Supplement 2: Notes from Pilot Implementations

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Overview of Pilot Implementations

This document provides some notes from the pilot implementations of the Molecular Case Study (MCS) authorship assignment. The different course contexts, disciplinary focus, and class size provides some insight into the adaptability of the assignment. Instructor and student reflections included at the end of the document provide glimpses of engagement in the assignment.

1. Logistics

As of August 1, 2021, the Molecular Case Study (MCS) authorship assignment has been piloted in six courses at three institutions by three instructors over three semesters. In all cases, students were provided with step-by-step instructions to guide their process (Supplement 1). Each instructor customized the assignment to suit varied in-person and independent time commitments, course objectives, and class sizes. A summary of the implementation logistics are included in Table 1.

Institution	Proportion of Final Grade	Supervised/ Independent Time Commitment	Size	Notes
Boston University (BU)	10% of lab grade for a 4 cr lab/lecture course. The Lab is 30% of the course	2x 50 min + 2x 4h class time/ unknown probably ~ 2x 4h	30	Assignment replaced the last two weeks of a laboratory module allocated for independent student projects. Students had already learned and used bioinformatics and molecular visualization tools throughout the semester, but did not have experience with MCS. All students were juniors/seniors; most of them were chemistry and BMB majors but some were also engineers, neuroscience, human physiology students.
Rollins College (RC)	21% of 6 cr lab/lecture	6 h (2 days)/ unknown	7	Students had previous experience with molecular visualization software and MCS; all seniors; all biochemistry majors

	20% of 2 cr elective	8 h (8 days)/~6 h	8	
	20% of 6 cr lab/lecture	8 h (4 days)/~8 h	16	
Stockton University (SU)	20% of 4 cr lecture	3 h (2 days)/ unknown	5	Students had previous experience with MCS; all biochemistry majors
	15% of 4 cr lab	4 h (2x 0.5 days)/ unknown	14	Students had previous experience with molecular visualization and bioinformatics software but not with MCS; all biochemistry or biology majors

Table 1: Details of pilot deployment of Molecular Case Study (MCS) authorship assignment. cr - credits; h- hours; BMB - Biochemistry and Molecular Biology

2. Suggested Grading Scaffolds

There is a lot of flexibility in how the instructor can choose to weigh various parts of the assignment in grading depending on course objectives. For example, the advanced biochemistry course at Rollins College (RC) is writing intensive, so the grading emphasized that process. The steps listed below were included in the assignment instructions. Because the draft and final student authored case were worth a big proportion of the grade, students were provided with a very clear set of expectations for which pieces of the case must be completed (minimally) at each stage. This helped the students have clarity and made grading much easier. Further detail on the list of elements expected in an initial draft and draft and final version of the case writing portion of the assignment are in Table 2.

- Molecular Case Study Example-15%
- Project Proposal-10%
- Case Writing
  - Draft-30%
  - Final-40%
- Peer Review Assignment-5%

Category
Learning Objectives—minimum two per team member
Learning Objectives—different Bloom's levels, stated correctly, matched to intended audience
Organization—five sections, clear headings; subsections; logical order
Organization—exploration builds in a logical manner; good elements of formatting
Figures—minimum one per team member, with legends
Figures—complexity, accuracy, creativity, relevance to story
Table—at least one data table
Instructions—for student to obtain at least one 3D protein structure per team member
Instructions—for student to use a non-3D structural tool (such as BLAST)
Instructions—clarity, accuracy/functionality, ease of use, completeness
Assessment questions—minimum 2-3 per objective, appropriate to assess objective; Blooms

Assessment questions—suited to intended audience, requiring data analysis/interpretation, complex
Assessment key—accuracy and completeness
Introduction/background information—includes citations, relevant information
Storyline—creative, elements of mystery, connects structure to function; needs structure
Literature cited—minimum 5 citations, correctly formatted
Writing style—cohesiveness, clarity, polish

Table 2: List of basic requirements for student authorship of MCSs at RC. Items required in the first draft are shown in gray; all items were expected in the final draft.

