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| **GENERAL INFORMATION** |

**Lesson Title & Subject(s):** Amino Acid Jazz / Life Science

**Topic or Unit of Study:**

Biological Molecules > Proteins > Understanding & Modeling Protein Structure

**Grade/Level:** High School (12th grade)

**Instructional Setting:**

Assigned scenario: 26 students total (15 boys and 11 girls).

• 16 students are on-grade-level readers.

• 5 students are two grades below reading level (3 with identified learning disabilities in reading).

• 5 students are two grades above reading level (2 with identified gifted exceptionalities).

• 2 students are English language learners at the intermediate level.

• 3 students have been diagnosed with attention deficit hyperactivity disorder (ADHD).

Additional information: There will be a handout that is projected to a screen. Students initially work as a single large group, then break into heterogeneous groups of 3-4 students partway through the lesson.

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| **STANDARDS AND OBJECTIVES** |

**Your State Core Curriculum/Student Achievement Standard(s):**

Washington, my home state, uses the Next-Generation Science Standards (NGSS) as its main standards for science instruction. NGSS includes what it describes as three dimensions of learning: Crosscutting Concepts (CCs), Disciplinary Core Ideas (DCIs), and Science and Engineering Practices (SEPs). In addition, it provides grade-specific Performance Expectations (PEs), which combine the CCs, DCIs, and SEPs. Among these various standards, this lesson plan connects most directly to the following:

* **Crosscutting Concept** **#4: Systems and system models.** “Defining the system under study—specifying its boundaries and making explicit a model of that system—provides tools for understanding and testing ideas that are applicable throughout science and engineering” (NGSS Lead States, 2013, Appendix G, p. 79).
* **Science and Engineering Practice #2: Developing and using models**. “Develop, revise, and/or use a model based on evidence to illustrate and/or predict the relationships between systems or between components of a system” (NGSS Lead States, 2013, Appendix F, p. 53).

**Lesson Objective(s):**

Given the opportunity to learn about protein structure (condition), heterogeneous groups of students will create physical models of a protein (behavior) that score at least 16 out of 20 points on a rubric, provided below (criterion).

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| **MATERIALS AND RESOURCES** |

**Instructional Materials:**

For direct instruction (musical model) phase:

* Handout
* Computer linked to projector (to project handout)
* Pitch pipe or keyboard

For cooperative learning (physical model) phase:

* Provided in class: tape, string, glue, beads, construction paper, scissors
* Students bring any additional desired materials from home

**Resources:**

For students:

* Freeman, S., et al. (2017). Protein structure and function. In *Biological Science* (6th ed.) (pp. 78-92). Hoboken, NJ: Pearson Higher Education.
* Kimball, J. W. (2011, March 3). Polypeptides. Retrieved from http://www.biology-pages.info/P/Polypeptides.html.
* Rutgers University and UCSD/SDSU. Protein Data Bank (no date). Retrieved from http://www.rcsb.org.

For teachers:

* Burden, P. R., & Byrd, D. M. (2013). *Methods for effective teaching: Meeting the needs of all students* (6th ed.). Boston, MA: Allyn & Bacon.
* Crowther, G. J., & Davis, K. (2013). Amino acid Jazz: Amplifying biochemistry concepts with content-rich music. *Journal of Chemical Education*, *90*(11), 1479-1483.
* National Research Council (2012). *A Framework for K-12 Science Education: Practices,*
* *Crosscutting Concepts, and Core Ideas.* Washington, DC: National Academies Press.
* NGSS Lead States (2013). *Next Generation Science Standards: For States, by States*. Washington, DC: National Academies Press.

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| **INSTRUCTIONAL PLAN** |

**Sequence of Instructional Procedures/Activities/Events (provide description and indicate approximate time for each):**

1. **Student Prerequisite Skills/Connections to Previous Learning:**

*Identify pre-requisite skills students need to already know (i.e., possess, control, understand) to be successful in this lesson.*

Coming into this lesson, students should already have some understanding of the following concepts:

* Biological molecules are made out of atoms connected by covalent bonds.
* There are 4 major types of biological macromolecules: carbohydrates, lipids, nucleic acids, and proteins.
* These 4 types of macromolecules have different roles in cells. Proteins do most of the “work” inside cells.
* Proteins are made out of smaller molecules called amino acids.
* Proteins are made at intracellular structures called ribosomes. The order in which the amino acids are joined together is specified by messenger RNA (mRNA), which in turn depends on the genetic information in DNA.
* Acids donate protons (H+) to aqueous solutions, while bases remove protons (H+) from aqueous solutions.

