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1A-Authoring a Molecular Case Study

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This document is based on the instructions for engaging students in writing molecular case studies (Riley, K. J., Vardar-Ulu, D., Pollock, E., & Dutta, S. (2021) Biochemistry and Molecular Biology Education, 49(6), 853-855.) and was further developed through discussions at the Biome Institute in 2020, FMN in Spring 2021 and Spring 2022, and a working group of experienced Molecular CaseNet members in Fall 2022.

Goal of Molecular Case Studies

Use an engaging story to make a clear link between the molecular structure (including chemical interactions) and biological function(s) of a protein and/or their complex with other biological molecules.

In authoring a molecular case study consider the following:

How this case will help students …

- **apply foundational knowledge** about sequence, structure, and function of a specific protein of interest.
- **find and interpret information** from the scientific literature and/or other bioinformatics data resources that are related to the protein or system of interest.
- **integrate their learning** by exploring examples where similar chemical/ biochemical principles and biological concepts are applied to solve a diverse set of biological and biomedical problems.

How the case will help educators cover the following community standards and professional society learning objectives**:**

- Biology: ASBMB Foundational concepts
- Chemistry: Macromolecular, Supramolecular, and Nanoscale (MSN) Systems in the Curriculum
- Bioinformatics: NIBLSE Bioinformatics Core Competencies
- Molecular Visualization: BioMolViz Framework
- Vision and Change in Biology (BioCore): BioCore Guide

Review the learning objectives in the links above, and select several for your case. Be sure to note any learning objective numbering/classification. You will provide your refined learning objectives as part of the teaching notes. Other disciplinary community standards can be added to the case based on the case context and participating educator interests and expertise.

Steps for authoring a molecular case study:

Each Molecular Case Study (MCS) needs to include the following five sections: 1. Presenting the case context, 2. Getting to the structure(s), 3. Exploring the structure(s), 4. Connecting structure to function, and 5. Assessment - applying skills to new problems. These subsections, and the overall process outlined in this document, are summarized in Figure 1. You may have multiple subdivisions or modules under each of these sections.

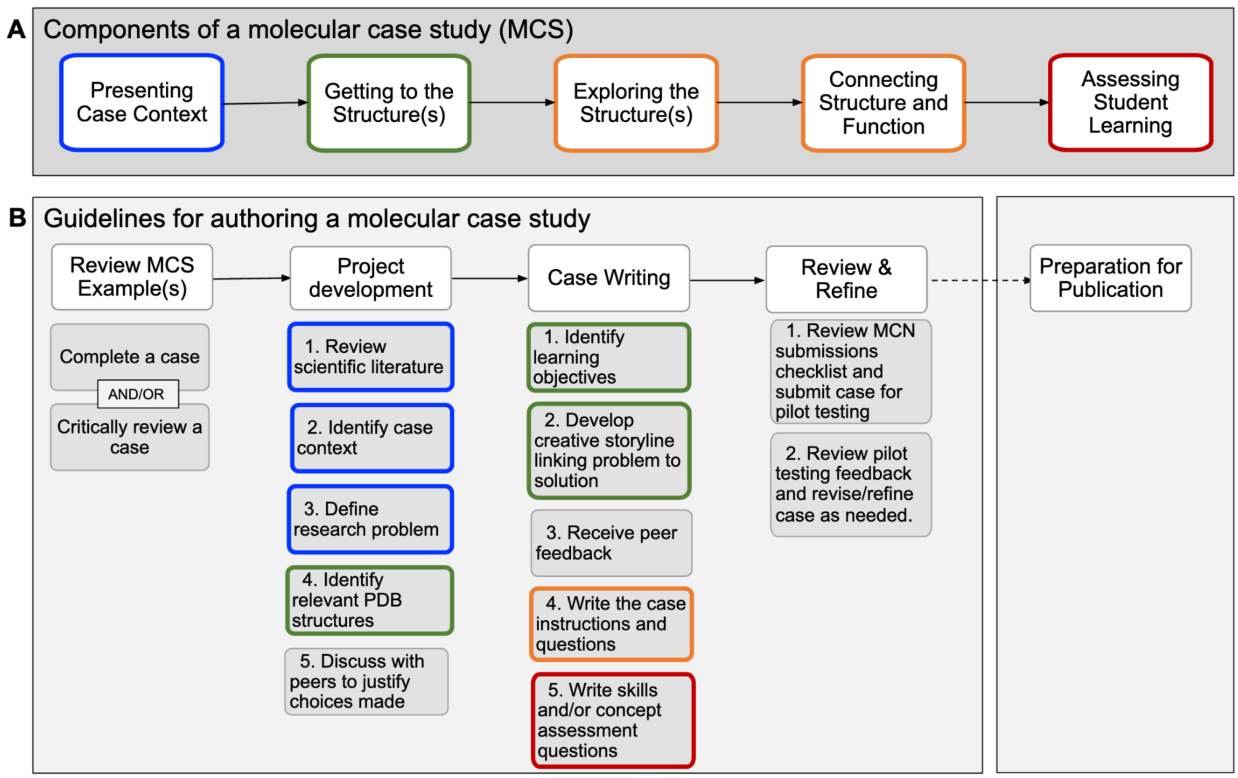

***Figure 1**: A. The main components of a molecular case study; B. Guidelines for authoring a molecular case study*

Presenting Case Context: This section of the case study sets up the problem that will be answered through the MCS. The "hook" will be introduced here to capture the students' interest and set up the scientific question(s) addressed in the study.

