DNA and DNA Origami Lesson Plan

Grade Level: Variable - Middle School through High School

Next Generation Science Standards:

- **MS-ETS1-1.** Define the criteria and constraints of a design problem with sufficient precision to ensure a successful solution, taking into account relevant scientific principles and potential impacts on people and the natural environment that may limit possible solutions.
- **MS-LS1-1.** Conduct an investigation to provide evidence that living things are made of cells; either one cell or many different numbers and types of cells
- **MS-ETS1-3.** Analyze data from tests to determine similarities and differences among several design solutions to identify the best characteristics of each that can be combined into a new solution to better meet the criteria for success.
- **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-ESS3-4.** Evaluate or refine a technological solution that reduces impacts of human activities on natural systems

Objectives:

1. Students will hear about individual stories and research being done by an undergraduate student in this field. (Part 1, Section 1)
2. Students will learn about the scale and structures of DNA. (Part 1, Section 2)
3. Students will be able to describe how DNA Origami is used to build nanotechnology. (Part 2, Section 1)
4. Students will be able to explain potential applications of a DNA origami box. (Part 2, Section 1)
5. Students will take a virtual tour of the lab to better understand research methods. (Part 2, Section 2)

Time:

45 Mins to 3 Hrs* - *This can be broken out into two or more separate days depending on which activities you'd like to do based on student's current background knowledge and time available. 3 Hrs assumes no prior knowledge.*

Materials:

1. YouTube Video Clip: Charlotte Andreasen [3]
2. Cracking the Code of Life Activity [4]
    - Table salt
    - Large test tubes with stoppers (1 per student)
    - Plastic cup (1 per student)
    - Mild detergent or dish soup

- 95% Ethanol
- Small clear tube with seal
- Ice

3. Nanoscale [6]
4. Self-Assembly of a Nanoscale DNA Box with a Controllable Lid [2] (for reference only)
5. DNA Box with a Lid Activity
   - Cardstock or heavy weight paper
   - Scotch tape
   - Optional:3-Hole Punch
   - Optional: Pipe cleaners (8 per student, cut into 2" lengths)
   - Scissors
   - Popsicle sticks (1 per student)
6. YouTube Video Clip: Dr. Rebecca Taylor [5]

VOCABULARY IN THIS LESSON:

DNA, Double-Helix, Nanotechnology, DNA Origami, Nanoscale, Microsystem, MechanoBiology, Gel Electrophoresis, Centrifuge, Annealer

PROCEDURES:

1. BEGINNING – SECTION 1

Today we're going to learn about what an undergraduate student researcher at Carnegie Mellon University in Dr. Taylor's Microsystems & MechanoBiology Lab is studying. We'll see clips of her research, take a 360° digital tour the lab where she works, and hear about what motivated them to really use science as a tool to learn about the world.

Let's start off by viewing a video clip of Charlotte Andreasen,[3] a student working in Dr. Taylor's lab. Pay special attention to how her research could lead to a medical diagnostic tool in the future.

Post Video Discussion Prompts:

1. How old is Charlotte?
2. What prompted Charlotte to engage more in science?
3. What is Charlotte researching in Dr. Taylor's lab?
4. Explain: DNA Origami
5. Are the DNA structures loose in the fluid?
6. What can lead to heart deformations in babies?
7. What are some of the tools and/or equipment that Charlotte uses in the lab?
8. What might Charlotte do in a typical day in the lab?
9. According to Charlotte, what's the most important skill to have in the lab?
10. What career is Charlotte interested in pursuing in the future?

1. BEGINNING – SECTION 2

Before we do our own research study, we need some more background information.

In order to understand how Dr. Taylor's lab nanoengineers DNA origami, we must first have a base knowledge of DNA, and its structures. DNA or Deoxyribonucleic acid is the molecule that stores information which determines inherited traits.

Each strand of DNA is composed of: a sugar (deoxyribose) and an acid (phosphate).
This combination connects pairs of bases in which information is stored. These base pairs are Adenine and Thymine, and Guanine and Cytosine. These sequences of base pairs work as a code to determine things like hair color and eye color.

