2019

BIOC 321: Elements of Biochemistry – A Peer Review of Teaching Project Benchmark Portfolio

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ABSTRACT

The benchmark portfolio of Biochemistry 321, Elements of Biochemistry, aimed to provide a broad overview for this large-enrollment class for non-biochemistry majors. This course was delivered in a blended format, and the learning objectives were aligned with the American Society of Biochemistry and Molecular Biology (ASBMB) foundational concepts and skills. Classroom response system iClicker was employed and Think-Pair-Share method was utilized to facilitate the in-class discussion and group-learning. Additional activities include the 3D molecular models for visualizing and hands-on learning of the structure-function relationship concept, and practicing problem-solving through the end-of-chapter essay questions. Data analysis suggested that the iClicker response system and group discussion are effective on learning, and different study strategies used by students might play an important role in exam performance. Class-attendance was also examined and it correlated to low exam performance. The future plan includes to adjust the delivery format of the course and emphasize the in-class practice of problem-solving through group-learning, use additional formative assessment, and to develop the course to become more learner-centered to improve student success.

Keywords: biochemistry, blended, ASBMB, group-learning
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I. INTRODUCTION

1.1 Objectives of Peer Review Course Portfolio

BIOC 321, elements of biochemistry, is a one-semester comprehensive biochemistry course for non-biochemistry majored students. Traditionally this course is fast-paced and content-driven, which has posed a challenge for many students. Since this is the first time I teach this course, my main objective for this benchmark portfolio is to provide a broad overview of the course. In this portfolio I’d like to focus on the following aspects: 1) alignment of learning objectives to the American Society of Biochemistry and Molecular Biology (ASBMB) foundational concepts and skills (Appendix I); 2) effectiveness of current teaching methods and pedagogy on student performance, and 3) identification of barriers for learning and areas for course improvement and further development.

This portfolio will provide an opportunity for me to reflect on and assess my approach to facilitate student learning, better understand how learning can become more effective, and identify areas that I can improve. The portfolio can also be beneficial to those teaching similar types of courses.

1.2 Description of the course

BIOC 321 is a pre-requisite for several upper-level courses for various majors. Students are mostly juniors and seniors from different background across the discipline, including nutrition and dietetics, biological system engineering, food science and technology, etc.

This course is delivered in a blended format, in which half of the course is pre-recorded and posted online, and the other half face-to-face. The advantage of online-lectures is that students can take down detailed notes and review the materials as much as they want, and the in-class sessions provide contact time with the instructor and peers, so that students can be guided to practice problem-solving and build up team-work skills. The comparison and effectiveness of these two formats are not assessed in this portfolio, but student feedback may provide insight for pedagogical improvement.

One challenge of the course is that it’s built on student prior knowledge in mathematics, chemistry, biology, and physics. Many students either don’t have a good foundation in those subject areas or they forgot what they’ve learned, so the first couple lessons are focused on reviewing those topics that are related to biochemistry concepts.

Other learning objectives/goals are aimed to align with the ASBMB foundational concepts and skills (Appendix I):

- Recognize the structure of a defined set of important biochemical molecules (proteins, nucleic acids, carbohydrates, and lipids), and discuss how the structure is governed by foundational principles of chemistry and physics

- Apply the principles of thermodynamics to compare different forms of biological energy
• Explain the mechanisms on how enzymes catalyze biological reactions, and interpret the kinetic parameters including Vmax, Km, and Kcat

• Discuss how structure determines function and regulation of the macromolecules

• Compare and contrast the processes involved in the biosynthesis and degradation of the macromolecules

• Explain how genetic information is stored, transmitted, and maintained from one generation to the next in prokaryotes and eukaryotes

• Explain the role of evolution and homeostasis in the structure and function of biological molecules and organisms

• Relate biochemistry to everyday examples and apply biochemical principles to explain phenomena in different context

To accomplish these objectives and goals, students learn through reading the text, listening to the lectures, practicing problem-solving through in-class clicker questions and group discussion, and solving the end-of-chapter problems. The entire course is divided into four modules, and at the end of each module students will take an exam as summative assessment.

II. TEACHING METHODS/COURSE MATERIALS/COURSE ACTIVITIES

2.1 Lectures and Online Videos

The textbook will be the main material for this course (Essential Biochemistry by Pratt and Cornely, 4th Edition). This text is concise and suitable for the one-semester course for non-major students. It contains learning objectives that cover a broad range of ASBMB foundational concepts and skills. Students are expected to read the text before and after the lectures, which will prepare them for the lecture and help improve their understanding of the material.

Lectures will be given for most of the in-class time to review materials and explain concepts. In-class and online lecture PowerPoint slides are also provided, which outline and explain the main ideas from the text to give students in-depth understanding of the materials. Links to online videos are embedded in the slides to facilitate the learning of complex concepts.