3. Time Commitment

The students authoring MCS assignment was initially used as an emergency replacement from lost lab time, and later was successfully deployed in a variety of different course structures (Table 1). The later iterations allowed for the estimation of student independent time for this assignment - it ranged from six to eight hours of time dedicated to this project by each individual. The pilot implementation shows that there is flexibility in how much supervised and independent time can be committed to this assignment. Future iterations of this assignment can look at time commitment in greater detail.

4. Examples of Cases Produced by Students During Pilot

Students drafted a total of 12 (RC), nine (SU), and 10 (BU) novel MCS. The cases varied widely in both the study subject and the means used to explore the main case-related protein (Table 3). Roughly 25-30% of final student submissions were of sufficient quality to warrant external peer review and are ready to be submitted for review and publication on MCN (https://molecular-casenet.rcsb.org/).

Protein	**Diseases**	**Main Molecular Explorations and Bioinformatics tools/resource used**
lysosomal hydrolase	Sanfilippo's syndrome	• *Genetic testing* • *KEGG database to explore metabolic pathways* • *Chemical mechanism from literature*
cytochrome P450	vitamin D deficiency	• *Analyzing data from literature* • *Sequence alignment*
MPro protease from SARS-CoV2	COVID	• *BLAST searches to identify proteins with similar sequences* • *Analyzing data from literature*
lactate dehydrogenase	cancer, malaria, infertility, heart disease	• *Analyzing literature and/or student-generated data* • *Sequence alignment* • *Enzyme mechanism and inhibition (esp. for drug development through exploration of Drugbank)*

Table 3: Examples of student authored molecular case studies

These cases are on their path to publication - later this year, selected cases will be submitted to the Molecular CaseNet for review and publication (with digital object identifiers through the QUBES platform).

Learning Gains and Alignment to Course Objectives

The Students Authoring MCS assignment helped align with many course objectives - some that were discipline specific and others that taught them transferable skills - e.g., introduction to public data resources and skills to navigate through available data resources to gather topic specific information.

1. Disciplinary Objectives

In each of the pilot implementations the overall goal of having students write a molecular case study was designed to tie the concept of a structure-function relationship of biomolecules directly to your particular course goals. This affects the stated "overall project goal" and how the project aligns with your curricular objectives. A few examples are provided below.

Example 1 Course: 400-level advanced biochemistry elective focused on fermentation
Overall project goal: Make a clear link between the structure and function of a protein that plays a critical role in a fermentative pathway.
How does this project (authoring a molecular case study) fit in the fermentation course objectives?
Throughout this project, you will have the opportunity to…

- Apply foundational knowledge about identity, structure, and function of a protein related to a topic of special interest to you.
- Find and interpret primary biochemical literature related to your protein or system of interest.
- Study examples of how similar biochemical principles are applied to solve a diverse set of challenges relevant to industrial or in-home food production

Example 2 Course: 400-level introductory biochemistry laboratory course where students purify and characterize the enzyme Lactate Dehydrogenase (LDH)
Overall project goal: Make a clear link between the structure and function of LDH as a critical protein in a student-chosen biological context.
How does this project (authoring a molecular case study) fit in with biochemistry curricular goals?
Through this project you will have the opportunity to:

- Apply foundational knowledge about identity, structure, and function of the protein (LDH) you have personally purified and characterized in the laboratory as it relates to a biological function of special interest to you.
- Find and interpret biochemical literature and/or data related to LDH.
- Study examples of how a variety of biochemical principles and techniques similar to the ones you used in the laboratory are applied to study a diverse set of biological questions.