Each individual has 3,000,000,000 base pairs that make up their genetic material, or genome. This means that each cell that has a nucleus includes these 3,000,000,000 base pairs.[7] With this knowledge in mind it becomes easier to understand the physical scale of nanotechnology.

2. MIDDLE – SECTION 1

To better understand the structure and size of DNA, let's take a look at some DNA in the Cracking the Code of Life Activity.[4] *Proceed through the Cracking the Code of Life Activity and handout, minus the PBS videos (Approx. 120 minutes)*

The Cracking the Code of Life Activity allowed us to see our own DNA, but let's just review the size of DNA and the Nanoscale.[6] A sheet of paper is about 100,000 nanometers thick, while a strand of DNA is about 2 – 2.5 nanometers in diameter.

Now that we understand the structures of DNA and have heard from Charlie about how DNA Origami can be used to build nanostructures, let's hear more from Dr. Taylor[5] about the application of her lab's work.

One potential application for DNA origami would be a medicine delivery box.[2] DNA is able to be folded into different shapes, such as a box with a lid. Researchers are able to code this box to open when two or more external signals are present, which would then release any medicine contained within the box at a specific location. Let's test this theory with an activity. ***(See accompanying activity pages 7-9.)***

Pre-Activity Prep:

1. Print, then cut out each of the 10 shape sets. 1 set per student. Print and cut additional pages if necessary.

During Activity:

1. Each student should receive 1 set of shapes. Shapes can then be cut out. Shape with white middle should be taped to a side on the box.
2. The solid shape can be taped to a popsicle stick and then handed back to the teacher.
3. Mix up the popsicle sticks with solid shapes and redistribute to the class.
4. Once redistributed to students in the class, have them seek out the matching shape that would serve as the external signal which would then open their box, releasing the medicine or other deliverable. Multiple rounds will be needed, which would exemplify

the fact that the box would need to travel through the area of the body to find the right signals.
Please NOTE: According to research, not one but two external signals are needed to open the box. One has been eliminated for time efficiency purposes.

2. Middle – Section 2

Armed with a better understanding of DNA and the current and future models for working in biological pathways, Let's take a walk through Dr. Taylor's lab and see where this nanotechnology is being created. In order to do research, the following resources and steps take place:

360 Tour Point(s) of Interest - Electrophoresis Equipment

1. After annealing DNA origami structures, gel electrophoresis is used to determine if structures have formed without aggregating (clumping together).

360 Tour Point(s) of Interest - Fume Hood

2. Anything involving chemicals that could be harmful is done in the fume hood, which keeps the air inside from entering the lab.

360 Tour Point(s) of Interest - NanoDrop

3. After annealing and purifying samples, NanoDrop software is used to determine the concentration of DNA structures in solution.

360 Tour Point(s) of Interest - Spinner/Vortex

4. These are used to mix solutions both to resuspend particles that have settled out and to maintain an even concentration throughout the solution.

360 Tour Point(s) of Interest - Annealer

5. DNA strands are put into solution together but need to be kept at specific temperatures over a range of time to properly form structures. The annealer is used to maintain these temperature ramps.

360 Tour Point(s) of Interest - Microscope

6. We use this microscope's total internal reflection fluorescence (TIRF) capabilities to image structures that are attached to a coverslip and decorated with fluorophores. The fluorophores light up under specific lasers from TIRF, which we can use to see what's happening since the structures are too small to see themselves, even under the microscope.

360 Tour Point(s) of Interest - Pipettes

7. Pipettes are used in almost everything we do to move precise amounts of solutions.

360 Tour Point(s) of Interest - Centrifuge

8. The centrifuge spins samples and uses centrifugal forces to separate large structures out of solution and from DNA strands that didn't form into anything. This purifies the samples.

