Molecular CaseNet: Developing case studies using molecular representations for use in introductory chemistry, biology and biochemistry classes

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Abstract #5168

Understanding "Structure and Function" relationships is foundational to learning biology, chemistry, and biochemistry. However, exploring and using biochemical data resources, especially the Protein Data Bank, to develop a deeper understanding of the relationship between structure and function, are not common practices, in introductory courses. This project brings together biology and chemistry educators to develop case studies centered around representations of biological macromolecules. We hope these studies, at the interface between both disciplines, will facilitate deeper understanding of structure/function in biology and chemistry and reduce conceptual barriers that hinder a common understanding. This presentation will focus on a hemoglobin case study that was developed and used in introductory chemistry and a one-semester biochemistry course. Discussion will focus on implementation of using the same case at different levels of instruction, ideas for other content and molecular representations that could be used to bridge the disciplines of biology and chemistry and how you can get involved and contribute to the Molecular CaseNet. NSF Award #: 1827011

Objectives of Molecular CaseNet

1. Determine case study topics and format for Molecular Case Studies
2. Develop model case-studies, with input from diverse participants to ensure curricular relevance
3. Share model cases to recruit new members to the network

Conceptual Frameworks

Vision & Change

- Structure and function
- Systems

ASBMB: Macromolecule Structure/Function

- Structure and function are related
- Macromolecular interactions
- Macromolecular structure/activity is dynamic and regulated
- Chemistry and physics determines structure/function

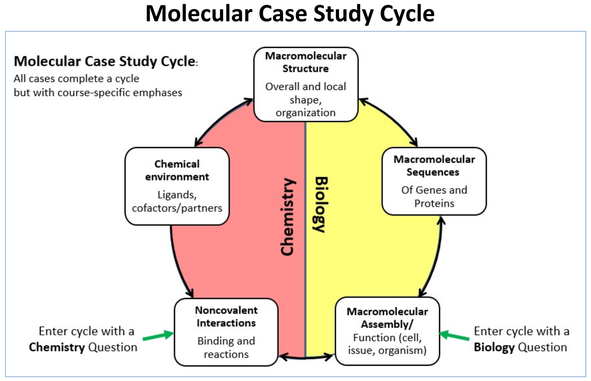
Next Gen Science Standards (NGSS) – 3D Learning

Core ideas	*Crosscutting Concepts*	*Sci. & Eng. Practices*
• From Molecules to Organisms • Heredity • Biological Evolution	• Patterns • Cause and effect • Structure and function	• Ask questions • Develop models • Analyze data • Obtain, evaluate, communicate info

Developing a Molecular Case Study

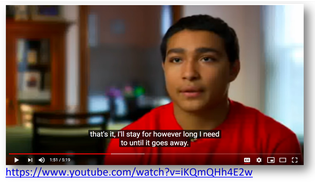
1. Select a topic that is
   - compelling and emotionally connecting;
   - relevant/interesting to educators/students in biology and chemistry;
   - suitable for understanding structure/function relationships
2. Define a format for the cases – Molecular Case Study Cycle
3. Identify learning objectives and write up case details, teaching notes.

Molecular Case Study Cycle



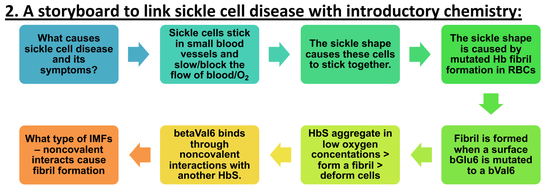
Our 1st Molecular Case Study: Nicholas' Story

1. Topic: A compelling and emotionally-charged story that links structure/function



https://www.youtube.com/watch?v=iKQmQHh4E2w

2. A storyboard to link sickle cell disease with introductory chemistry:



3. Student Learning Objectives

Introductory Chem/Bio Learning goals: Students will be able to …

INTRO CHEMISTRY	IN COMMON	INTRO BIOLOGY (Molecules/Cells)
• identify non-covalent (IMFs) and covalent interactions between ligand and biomacromolecule • identify atoms from their CPK colors; • describe advantages and disadvantages of different types of renderings of biomacromolecules; • explain how a mutation in a protein can lead to altered protein structure, function and properties	• describe how the three dimensional structure of a molecule impact its function, including the ability to interact with other molecules. • describe the binding properties of hemoglobin and oxygen	• explain how the structure of a cell and its shape impacts its function. • explain how the sickle cell shape affecting RBC function • explain how structure constrains function in cellular physiology. • explain how fibers of abnormal hemoglobin deform red blood cell into sickle shape