No highly specialized skills are needed for this lesson, but students are assumed to be capable of the following:

* Analyzing scientific concepts, structures, and processes via analogies and (qualitative) models.
* Working cooperatively with classmates.
* Interpreting a rubric.
* Evaluating a product for its compliance with a rubric.

1. **Presentation of New Information:**

As described in my article (Crowther & Davis, 2013, quoted below), the teacher begins this lesson with an anticipatory set that is deliberately odd, and thus intriguing.

“Let’s sing a song”, I say. “Repeat after me.” I lead students through the alphabet song in call-and-response format, except that we only sing the 20 letters that are one-letter abbreviations for amino acids. (See Figure 1; note, though, that students do not have the handout at this point.) That is, I sing “A, C D E F G”; the students repeat “A, C D E F G”; I sing “H I K, L M N P”; the students repeat that; and so forth.

We discuss what was just sung. “What kind of strange alphabet was that?” I ask. Students will not recall exactly how many letters were included but will know that there were less than 26. “Are there some alphabets or codes that use less than 26 letters?” With encouragement, students will come to the idea that there are 20 naturally occurring amino acids and that each of these can be represented by a one-letter abbreviation.

I then distribute the handout [attached as a separate file] and note that amino acids also have three-letter abbreviations, which we rap (or “scat”, in the jazz lexicon) in sets of three to five, again as a

series of calls and responses.

Aside from drawing students’ interest, this introductory activity is intended to activate their prior learning on proteins – especially the fact that proteins are combinations of 20 naturally occurring amino acids.

The teacher then takes a step back and define the purpose of the lesson, which is to learn about the structure of proteins by making models of them. In particular, we will explore how amino acids are linked together to form proteins, and how the diversity and order of the amino acids used affects the overall structure and function of the protein. First we will make a musical model together as a class; then small groups will create physical models. Recall that models help us understand scientific concepts, processes, or structures by highlighting certain features of them. Models, therefore, are simplified versions of a “real thing” that give us insight into the “real thing.”

The direct instruction continues essentially as described in the attached article by Crowther & Davis (I will not include further text here to avoid being flagged by TurnItIn.com, but I feel justified in drawing extensively from that article because I wrote it!)

After completing the musical model of the 41-amino-acid chain (a small protein, often called a polypeptide or peptide), students are given an opportunity to ask questions about what we have done so far.

1. **Guided Practice:**

The teacher asks students the following questions, which they answer in think-pair-share fashion.

* Are the chains of amino acids straight, or do they twist and bend around? (Answer: they twist and bend. Otherwise, disulfide bonds between two cysteines would not be possible. Those two cysteines have to be brought into proximity by the twisting and bending of the chain. Also, the addition and subtraction of phosphate groups changes this 3D structure – otherwise the phosphates would not be an important mechanism of switching protein functions on and off.)
* What determines the order of the amino acids in a protein? (Answer: the gene for that protein specifies which amino acids are linked in which order.)
* In what ways are the song lyrics a GOOD model of protein structure? In what ways are they an INCOMPLETE or MISLEADING model? (Answers will vary. “Good” answers might mention that proteins really do consist of strings of amino acids, beginning with methionine and with a seemingly random order after that, and that the different ways we sing the names of certain amino acids helps identify them as having unique structures. “Misleading” answers might note that the song does not directly help us visualize the twisting and bending of the chain into a complex 3D structure; we can only sing out the amino acids one at a time, in a “straight line.”)
* What would happen if a genetic mutation caused a different amino acid to be substituted for one of the cysteines? (Answers will vary, but that amino acid will no longer be able to form a disulfide bridge with the other cysteine, so the 3D structure of the protein will change, and its function may be impaired.)

Students will then complete an “exit ticket” that covers the following three points:

* One thing that I already knew about proteins, or used to know, that today’s lesson reminded me of.
* One new thing I learned about proteins from today’s lesson.
* One aspect of today’s lesson that is still unclear to me.

1. **Independent Practice:**

Students are then arranged into predetermined mixed-ability groups. Thus, the grouping strategy is one of heterogeneous grouping to enable cooperative learning.

Each group is given an assignment: use their understanding of protein structure to create a physical model of a short protein (or the start of a protein, for longer proteins) of its choice. Each group includes four defined roles: one material-gatherer, one lead builder, one annotator, and one rubric-checker. The members of the group agree on a protein to model, look up the amino acid sequence of the chosen protein in the Protein Data Bank (rcsb.org), and agree on a modeling strategy.

