How Proteins “See” DNA:
Lessons Integrating Additive Manufacturing and Molecular Modeling

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INTRODUCTION

- A core competency outlined in *Vision and Change* is the ability to use modeling and simulation to explore biological systems.
- Teaching about biological macromolecular complexes (e.g., protein-nucleic acid complexes) is especially challenging because:
  - There are two types of macromolecules
  - Their representation conventions are different
    - Amino acid side chains are either not shown (implied) or shown in a ball and stick representation
    - Nucleic acid bases are either not shown (implied), shown as sticks, or in ball and stick representation.
  - The various types of interactions between specific atoms in the protein and nucleic acid components (e.g., hydrogen bonding, ionic interactions, pi-stacking interactions etc.) have to be imagined and interpreted.

CHALLENGE

- Students often find it hard to build a mental map that allows them to move back and forth between different representations of polymer sequences, their 2D and 3D structures (including atoms, bonds, interactions) in order to understand the interactions in biomolecular complexes and their biological functions.
- We have developed some ideas for addressing these challenges and would like to discuss them in this work-in-progress session.

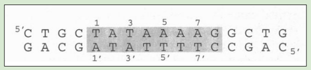
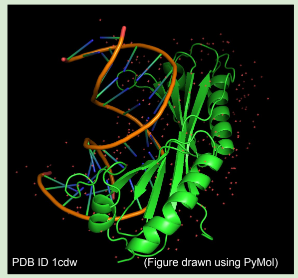
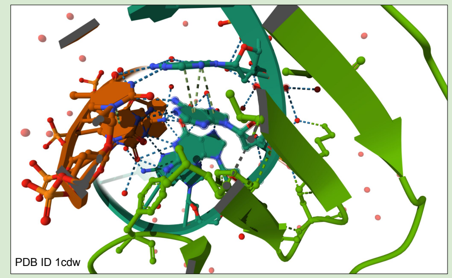
HYPOTHESIS

- Using an example of an authentic protein-nucleic acid complex can engage students in learning about structure and function relationships.
- Students learning about different representations of proteins and nucleic acids should be scaffolded
- Visualizing the structure in multiple representations can help students build a mental map of different features in the 3D structure and gain a deeper understanding of its function(s).

AVAILABLE RESOURCES

Exploring 3D structures of DNA and its complexes to understand protein-nucleic acid interactions and functions using

- Molecular visualization tools - they are free and accessible, but
  - May be technical/challenging to use
  - Learning to use them needs time and practice
- Traditional DNA model kits provide a tactile approach for explorations, but
  - Offer limited modification capabilities and
  - Are generally expensive.

Sequence	Structure	Function
Target DNA binding site	Of the TBP protein bound to the target DNA sequence	Of TBP bound to the TATA box - required for transcription
 Nikolov DB, Chen H, Halay ED, Hoffman A, Roeder RG, Burley SK. Crystal structure of a human TATA box-binding protein/TATA element complex. Proc Natl Acad Sci U S A. 1996 May 14;93(10):4862-7. doi: 10.1073/pnas.93.10.4862. PMID: 8643494; PMCID: PMC39370.		

Project Outline:

- Students will use a **molecular visualization software** to:
  - Model a given DNA sequence and DNA-binding protein
  - Identify potential binding regions
  - Modify the components and convert them to Spatial models
  - Export for 3D printing
- Students will then use **slicing software and 3D Printers** to
  - Upload the exported files (.stl) and slice them according to their printer’s specifications
  - 3D print
- Students **examine the protein conformation** that binds to the DNA - either to a specific sequence or to the DNA backbone.

Have questions? Write to Melanie (melanie.lenahan@raritanval.edu)

OUR APPROACH

We would like to create custom models of specific scenes showing protein-DNA complexes for exploration by combining the

- Versatility of molecular visualization tools and
- Accessibility of 3D printing options available locally in institutions

WHY?

- By introducing additive manufacturing, more commonly known as 3D printing, instructors are able to make educational resources that fit their needs more closely for a fraction of the cost.
- Students learn a transferable skill, beyond disciplinary knowledge about proteins and nucleic acids.

HOW TO IMPLEMENT ACTIVITY

- We are designing a matching activity where students can engage in designing and studying models of specific protein-DNA complexes.

OR

- Students participate in a matching activity using pre-made models:
  - They will be given four DNA Sequences - one functional and three non-functional
  - They will also be given different proteins that specifically binds to one of these DNA sequences (e.g., restriction enzymes, TATA-binding proteins, CRISPR-Cas complexes, and transcription factors)
  - They must determine which proteins bind to the nucleic acid target site.

ROLES

- The activity idea was developed by Dr. Lenahan, the 3D printing expertise will be developed under the supervision of Ms. Mojica, and Dr. Dutta will help with identification of 3D structures of relevant protein-nucleic acid complexes
- The completed activity will be shared in the BSF CoP.

INVITATION

- Tell us about your experiences in teaching about the structure and function(s) of protein-nucleic acid complex(es).
- Help us brainstorm key ideas to incorporate in lessons where students learn to “See” what the protein “Sees” when it interacts with nucleic acids like DNA or RNA.
- Join us in developing this lesson and pilot it in order to test its accessibility and relevance in different courses.

QUBES A BioQUEST Project
Biomolecular Structure and Function BSF CoP Community of Practice