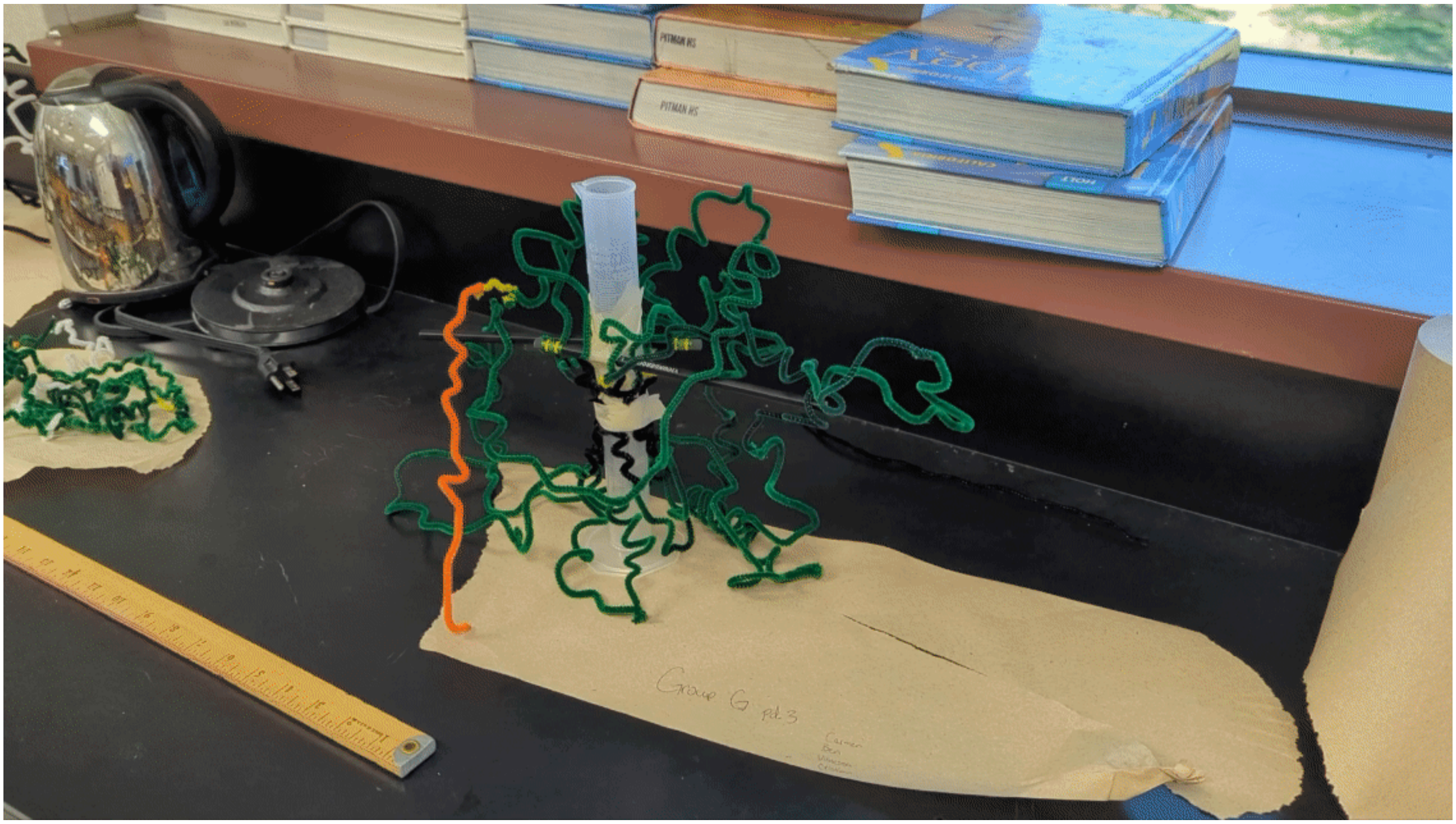
9. (Explain) Once the students are done with this task, the instructor can go group by group and instruct them on how to make the beta barrel. Having students identify beta sheets 1-4 can be an excellent assessment of their

primary and secondary topography knowledge of their model. Then the instructor can help the students tape the beta sheets around the graduated cylinder. **Helpful tips: a plastic graduated cylinder works perfectly for taping the beta sheets around to form the beta barrel. Also, this image generated from using AlphaFold's internal tools is exceptionally helpful to have students wrap their heads around where the beta sheets are.**