The physical model can be of any form that fulfills the rubric (below), which is passed out at this point. The students are given access to some basic art supplies in the classroom (tape, string, glue, beads, construction paper, scissors) but are encouraged to bring in anything else they want from home. The component-gatherer is responsible for obtaining all necessary materials, the lead builder puts them together, the annotator prepares a short statement/key explaining the model, and the rubric-checker makes sure that the model covers all of the points mentioned in the rubric. After groups are given some time in class to plan their modeling, they are given time on a subsequent day to build and annotate the model while the instructor circulates among the groups.

1. **Culminating Activity:**

After the physical models are built, each group is asked to briefly highlight one aspect of its model that it is happy with. Each group is also asked to compare the musical model and physical models of the protein. What are the advantages and limitations of each? (Answers will vary. For example, some students might find that the musical model persists in their head, and thus will be useful during tests, while other students may report that the visual of the physical model is both more compelling and more realistic.)

Finally, the models are collected and graded according to the rubric.

**Instructional Strategies:**

The presentation of new information (step 2 above) is accomplished through direct instruction. Although information is covered in a call-and-response format, the students are essentially repeating words back to the teacher, with limited opportunity for constructivist cognition. Aside from any questions that the students raise, the teacher is in control of the flow as he explains how different amino acids have different chemical properties and how those are reflected in the song.

The guided practice (step 3 above) is often referred to as questioning and/or as checking for comprehension. The teacher asks a mix of straightforward and less straightforward questions, both to review the basics and to stimulate independent thinking.

The independent practice (step 4 above) qualifies as cooperative learning, since students of mixed ability work together, each with a defined role, so that there is accountability at both the level of the individual and at the level of the group. I argue below (under Scientific Inquiry) that this part of the lesson can also count as problem-based learning (PBL), since students are presented with an open-ended problem which they have to define, research, and solve.

**Differentiated Instruction Accommodations:**

Students reading below grade level:

* For this lesson, most learning occurs through oral and kinesthetic practice and discussion, thus reducing the impact of reading difficulties.
* Students also have the opportunity to read a brief web page written by a textbook author (Kimball, 2011) so that they can digest a manageable chunk of material without getting lost in long passages.

Students above grade level:

* Students will have an opportunity to go beyond the requirements of the group assignment and research an additional aspect of their protein of interest and include that in the group’s physical model (included in the rubric as a bonus point).
* Advanced students may enjoy using a website (rcsb.org) that is also used extensively by professional scientists to support their research.

ELL students:

* A guide to pronouncing the names of the amino acids is included in the handout.
* The accommodations for students reading below grade level (above) should also benefit ELL students.
* Since music is often used to teach foreign languages, the inclusion of music here might be helpful for students for whom English is a foreign language.

ADHD students:

* The detailed, clearly written rubric will help keep these students organized and focused regarding the key aspects of the lesson.
* Students will be welcome to take breaks as they build their physical models, so that they can refresh their focus as needed.

**Possible uses of Technology:**

1. The teacher uses a Surface or similar tablet PC to annotate the handout in real time. This helps students take notes on their own copies of the handout and also preserves a record of what went on in class for subsequent review, if needed.
2. Students use the Protein Data Bank website, rcsb.org, to look up the amino acid sequence of a protein of interest. Students may have trouble thinking of a protein that interests them, so examples will be offered, such as:

* Albumen (ubiquitous protein in the blood that binds to lots of different things)
* Alcohol dehydrogenase (catalyzes the first step of alcohol breakdown in the liver)
* Aromatase (enzyme involved in converting male sex hormones into female ones)
* Aquaporin (channel in cell membrane that lets water in and out of cells)
* DNA polymerase (enzyme that copies DNA)
* Dystrophin (protein that is mutated in cases of muscular dystrophy)
* Flagellin (protein making up flagella, which bacteria use to move)
* Hemoglobin (oxygen-carrying protein in the blood)
* Histones (proteins that serve as spools around which DNA is wrapped)
* Myosin (molecular motor that powers muscle contraction)
* Sodium channel (channel in cell membrane that lets Na+ ions enter the cell, thus allowing transmission of information through the nervous system)

1. The class website includes links to an “Amino Acid Jazz” page (http://faculty.washington.edu/crowther/Misc/Songs/jazz.shtml) that includes lyrics, sheet music (with note-by-note playback), and an audio file, so students can get extra practice if they desire.
2. If the school owns a 3D printer, students could use the printer to create their model.