Getting to the Structure(s): This section connects the problem presented in the Case Context to the molecular scale, introducing the biological molecule featured in the case. Students should be guided to the structure of interest; cases may explicitly describe the molecule to be found or set up a mystery for students to work through to find the molecule. The ultimate goal of this section is for students to find or access the PDB ID of a structure to model.

Exploring the Structure(s): In this section, students use a PDB structure to begin to address the problem presented in the case context. This section should contain some explicit guidance on how to use the molecular modeling program selected for the MCS. The level of detail presented in the steps will vary, depending on whether the class has previous modeling experience.

Connecting Structure and Function: Through biomolecular modeling, students should explore a change to the structure that alters the function (e.g., mutation of an amino acid alters binding, the binding of an inhibitor changes enzyme activity). This part may include comparison and analysis of two or more structures (e.g., with and without mutation or with and without inhibitor) or prediction of the effect of changes based on available structural and functional information.

Assessing Student Learning: Each MCS should have one or more assessment question(s) that provide an opportunity for students to apply the disciplinary concepts and interdisciplinary skills learned in the case to a new problem/context. These questions may range from exploratory (e.g., exploring a different property/function of the same protein/complex discussed in the case) to engineering (e.g., designing mutations in the protein to introduce new properties or functions in the protein/complex discussed).

A. Reviewing Molecular Case Study Example(s)

Use a published case in your course and/or critically review a published (or late-stage draft) of an MCS. Reflect on the following:

- What was done well?
- What should be improved? and
- What did you learn from the way these cases are written?

B. Project Development

STEP 1: Review the submitter self checklist

Please review the Checklist for sharing the case study for piloting and also the requirements for submitting the case studies. It will be helpful to keep this checklist handy during project development and case writing.

STEP 2: Review scientific literature
Select a biological system of interest and review the relevant literature, as needed.

STEP 3: Identify case context
Outline the specific scientific question(s) you would like to answer about this biological system and identify the protein players that are involved in the chosen biological context.

STEP 4: Select a biomolecular visualization program to use in the case
The case should use one molecular visualization program to explore the relevant structure(s). Popular options include: Mol* from the RCSB PDB, iCn3D, PyMOL, and ChimeraX. Although the granular steps in the case will be described in the context of the selected software (e.g., where to click, which menu items to select), bear in mind that you should include broad instructions to describe the purpose of performing these steps (e.g., use the following steps to select the residues that interact with the ligand, or measure the distance between the two atoms). This will allow others to adapt your case and use a different molecular visualization software of their choice to accomplish those tasks.

STEP 5: Define research problem
Case studies often focus on:

- Physiological function vs. altered function: Identify a well defined, specific function and a change in that function to be investigated in the case.
- Native structure vs. altered structure: There should be readily available structural information in the Protein Data Bank about this protein and its altered form relevant to the functional change investigated.

Begin with a macroscale observation related to the problem: e.g., the baby turned blue (Happy Blue Baby case study). Then, connect this to the molecular structure: e.g., there is a mutation. Finally, return to a macroscale view to explain the physiological effects observed.

Details for how to include explanations for these are described in the “D. Write the body of your case” section below.

STEP 6: Identify relevant PDB structures: Perform a preliminary search in the Protein Data Bank (PDB, www.rcsb.org) to determine if adequate structural information is available for the proteins identified in the previous step and determine the main protein structure you want to build your case around.

Consider:

- Which structures(s) would help in illustrating the altered function (related to the question being asked)?
- Are there multiple structures of the protein in the PDB (e.g., bound to ligands/partner proteins, at different temperatures, pH, etc.)? Can these structures be compared/contrasted to learn something related to the case or to make a specific point?
- What do you want to learn from the 3D structure that cannot be learned by looking at its sequence/primary structure alone?
- Note the structural method(s) used to elucidate this/these structures? Are there specific considerations due to limitations of the method(s) used?
- What is the focus of the structural experiment - i.e., why did the authors solve the 3D structure? (Were they examining the apo structure, inhibitor bound structure, mutant structure, etc.)
- What are some of the interesting/unique features and spatial organization of the protein molecule (such as domains, motifs, secondary structures, etc.) that are relevant to the function investigated?
- Is the quality of the structure sufficient for it to be reliable? (Examine validation reports where possible.)
- What unique information could be obtained or hypothesized about the protein based on the deposited structural information?
- What aspects of the amino acid sequence, 3D protein structure and biological function are worth exploring in connection to the case?