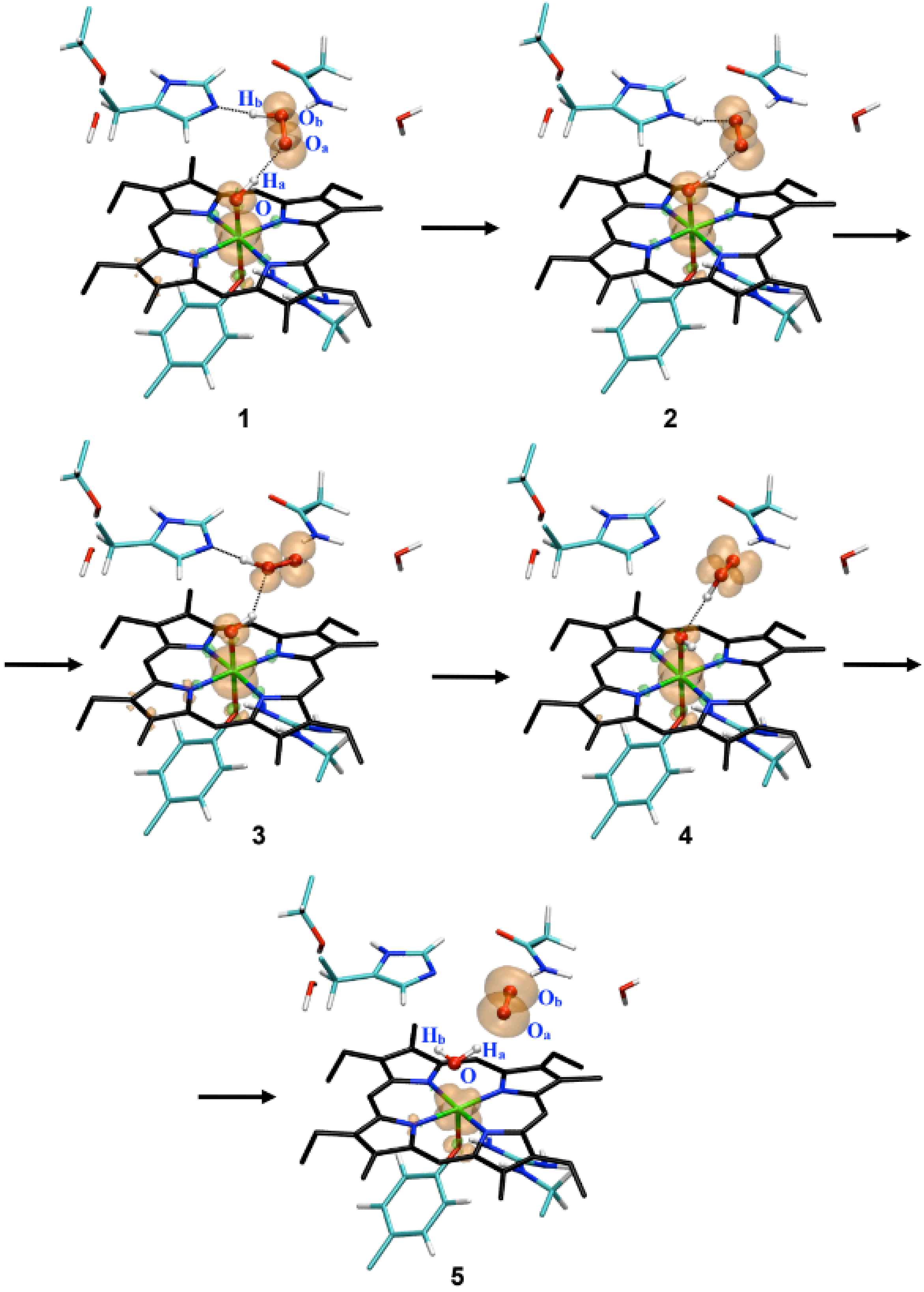
Beta barrel with eight beta sheets w/o loops and the amino acid sequences highlighted above 78-87, 106-114,131-139, 141-148, 220-223, 229-238, 276-284, 309-320