**Student Assessment/Rubrics:**

Formative Assessment: This occurs as the teacher questions students to check for understanding (e.g., see the questions above under “Guided Practice” and circulate among the groups as they build their models to confirm that they can articulate the reasons for the choices that they are making. The exit ticket at the end of the musical modeling serves as an additional formative assessment that incorporates metacognition.

Summative Assessment: Each group of students earns up to 20 points – 0, 1, or 2 points for each of the 10 criteria listed below – for its physical model of a protein. Groups that earn at least 16 points meet the objective.

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| **Criterion** | **0 points** | **1 point** | **2 points** |
| Protein identity | Protein is not identified. | The protein’s name is listed, but the species from which it comes is not. | Both the name of the protein and the species from which it comes are identified. |
| Protein function | Function is not listed. | Function is not described clearly. | Function is described clearly in 1 to 4 sentences. |
| Number of different amino acids | Every amino acid looks the same as every other one. | A few different types of amino acids (far fewer than 20) are shown. | 15-20 different amino acids are included in the model. |
| Amino acid identities | Names of amino acids are not shown (on the model itself, or in a key). | Names of SOME amino acids are shown (on the model itself, or in a key). | Names of ALL amino acids are shown (on the model itself, or in a key). |
| Connections between amino acids | Amino acids are not connected to each other. | Amino acids are connected incorrectly (e.g., in a branching pattern). | Amino acids are linked together in a linear, unbranched pattern (like a string of pearls). |
| 1st amino acid in protein | Identity of amino acids is unclear. | Amino acid chain does NOT start with methionine. | Amino acid chain starts with methionine. |
| Acidic/basic amino acids | Neither acidic nor basic amino acids are identified as such. | Acidic OR basic amino acids, but not both, are included and highlighted. | Both acidic AND basic amino acids are included and highlighted. |
| Length of protein | Protein is less than 10 amino acids long. | Protein is 10 to 34 amino acids long. | Protein is at least 35 amino acids long. |
| Phosphorylation | No phosphate groups are included. | Phosphate groups are added, but to the wrong amino acids. | A phosphate group is added to one or more serine, threonine, or tyrosine residues. |
| Disulfide bridges | No disulfide bridges are included. | Disulfide bridges are included, but are shown to occur between cysteines that are next to each other in the primary sequence, or between non-cysteines. | At least one disulfide bridge connects 2 cysteine residues that are far apart in the primary sequence of amino acids. |
| Optional bonus: additional feature not listed above | No additional features are included. | An additional feature of the group’s choice is included and briefly explained. |  |

**Scientific Discourse:**

The Next Generation Science Standards indicate that students should practice several forms of scientific discourse: “engage in argumentation from evidence; construct explanations; obtain, synthesize, evaluate, and communicate information; and build a knowledge base through content-rich texts across the three subject areas” (NGSS Lead States, 2013, Appendix D, p. 27). These challenges correspond approximately to recommended Science and Engineering Practices 4 (analyze and interpret data), 5 (argue from evidence), and 8 (obtain, evaluate, and communicate information).

In explaining these and other key SEPs, the NGSS Lead States (2013) repeatedly cite compare-and-contrast exercises as a form that this discourse can take. Thus, compare-and-contrast is a specific strategy of scientific discourse -- one that happens to be prominent in the lesson above. Students are asked by the instructor to draw scientific comparisons and contrasts at two different points: they compare and contrast the musical model of the protein with an actual protein, and later they compare and contrast the musical model with the physical model.

**Scientific Inquiry:**

This lesson is required to incorporate scientific inquiry via problem-based learning (PBL). Indeed, the lesson includes the essential features of PBL as summarized by Burden & Byrd (2013):

* *Students are presented with a problem.* Here, the “problem” is how to build a simple yet somewhat realistic model of a protein using cheap, readily available materials. (This is not an ideal PBL problem because it may not feel personally relevant to the students, but the students do get to choose a protein that is interesting to them.)
* *Students describe the problem.* Students have access to the rubric, which each group uses to help each discuss how its model must meet several criteria simultaneously.
* *Students identify solutions.* Working in groups, students brainstorm about which materials could represent amino acids, as well as features such as phosphate groups and disulfide bonds.
* *Students gather data and try solutions.* Groups collect the desired materials and assemble them into a physical model – their solution to the problem.
* *Students analyze the data.* The students compare their model to the rubric in order to judge how successfully the model captures essential features of protein structure.