360 Tour Point(s) of Interest - Mitchell

9. To do experiments, Mitchell dresses like his hero, Bill Nye the Science Guy.

3. Ending

At the intersection of Mechanical Engineering and Biology is new and innovative work in nanotechnology. The impact of this work on preventative tools for the early detection of heart deformation is unprecedented. Using DNA Origami could revolutionize the way that medicine and other deliverables reach their intended targets.

4. Evaluation

After moving through the entire lesson, students should be able to:

- Describe the structures of DNA
- Describe the scale of Nanotechnology
- Define DNA origami
- Talk about experimentation with DNA origami and medicine delivery

5. Differentiated Activities

- For students who had trouble learning the concepts

  Visual representations are often helpful for understanding DNA structures and bases. To get a better understanding of the structures and scale of DNA please visit:
  Khan Academy: Discovery of the structure of DNA[1]

- For the students who require a challenge

  Have students brainstorm what other applications could a small DNA box be useful? Why?
  - OR –
  Offer the Self-Assembly of a Nanoscale DNA box with a Controllable Lid[2] article to students so that they may read the article and talk about other ideas contained in the article.

Works Cited

1. "Discovery of the structure of DNA." *Khan Academy*, Khan Academy, https://www.khanacademy.org/science/high-school-biology/hs-molecular-genetics/hs-discovery-and-structure-of-dna/a/discovery-of-the-structure-of-dna.

2. "DNA Box" - Andersen, E., Dong, M., Nielsen, M. *et al.* Self-assembly of a nanoscale DNA box with a controllable lid. *Nature* **459,** 73–76 (2009). https://doi.org/10.1038/nature07971

3. "LGC STEM Career Explorations - Mechanical Engineering - Charlotte Andreasen." *YouTube*, YouTube, 1 Oct. 2019, https://www.youtube.com/watch?v=l79Yuzj1JO4.

4. "NOVA Online | Teachers | Classroom Activity | Cracking the Code of Life." *PBS*, Public Broadcasting Service, https://www.pbs.org/wgbh/nova/teachers/activities/2809_genome.html

5. "Rebecca Taylor: Building Medical Devices at the Nano and Micro Scales." *YouTube*, YouTube, 6 Sept. 2018, https://www.youtube.com/watch?v=drTe1m4Bs1U&feature=emb_logo.

6. "Size of the Nanoscale." *Nano*, https://www.nano.gov/nanotech-101/what/nano-size.

7. "What Is a Genome? - Genetics Home Reference - NIH." *U.S. National Library of Medicine*, National Institutes of Health, https://ghr.nlm.nih.gov/primer/hgp/genome.

NAME: ________________________________ DATE:___________________

Student Activity Sheet 1

DNA BOX WITH AN OPENING LID

The following activity will simulate a DNA box folding to be created, being held together by "scaffold linkers" (tape and optional pipe cleaners) and opening. This box, while scaled up from 42 x 36 x 36 nm^3, maintains the same dimensions as the ones referenced in the lesson plan and accompanying article. Printed on the page are DNA strands which build the flat surfaces of the structure.

Instructions:

1. Cut out the whole shape taking care to leave the tabs attached.

2. Fold on each of the black lines so that the blank side would be the inside of the box

3. OPTIONAL: If you have pipe cleaners, use a hole punch to punch out each of the white circles.

4. Assemble the sides of the box just as it would be done in research, beginning with side 1 and stopping at 5. Do not tape down side 6 to any of the tabs.