STEP 7: Explore other bioinformatics resources: Once you've identified your biomolecule, expand your search to other biological databases to identify tools beyond molecular visualization to supplement your storyline. Consider resources that look both at DNA/RNA sequences and protein sequences, structures, functions, and more. For example:

- Gene Sequences: **NCBI Genbank**: https://www.ncbi.nlm.nih.gov/genbank
  Protein Sequences: **UniProt**: https://www.uniprot.org/
- Protein secondary structure prediction **JPred**: https://www.compbio.dundee.ac.uk/jpred
- Protein family annotations (functions, domains etc.) **Pfam**: http://pfam.xfam.org
- Metabolic/signaling pathways **KEGG PATHWAY**: https://www.genome.jp/kegg/pathway.html
- Comparing protein/nucleic acids sequences **BLAST**:

https://blast.ncbi.nlm.nih.gov/Blast.cgi

- Comparing protein sequences **CLUSTAL Omega**: https://www.ebi.ac.uk/Tools/msa/clustalo

Consider:

- What can be learned quickly/easily from the primary and/or secondary structure of proteins, and what cannot?
- How can you use the DNA or RNA sequences to learn more about the wild-type or a mutant protein?
- Are there proteins with related/redundant functions? Is your protein part of a metabolic pathway? Signaling pathway? Multi-protein complex?
- How conserved is the protein across species? Does it make sense to do a multi-species alignment in CLUSTAL OMEGA?

STEP 8: Review and Justify choices made: Ensure that the choice of PDB structures and information gathered from various resources are supported by primary literature and/or experimental data for the claimed link between the structure and function of the central protein. If necessary, discuss your choices with a member of Molecular CaseNet and/or a researcher with experience on the topic chosen for the molecular case study.

The structure(s) and bioinformatics data selected should help answer the problem or question presented in the case. Consider how you will justify these choices in the Teaching Notes documentation (see template document) so that other educators using this case study understand why this/these structure(s) and bioinformatics resources were selected for this case - e.g., this PDB structure has a specific mutation in the protein, or includes a drug/inhibitor that is relevant to the case.

Congratulations, you are ready to begin writing your case! To align with best practices in education, we have outlined the following steps to help you adopt backward design in your approach.

C. Case Writing

STEP 1: Identify learning objectives

Your learning objectives should be appropriate for the specific audience you are targeting. Each section of your case should have 2-3 learning objectives that all tie to one main overall learning goal for the case. Learning objectives should be matched to existing standards whenever possible. Need help writing Learning Objectives? Here are some suggested tips.

STEP 2: Develop a creative/engaging storyline

Provide a context for the molecule that is delivered in non-scientific language aimed to capture the interest of the audience. This “hook,” which can be in the form of an image, a short audio/video, or written piece (such as a newspaper article or story), will constitute the introduction to the case and convey the biological/chemical/ecological etc. question to be addressed in the study.

Consider:

- Who is your audience and what is the take home message you would like them to have after completing this case study?
- Are there YouTube videos that you can find from a reliable source or can you create one based on reliable data?
- Are there articles to get a reader hooked into your story?
- Can you use a real life example from a newspaper story or clinical publication? Otherwise, you are welcome to create a fictional storyline.
- If fictional, is your storyline entirely scientifically plausible?
- Are the images, videos, stories used for the case appropriately attributed? If using any copyrighted materials, all necessary permissions should be obtained.

STEP 3: Write case instructions and questions

Each MCS needs to include the following five sections: Presentation of the case context, getting to the structure(s), exploring the structure(s), connecting structure to function, and assessing student learning (i.e., applying skills to new problems). You may combine sections into one part of the case, or have multiple subdivisions or modules under each of these sections.

Determine the number of subsections/modules your case study will have. Include each of the five mandatory MCS sections, see Figure 1.

List the literature data, bioinformatic tools, and PDB structures you will use in each section to meet your stated objectives. You must explore molecular interactions within the protein as well as between the protein and a binding partner for the structure/function relation sections of the case.

Write the instructions for how to obtain information related to the case (see box below)

Consider:

- Where and how will readers find information? How can you provide or help them obtain information (e.g., will you provide a PDB ID directly, have them find their own, have them find an article with the specific structure)?
- If some of your information should be described in embedded text, figures, or tables—keep the text short and sweet and custom tailor your figures/tables.
- You can use some already-written instructions or a YouTube tutorial for finding specific details like a hydrogen bond or coloring an individual residue, etc.
- Is there a logical order for exploring various aspects of the case?