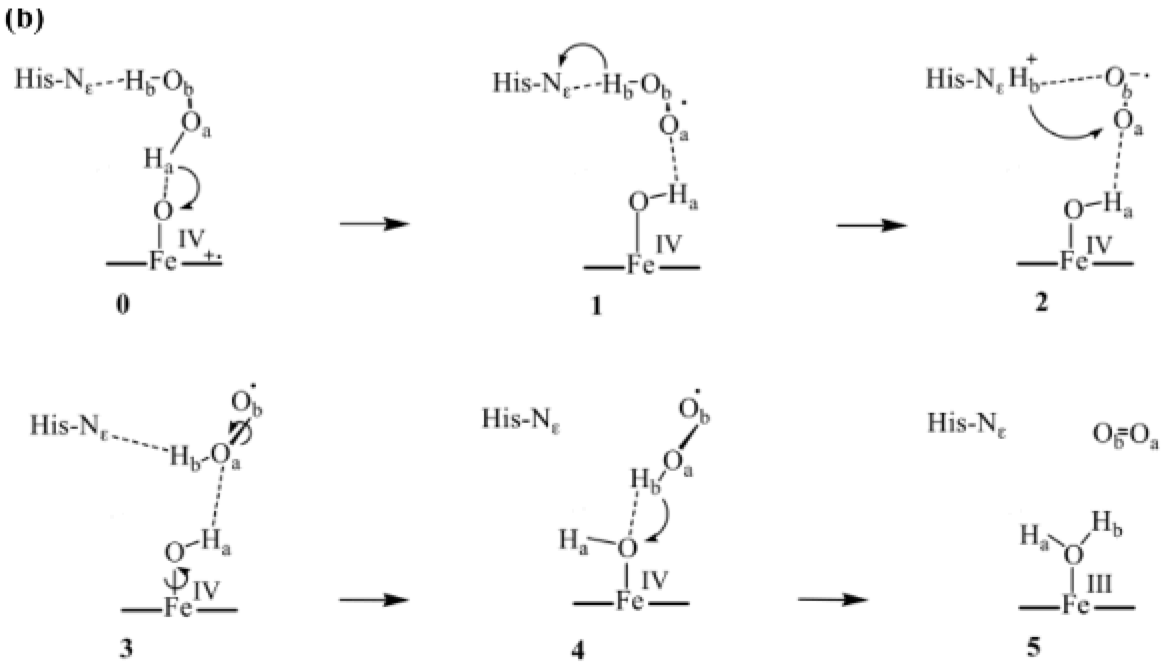
Next, the instructor can ask the students to have two short red pipe cleaners ready to label individual amino acids. The instructor can say "please identify amino acid 75 and 148, these should be His and Asn respectively". The instructor will see "ah-ha" moments as students realize how essential the beta barrel is to the overall tertiary structure of this enzyme and in locating the exact active site. The instructor can say something like "now that you have labeled these two amino acids, can you see where your active site is?" This process will serve as an excellent quiz for students to understand how the tertiary structure is impacted by the individual folds from the secondary level.