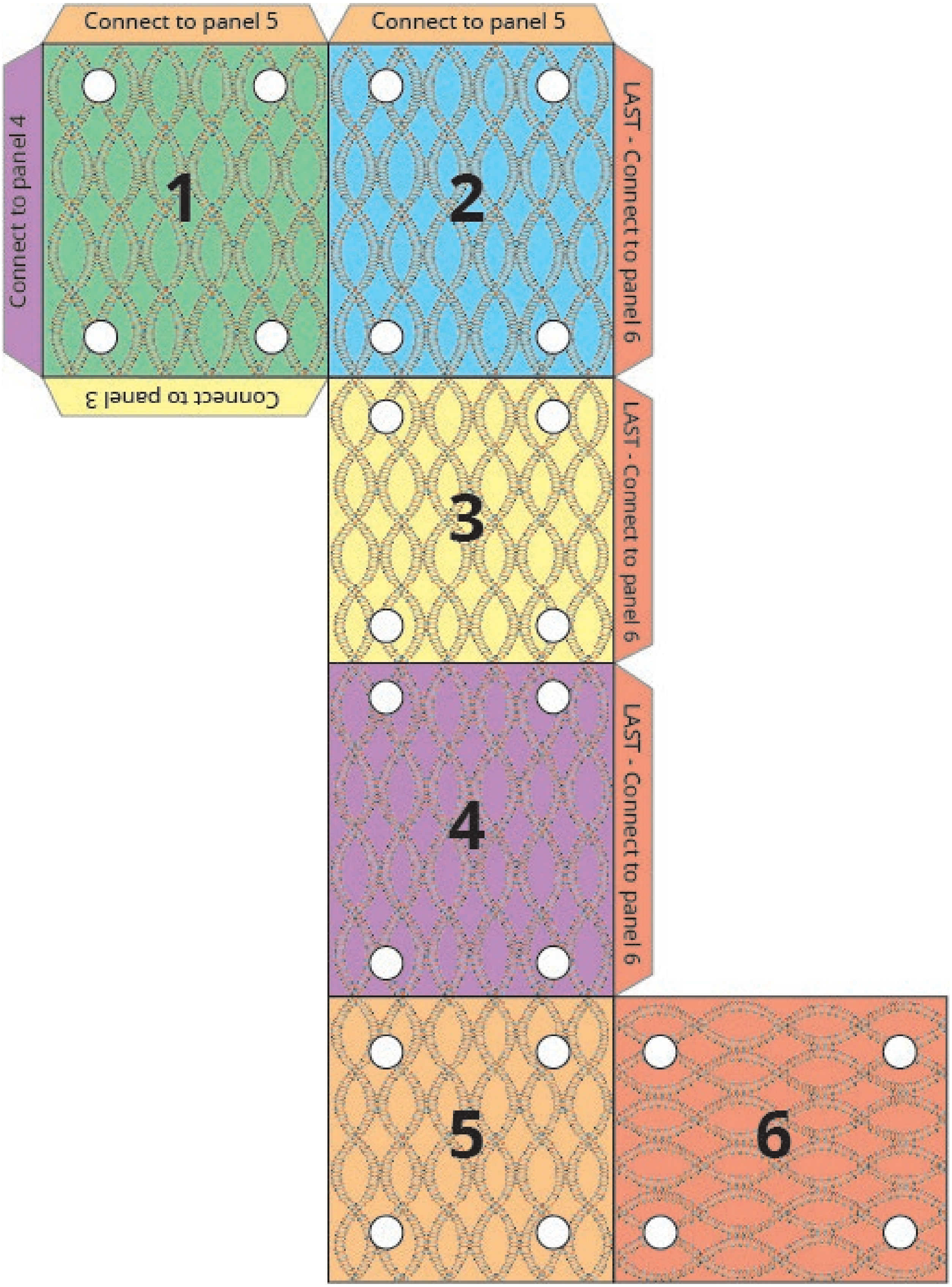
Please NOTE: In research either the true top (side 3) would be the one to open, but for the purposes of this activity, side 6 will open.

5. OPTIONAL: If you have (8 - 2") pipe cleaners, these are your "scaffold linkers" that hold the structure together. Starting on side 1, each hole will have 2 pipe cleaners, with one going to another side of the box. However, if I look at the corner of sides 1, 2 and 5, the holes adjacent to side one only have 1 "link" each.

6. Cut out both the shapes that your teacher has given to you. Tape the one with the white middle to your box. Tape the other one to the top of a popsicle stick and give to your teacher for redistribution.

Wait for Teacher Instruction to Continue

DNA BOX WITH AN OPENING LID



Teacher Resource (External Signals)