2. Introduction to a Bioinformatics Data Resources

In order to write the cases students had to learn how to navigate through the Protein Data Bank (PDB) to identify specific proteins/complexes. The process of selecting a protein of interest and the type of protein that a student may select are both customizable. Consider one of three variations:

a. Assign all students the same protein as the subject of the study. You may provide a specific protein (i.e. everyone will write a case study about lactate dehydrogenase using PDB ID XXXX), or you may ask students to find any one of the structures of LDH from different organisms or with different cofactors/ligands bound. This may best suit the constraints of large classes or lower-level courses.
b. Allow students to select a protein within a defined functional scope (i.e., a transcription factor or a G-protein coupled receptor)
c. Allow students to select a protein with a specific type of domain or motif (i.e., a leucine zipper or a transmembrane domain-containing protein)

3. Writing Objectives

It is helpful to introduce molecular case studies as a writing genre before asking students to author them. This provides some models for what to include and what to avoid when they author cases. Consider one of two variations:

a. Have students complete an entire molecular case study as part of the course.
b. Have students critique a molecular case study in a peer review-type assignment. Ask students to critically evaluate the alignment of the objectives with the course and critique what should be improved.

4. Attributions in Scientific Writing

The formatting of the literature cited may fit with your stated course policies. If you do not have requirements, we suggest the use of the style of the *ACS journal Biochemistry* or *Cell*. If students are not yet comfortable finding and reading primary literature or general information literacy, they may benefit from meetings with librarians.

5. Custom Objectives

There are other ways you may supplement this exercise to tailor it to your course:

a. **Examining experimental data**: You could require students to include experimental data from previously completed experiments or published literature from class (examine a gel or other experimental data).
b. **Exploring bioinformatics data resources**: It may also be valuable to familiarize your students with the various bioinformatics data resources and visualization tools available online in a separate assignment - e.g., have them practice using these data, resources, and tools (either when doing the example cases or as separate worksheets prior to beginning this project). Some of the other bioinformatic resources that students encountered also listed in the [Molecular CaseNet Resources]

Examples of some of the custom course objectives that the authoring MCS activities can meet are listed in Table 4.

Course Objective	MCS Activity(ies) Meeting Objective
Upon successful completion of this course, students will apply their foundational knowledge of the structure/function of biomolecules to complex biochemical problems and disease.	• cases are a molecular exploration of disease
Upon successful completion of this course, students will critically analyze, present, and discuss techniques and data from primary and secondary literature, sometimes under time constraints to reflect real-world scenarios.	• teams gave "elevator pitch" mini presentations to summarize their MCS cases • critical analysis of literature included in case • required multiple biochemical techniques to be integrated into case study story line
Upon successful completion of this course, students will define a biochemical problem from multiple contextual factors and identify multiple approaches to solve the problem that apply within a specific context.	• For students to be able to author a realistic storyline that accurately fits a molecular case, they need to first understand a biochemical problem from multiple perspectives (the patient, the researcher, etc.). • To create an accurate key, students must explore multiple ways the reader may solve the problem.
Upon successful completion of this course,	• the assignment requires students to consider

students will distinguish between different biochemical methods to propose the appropriate approach to test a given hypothesis and predict the outcome of proposed biochemical experiments.	the different experimental approaches for testing something like the consequences of a mutation or ligand binding ● students must lead the reader to be able to predict the outcome of experiments based on their own prediction

Table 4: Examples of course objectives in an advanced biochemistry course and the MCS assignment activities that teach and assess each objective.

6. Collaboration and Iteration

Collaboration and iteration are two crucial parts of a CURE experience. The MCS authorship process requires review and revision of case study drafts in multiple iterations. Thus the project introduces students to the process of science and scientific writing. This part of the project requires a significant input of dedicated time on the part of the instructor or teaching fellow, just as a hands-on lab experience requires supervision and correction. The total number of iterations and the extent of student-faculty collaboration is up to each instructor.

Reflections

1. Instructor Reflections on Challenges During Pilot Implementation

In piloting this assignment at three institutions of different enrollments, geographies, classifications. In spite of these differences, all instructors strongly felt the exercise was worthwhile and witnessed learning gains among most students. All three instructors plan to use this assignment again in the next year.

Boston University is a private research institution with a large student body. The laboratory curriculum is developed and coordinated by laboratory instructors while individual undergraduate laboratory sections are taught by graduate student teaching fellows (TF). Biochemistry Laboratory sections were capped at 10-12 students during COVID; students worked collaboratively in groups of 3-4 during the independent student project module of the Biochemistry lab. The students had direct access to the professor as well as a dedicated TF (one for two groups) throughout the project. After the course was completed, one third of the students continued working on their cases (throughout the winter break). They were refining their cases for the possibility of a final publication and one group even got a chance to field-test their cases in a "lecture only" single semester biochemistry course in the following spring.