Biochemistry/Advanced Biology Learning goals: Students will be able to …

BIOCHEMISTRY	IN COMMON	ADVANCED BIOLOGY
• Describe/compare the structure/properties of T and R states of Hb and their respective binding properties; • describe cooperative binding and how different allosteric effectors and ligands affect the equilibria between T and R states of hemoglobin; • Describe and use different mathematical models (Hill, MWC, KNF) that account for cooperative binding of ligand and relate them to structural changes in hemoglobin	• explain the structure of normal (HbA) hemoglobin,, and the role of hemes in binding oxygen (Level 1) • explain the cooperative binding and release of O_2 by tetrameric HbA (Level 2) • Correlate binding of O_2, CO_2 and NO to hemoglobin with graphs of fractional saturation vs pO2; • describe different allosteric effectors of O2 binding to hemoglobin and how they regulate Hb structure and O_2 binding properties;	• explain the structural difference between HbA beta globin and HbS beta globin and the genetic cause (basis) of this difference (Level 1) • explain why the HbS mutation causes tetrameric polymerization (Level 1) • explain how HbS polymerization elicits sickle cell disease pathologies • obtain information on the molecular basis of possible treatments for sickle cell disease

Additional Modeling/Presentation Goals that could be addressed with the Case Study

Basic
- use online interactive web tutorials to display and understand structural features of biomacromolecules, ligands, and their interactions;
- display different renderings of molecules and proteins using web-based molecular modeling programs, given instructions for their use;
- optimally orient molecules to display key feature of structure and function using web-based modeling programs;
- orient 3D printed models of proteins with computer models of the same protein structure
- use PPTX and screen capture to create/complete assignments focusing on structure/function

Advanced
- Use specific programs (JSmol, Chimera, Pymol, etc.), through the command line and/or GUI, to open/render biomolecules to explain structure/function

4. Sickle Cell Hemoglobin (HbS): Beta-tested Classroom Experiences

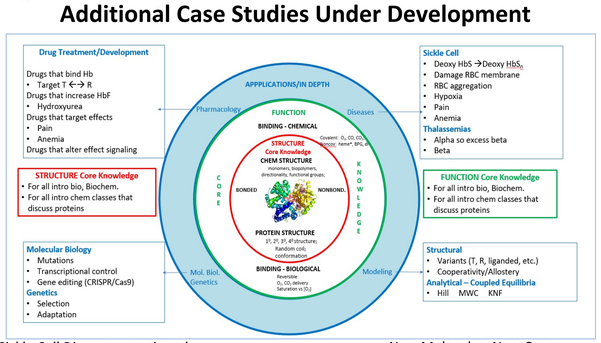
General Chemistry I
- 48 students at Kennesaw State University
- Goal: Provide biological context for IMF
- 20 min of a 50 min class to show application of IMF
- Used first 2 minutes of video to introduce context.
- Instructor used OMM model as demonstration to highlight important aspects.
- Drew Lewis structures of amino acids on board to have students predict interactions.
- Used OMM to compare their predictions using the Lewis structures to what happens in the protein.

Intro to Chemical Structure and Properties
- 23 students at College of St. Benedict-St. John's University
- Goal: Understanding IMFs in a biological/medical setting
- Pre-class group assignment in flipped classroom activity where students watched video along with 2 videos describing sickle cell
- Each group is assigned a different PDB ID to investigate different aspects of Hb-ligand binding interactions.
- Students model using: Ligand PDB (heme); NCBI - iCn3D for HbS dimer
- Students present their portion of the Hb story to create a class story of Hb
- Class concludes with a discussion of how structure of Hb impacts function in the form of sickle cell.

Biochemistry (1 semester survey)
- 72 students at Kennesaw State University
- Goal: Structure impacts function of Hb ligand binding
- Pre-class videos and quiz in flipped classroom format
- 2 class periods used OMM to explore HbA structure and HbS structure
- Students self-guided exploration of the OMM to explore HbA structure
- Guided activity with questions to explore HbS structure with occasional whole-class guidance by instructor

Biochemistry Student Feedback
- N=46 students participated in the IRB approved survey
- **Strengths**
  - Visualization of the structure (57%)
  - Step-by-step radio buttons (15%)
  - Detailed Information (11%)
- **Areas for Improvement**
  - Additional discussion during the activity (17%)
  - More guidance is needed in determining what to take away (15%)
  - Information was difficult to follow (11%)
  - So much detailed information there was not enough time (11%)