2.2 Clicker and Think-Pair-Share

Clicker questions are used to assess students’ understanding of the concepts and to give just-in-time feedback. This course is content-dense, and challenging to the non-biochemistry majored students. Using clicker questions right after introducing a difficulty concept can help instructor capture misconceptions and clarify them in time.
Well-designed group social learning has been shown to be an effective strategy to increase student learning. Think-pair-share activity provides students social learning environment right in the classroom, and can be assessed right away using the clicker system. Students first vote for the answers individually. If a significant number of students get the answers wrong, they will be instructed to discuss with their neighbors in small groups and then resubmit their answers. Depending on the results, instructor will either summarize the responses if the correctness is improved to desired percent, or explain the concept again and then the students vote for the third time. Examples of clicker questions and poll results are given in the Analysis of Student Learning 3.3.

2.3 Weekly Short Assays

After each lecture there are practice problems selected from the end-of-chapter of the text. The purpose is to help students learn to apply the material through problem solving. The keys of the problems can be found at the end of the book so that students can learn on their own.

One essay question is assigned for each chapter, which is required to be submitted online for grading. This holds students accountable to learn the materials, and for the instructor to provide feedback for their learning.

2.4 3D Molecular Models and Worksheets

One ASBMB foundational concept is the structure-function relationship. Spatial learning method is used to facilitate the understanding of protein structure and function through an NSF-funded project in our department, in which 3D molecular models are created for facilitating the learning in the classroom.

Students form groups of three, with each member choosing one model to study. There are two accompanied online worksheets, one on amino acid structure and peptide bond, and the other on the secondary structure of proteins. Students are guided step-by-step by the worksheets, which also provide instant feedback and explanations. This approach allows students to visualize abstract concepts, receive feedback on misconceptions, and learn through hands-on experimentation in groups.

2.5 Review Sessions and Exams

Four exams are used as summative assessment. Each exam covers 5-6 chapters and is composed of two essay questions, five short answers, and fifteen multiple-choice questions (Appendix IV). Before each exam, a review session is given using class time to help students review key concepts.

Method of constructing concept map is introduced as a tool to organize and visualize topics. Examples of self-testing questions for each chapter are provided, and old exams are used to illustrate the problem-solving process.

2.6 Study Group

Students are encouraged to form study groups of five to eight to meet regularly outside of class, because students in study groups learn the material at a deeper level than students who study
alone and usually score better on exams. The end-of-chapter practice problems can also be used for study group discussion.

In summary, these teaching methods, course materials and activities facilitate students to learn complex concepts and apply them, prepare students for their upper-level majors’ courses, and build up their team-work skills that will benefit them beyond the classroom.

III. ANALYSIS OF STUDENT LEARNING

3.1 Exam Scores

This course is composed of twenty-one lectures that are divided into four modules. It covers a wide range of topics including the structures and functions of four major types of biomolecules, metabolism of these biomolecules, and widely used biotechnology methods. For each module there is a comprehensive exam to assess student learning. Each exam is comprised of two essay questions, five short answers, and fifteen multiple-choice questions. The example of exam can be found in Appendix IV.

<table>
<thead>
<tr>
<th></th>
<th>86-100% A</th>
<th>74-86% B</th>
<th>62-74% C</th>
<th>50-62% D</th>
<th>&lt;50% F</th>
</tr>
</thead>
<tbody>
<tr>
<td>Exam 1</td>
<td>6%</td>
<td>41%</td>
<td>30%</td>
<td>18%</td>
<td>7%</td>
</tr>
<tr>
<td>Exam 2</td>
<td>11%</td>
<td>39%</td>
<td>21%</td>
<td>24%</td>
<td>4%</td>
</tr>
<tr>
<td>Exam 3</td>
<td>20%</td>
<td>27%</td>
<td>23%</td>
<td>13%</td>
<td>16%</td>
</tr>
<tr>
<td>Exam 4</td>
<td>30%</td>
<td>30%</td>
<td>22%</td>
<td>10%</td>
<td>7%</td>
</tr>
</tbody>
</table>

![BIOC 321 Exam Scores](image)

Figure 1: Grade distribution of four exams
Looking at the distribution of the grade (Figure 1), one encouraging data is that the percentage of student number with A grade increased for each exam. For all exams, B grade has the highest percentage of students, except that in exam 4 A equals B. These data may not be used to measure learning gain though because each exam tested on different topics.

3.2 Exam Multiple-Choice Questions

There are fifteen multiple-choice questions in each exam using Scantron, and the statistics of each question is analyzed. The average percentage of correctness for questions from each chapter is calculated and shown in Table 1 and Figure 2. Correctness lower than 60% is highlighted in gray in Table 1, and marked by asterisk in Figure 2. We see that chapter 5 protein function and chapter 15 Citric Acid Cycle are the lowest with less than 50% correctness. These data reveal the content areas that need to be strengthened in teaching and learning.