eisco
100:1
TC/TD 20°C
100
ml
90
80
TICONDEROGA

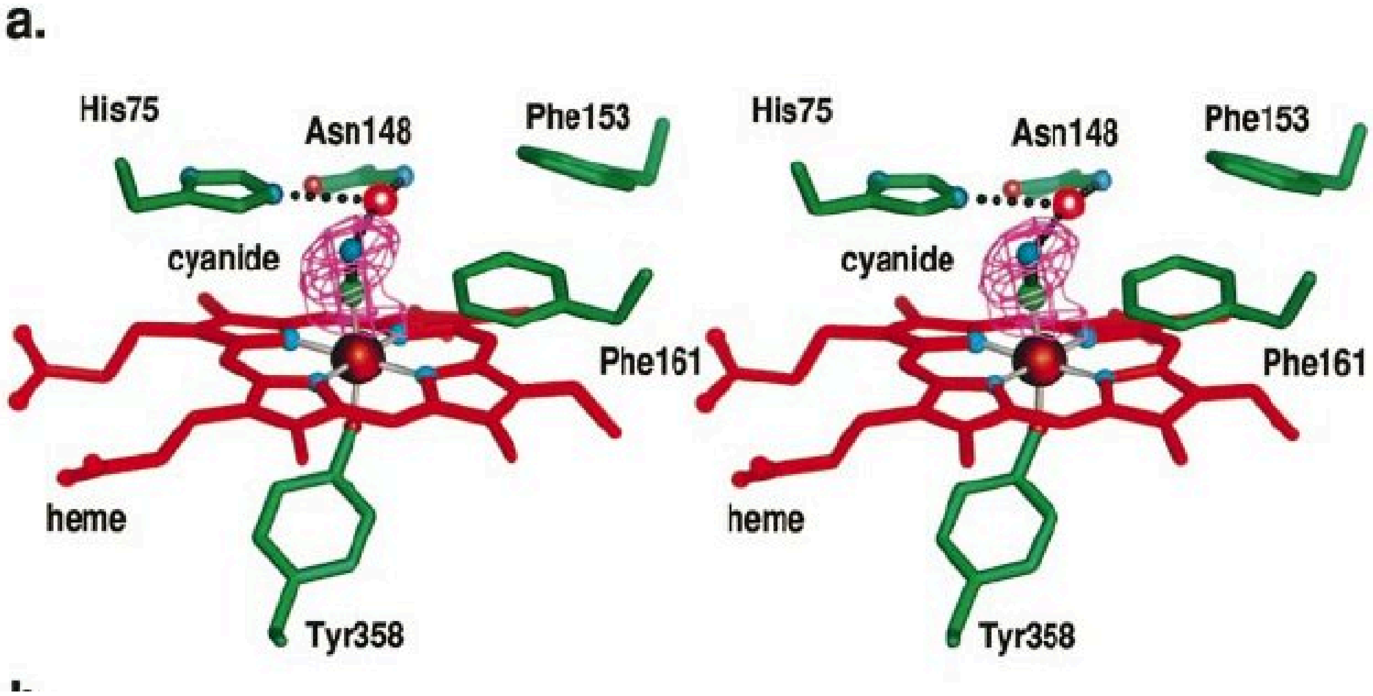


10. Once the students have correctly identified the active site they are ready to begin the stop motion animation portion of this project. Show students the [video from the Protein Data Bank on enzyme function](). The main parts for this project are 2:15 - 4:00. This will direct students on how to animate the functioning of an active site.
11. (Elaborate) Have students build His, Asn, a Heme Group, and two hydrogen peroxide molecules out of clay and toothpicks. These structures are easily obtained from a quick google search. This presents an excellent opportunity to check in on the basics of bond numbers of the individual atoms and their general chemistry background.
12. Once students have this built, have them review the images (S4 and S3 respectively) from Alfonso-Prieto et. al. (6).


H_b
O_b
O_a
H_a
O
1
2
3
4
H_b
H_a
O
O_b
O_a
5



13. (Evaluate) Have students build their stop motion from the images and then create a narration that includes key concepts like: Monomer, polymer, hydrogen bond, polypeptide, catalase, enzyme, protein, hydrophilic, water, polar, hydrogen peroxide, stabilize, secondary structure (hint: beta sheets are important), tertiary structure (hint: beta barrel folding leads to his75 and asn148 doing a thing), active site, histidine residue, asparagine residue, heme group, oxidized iron
14. Extension: show students an image demonstrating how cyanide can be a competitive inhibitor of catalase (3) and have students discuss how this inhibits catalase's function -



1. Exploring Enzymes: A Catalyzing Science Project

   November 2016, Science Buddies, Svenja Lohner
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2. Molecule of the Month: Catalase

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3. Active and inhibited human catalase structures: ligand and NADPH binding and catalytic mechanism.

   Putnam CD, Arvai AS, Bourne Y, Tainer JA.

   J Mol Biol. 2000 Feb 11;296(1):295-309. doi: 10.1006/jmbi.1999.3458. PMID: 10656833.

4. Jumper, J., Evans, R., Pritzel, A. *et al.* Highly accurate protein structure prediction with AlphaFold. *Nature* 596, 583–589 (2021). https://doi.org/10.1038/s41586-021-03819-2
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   Mercedes Alfonso-Prieto, Xevi Biarnés, Pietro Vidossich, and Carme Rovira

   Journal of the American Chemical Society 2009 *131* (33), 11751-11761

   DOI: 10.1021/ja9018572