Additional Case Studies Under Development

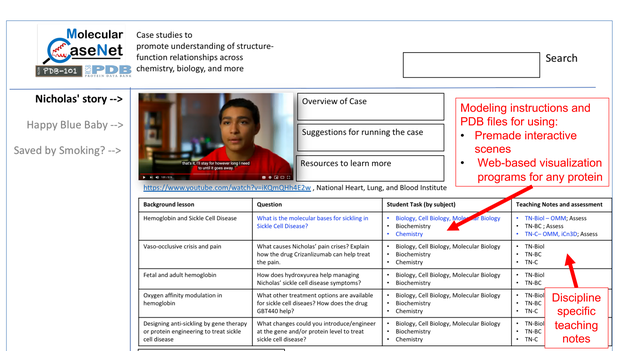


Sickle Cell Disease – continued
- Pain in Sickle Cell Disease
- Hydroxyurea treatment
- Treating Sickle Cell Disease

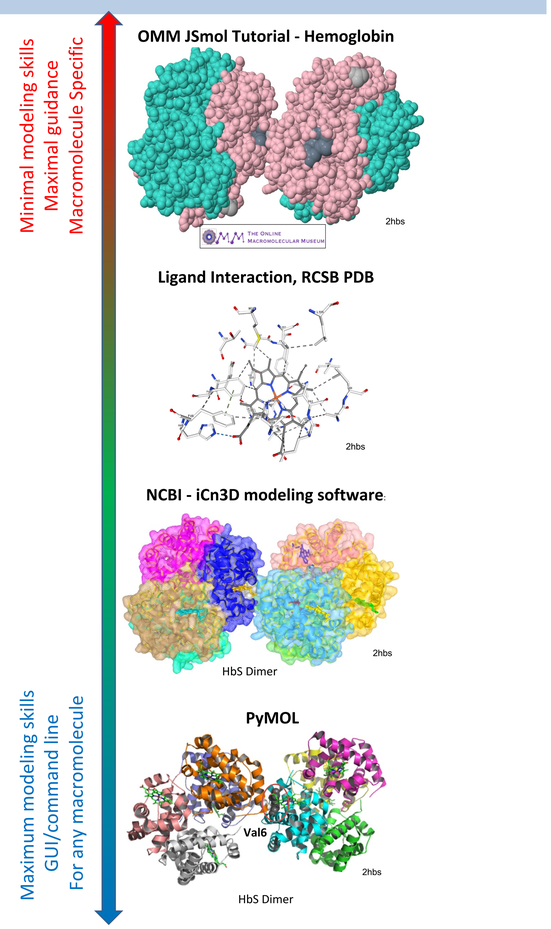
Other Hemoglobinopathies
- Thalassemia
- Happy Blue Baby
- Saved by Smoking

New Molecules, New Cases
- COXI and COXII drugs
- LSD and serotonin
- Influenza and the MHC
- C-Si bonds & directed evolution

A Planned Searchable Web Repository



Modeling PDB Hemoglobin Structures



We would love to hear from you!

- What challenges do you face in connecting chemical concepts to biological concepts?
- Which part of the molecular case study cycle do you find to be most difficult to connect in your class?
  *Place a sticker next to the part of the cycle you find to be most challenging
- What challenges do you face in teaching how to develop and use models in your classroom?
- Are there other cases or systems you would like to have included?

- Join our group Molecular CaseNet
- Use/evaluate case studies
  Contact - sdutta@rcsb.rutgers.edu

Complete our Survey

Molecular CaseNet Workshop
- May 4, 2019
- Emory University Atlanta, GA

Register Now!

References

Conceptual Frameworks:
- Vision and Change- BioCore Guide: A Tool for Interpreting the Core Concepts of Vision and Change for Biology Majors, CBE Life Sci Educ. 2014 Summer; 13(2): 200–211.
- ASBMB Learning Goals- https://www.asbmb.org/education/teachingstrategies/foundationalconcepts/MacromolecularStructureFunction/
- Next Generation Science Standard (NGSS)– 3D Learning. https://www.nextgenscience.org/three-dimensions

Modeling PDB Hemoglobin structures
- OMM JSmol tutorial- Marcey and Terrell. Hemoglobin A Structure, Sickle Cell Anemia, and Carbon Monoxide Toxicity. http://earth.callutheran.edu/Academic_Programs/Departments/BioDev/omm/jsmolnew/hemo/hemoglobina.html
- RCSB PDB Ligand View- Alexander S Rose Anthony R Bradley Yana Valasatava Jose M Duarte Andreas Prlić Peter W Rose (2018), NGL viewer: web-based molecular graphics for large complexes, Bioinformatics, 34, 3755–3758.
- iCn3D: Available from: https://www.ncbi.nlm.nih.gov/Structure/icn3d/icn3d.html
- Pymol: https://pymol.org/2/
- PDB Structure: Harrington, D.J., Adachi, K., Royer Jr., W.E. (1997), The high resolution crystal structure of deoxyhemoglobin S., J.Mol.Biol. 272: 398-407. (PDB ID 2hbs)