Rollins College is a primarily undergraduate liberal arts college where upper-level courses are capped at 12-16. Students usually know each other very well and are accustomed to working collaboratively and directly with their professor in lab and lecture settings. Self-selected collaborative groups ranged from one to four students with the majority of students working in pairs. Students expressed sincere enthusiasm at the possibility of reaching eventual publication and co-authorship, and a few individuals chose to continue working on the project post-graduation.

Stockton University is a public university with no graduate students in chemistry or biology. Groups ranged from one to three students, with the lecture class opting to work entirely as individuals while in the lab class students worked with the lab partners they had been assigned at the beginning of the term. Implementation went more smoothly in the lecture course, where students had previously done two published case studies as part of the planned course experience. Lab students were encouraged to review a case study but this review was not graded and generally not done. The quality of the final product was higher in the lecture course, where students were also more enthusiastic about the project.

2. **Student Feedback During/After Pilot Implementation**

Students from all institutions were involved in authoring Molecular Case Studies as an alternative to a lab-based CURE experience. They were highly enthusiastic and motivated throughout the project and expressed intellectual satisfaction and individual pride about their final products. Furthermore, 25-30% of students from each institution continued to refine their cases for 1-4 months after the end of their respective courses, reflecting their genuine enthusiasm and commitment to the project.

The largest single cohort at Boston University (30 students) was given an end of semester survey where they were instructed to reflect on their experience of authoring MCS for their independent project module in the laboratory and compare it with the other three categories of laboratory assignments they were asked to complete in the same semester: lab reports (prepared individually), enzyme purification poster (prepared as a team of four), and enzyme characterization paper written in a journal format (prepared as a pair). Students were also instructed to evaluate 19 statements to specifically report their level of agreement on the indicated learning gains from writing MCS (Table 5). While only 20% of the students reported any familiarity and comfort with using NCBI databases, Uniprot, BLAST, or Protein Data Bank (PDB) at the start of the semester, this percentage increased to over 80% at the end of the semester. Although about a third of the students acknowledged that writing MCS took a lot of time and effort, only 2 students out of 30 did not recommend it as an option for the independent projects module of the course in future semesters and 3 reported not enjoying the activity. MCS writing assignment was perceived by the students as helping to fulfill more of the indicated gains than any other single assignment in the course.

Statement	**Completely Agree/Agree**	**Neither agree or disagree**	**Disagree/ Completely Disagree**
Helped me integrate biochemical concepts I studied in the course with their practical applications	29	1	0
Made me more comfortable with accessing and using databases and bioinformatics tools	28	2	0
Increased my understanding of the interactions between macromolecules and the importance of such interactions to functional specificity	26	3	1
Helped me identify, locate, and use the primary literature	26	3	1
Helped me connect concepts and ideas encountered in one or more different courses	25	5	0
Made it easier to navigate and retrieve data from online databases	25	5	0

Deepened my understanding of biochemical concepts I studied in the course	25	4	1
Improved my teamwork and collaboration skills	24	6	0
Improved my confidence in my understanding of the biochemistry course material	23	7	0
Made me more comfortable working with complex ideas	22	6	2
Improved my written communication skills in explaining scientific concepts and data	21	9	0
Improved my ability to synthesize new material and recognize solutions to complex problems	21	7	3
Increased my understanding of how new knowledge is constructed	21	7	3
Increased my understanding of experimental design	21	6	3
Improved my data interpretation skills	20	8	2
Increased my enthusiasm for the biochemical field	19	8	3
Improved my data analysis skills	19	8	3
Improved my oral communication skills in explaining scientific concepts and data	16	12	2

Table 5: Distribution of the level of student agreement (n = 30) on their perceived learning gains from completing writing Molecular Case Studies, ranked from highest to lowest gains.