Write the body of your case. While writing, be sure to describe the research problem, as detailed below.

- **Physiological function vs. altered function:** Identify a well-defined and specific function and a change in that function that is being investigated in the case.

  Within the introduction section of the case, there should be a well articulated question that clearly ties the hook (introductory video, image, story etc.) to the structure-function question being investigated.

  There should be a dedicated section in the case that delivers adequate biological and chemical background to explain the biological system at hand and help appreciate the importance of the investigated question.

  Furthermore, this section should clearly describe all the important cellular players within the biological system, how they are related functionally with respect to each other, and how they individually or collectively impact the investigated function. The case should include several specific questions (and answers) about this section that assess the audience's understanding of the functional information related to the case.

- **Native structure vs. altered structure:** Case discussions should include sequence and structure explorations. There should be a section that delivers specific structural information at a molecular level about the central protein investigated.

  Furthermore, this section should clearly describe the structural relationship between the central protein and its interacting partners within the investigated biological system. The case should include several specific questions (and answers) about this section that assess the audience's understanding of the structural information related to the case.

Consider using literature or online bioinformatics tool to investigate:

- What biological phenomenon is affiliated with your protein under normal and altered or disease contexts?
- How/why was your protein named as it is?
- What are its substrates, ligands, reaction mechanisms, or binding partners?
- What organism does it come from? How conserved is the protein across species?
- What are the physical stats of the protein (e.g., MW, pI, number of amino acid residues)?
- How is your protein regulated in the cell? What are the post-translational modifications on the protein (if any), and what role do they play in its function?

STEP 4: Create assessment questions and an answer key.

- **Write a series of main assessment questions for the case.**
  Refer to your learning objectives, and write questions for students to answer. These may be interspersed throughout the case, for students to consider as they work through, or be placed at the end.
- **Write one additional assessment question (and the associated answer key)** that relates to the case study, but goes a step beyond the case as written. The student should apply knowledge gained from working through the molecular case study to a slightly different scenario that requires molecular visualization to answer the question. This will be used as a post-test to measure student learning of both the concepts and skills learned in the case.
- **Considering/assessing the bigger picture (if applicable):** Write a question/discussion prompt to explore the case's relationship to issues of diversity/inclusion/equity, science and society, and/or social justice.

Even if multiple authors are writing different portions of the case, they should collaboratively create a single comprehensive key. Where possible, provide a rubric for grading the responses. Use the following as a guideline in developing the key.

Consider:

- What is the main idea in the answer? Is it clear, and correct?
- What is the evidence for the answer? Is there a figure of the molecular structure to support the claims made, or can you create one?
- Is the language used in the answer grammatically correct, relevant to the case study, and broadly understandable?

Each learning objective should be measured with 1-2 questions (assessments) to determine if students have met the objective.

Consider:

- After the student obtains the structure, what will they do to gain skills in understanding how to interpret the 3D image?
- How do your questions require the reader to demonstrate the link between molecular structure and function?
- Do you have variety in the kinds of questions you are asking and the ways in which the student can respond (e.g., by pasting an image, a M.C. question, a brief essay)?
- Critically Evaluate: Do your questions *require* the students to engage with the figures or structure, or is it possible to answer the questions without them?
- Are the questions written considering the target audiences' prior exposure to the subject matter?
- Do the questions use inclusive and accessible language, avoiding jargon and providing accepted alternative terminology where possible?

You may include any type of question; the box below contains quality resources for multiple choice questions, specifically.

BOX: Resources for Writing Good Assessment Questions

- Writing Good Multiple Choice Test Questions (Vanderbilt University)
- Best Practices for Designing Exams (University of Michigan)
- Designing Effective Multiple Choice Questions (McGill University)
- Best Practices for Designing and Grading Exams (University of Michigan)
- Guide to Writing Multiple Choice Questions (from National Board of Medical Examiners, NBME)

REFERENCE FORMATTING

The literature cited and listed at the end of the case should be formatted e.g., using the APA (7th edition) style.

BOX: Example of Formatted References

In-text: (Coleman, 2001)

In the References section (Bibliography): Coleman, J. (2001). Nitric oxide in immunity and inflammation. International Immunopharmacology, 1(8), 1397-1406. https://doi.org/10.1016/s1567-5769(01)00086-8

Notes:

- Resource: Cite this for me for formatting (https://www.citethisforme.com/)
- Any specific data or images should also be cited using the same style.
- A rigorously researched case study will have 5-10 citations.

D. Review and Refine Case Study

- Consult the Molecular CaseNet Rubric and Checklist and revise as needed
- Find a peer (collaborator or colleague) to review the case you have written and ask them to provide feedback (see Peer Review Criteria list)
- Make sure that you address all issues in the feedback and consult the Molecular CaseNet case review rubrics before submitting the case for publication.