Table 1: Average correctness of multiple-choice exam questions for each chapter

<table>
<thead>
<tr>
<th>Chapter</th>
<th>Average Correctness</th>
</tr>
</thead>
<tbody>
<tr>
<td>Chapter 1 Chemical Basis of Life</td>
<td>90%</td>
</tr>
<tr>
<td>Chapter 2 Aqueous Chemistry</td>
<td>79%</td>
</tr>
<tr>
<td>Chapter 3 Genes to Proteins</td>
<td>84%</td>
</tr>
<tr>
<td>Chapter 4 Protein Structure</td>
<td>65%</td>
</tr>
<tr>
<td>Chapter 5 Protein Function</td>
<td>48%</td>
</tr>
<tr>
<td>Chapter 6 How Enzymes Work</td>
<td>71%</td>
</tr>
<tr>
<td>Chapter 7 Enzyme Kinetics and Inhibition</td>
<td>59%</td>
</tr>
<tr>
<td>Chapter 8 Lipids and Membranes</td>
<td>72%</td>
</tr>
<tr>
<td>Chapter 9 Membrane Transport</td>
<td>56%</td>
</tr>
<tr>
<td>Chapter 10 Carbohydrates</td>
<td>72%</td>
</tr>
<tr>
<td>Chapter 11 Metabolism &amp; Bioenergetics</td>
<td>80%</td>
</tr>
<tr>
<td>Chapter 12 Metabolism &amp; Bioenergetics</td>
<td>80%</td>
</tr>
<tr>
<td>Chapter 13 Glucose Metabolism</td>
<td>72%</td>
</tr>
<tr>
<td>Chapter 14 Citric Acid Cycle</td>
<td>47%</td>
</tr>
<tr>
<td>Chapter 15 Oxidative Phosphorylation</td>
<td>64%</td>
</tr>
<tr>
<td>Chapter 16 Photosynthesis</td>
<td>69%</td>
</tr>
<tr>
<td>Chapter 17 Lipid Metabolism</td>
<td>69%</td>
</tr>
<tr>
<td>Chapter 18 Nitrogen Metabolism</td>
<td>82%</td>
</tr>
<tr>
<td>Chapter 19 Regulation of Fuel Metabolism</td>
<td>65%</td>
</tr>
<tr>
<td>Chapter 20 DNA Replication and Repair</td>
<td>58%</td>
</tr>
<tr>
<td>Chapter 21 Transcription and RNA</td>
<td>70%</td>
</tr>
<tr>
<td>Chapter 22 Protein Synthesis</td>
<td>70%</td>
</tr>
</tbody>
</table>

Figure 2: Average correctness of multiple-choice exam questions for each chapter
3.3 iClicker and Think-Pair-Share

iClicker classroom response system was employed to facilitate group learning. The general practice is to ask students to vote for the questions individually first. If a significant number of students choose the wrong answer, they will be instructed to share their choices and reasoning with their neighbors, and then resubmit their answers. Depending on the results, I will either summarize the responses if the correctness is improved (Figure 3), or explain the concept again and ask students to vote for the third time (Figure 4). Example questions and data shown in Figures 3 and 4 indicated that group discussion and review of concepts are both effective strategies for learning.

Example Clicker questions and poll results:

Q1: Which of the following wound NOT form a suitable buffer?
   A. Acetic acid/acetate
   B. *Hydrochloric acid/chloride
   C. Carbonic acid/bicarbonate
   D. Phosphoric acid/dihydrogen phosphate
   E. All of the above can form a suitable buffer

   ![Figure 3: Clicker poll results](image)

Q2: Which of the amino acids listed below contain an imidazole ring in its side chain?
   A. *Histidine    B. Proline    C. Asparagine    D. Tryptophan    E. Arginine

   ![Figure 4: Clicker poll results](image)
During informal conversations with several students with high-, medium-, and low-exam performance, one interesting finding is that these students might have spent similar amount of time on study, however their strategies are very different, which may correlate to their respective performance (Table 2).

Table 2: Correlation between study strategy and exam performance

<table>
<thead>
<tr>
<th>Exam Performance</th>
<th>Study Strategy</th>
</tr>
</thead>
</table>
| **High-performance** | 90% | • Focus on lecture and take down notes  
  • Organize notes using figures and bullet points to include details  
  • Study materials after each chapter  
  • Start reviewing for exams at least one week before  
  • Self-testing when preparing for the exams |
| **Medium-performance** | 65-90% | • Organize notes but lack of understanding on details  
  • Start reviewing a few days before the exams |
| **Low-performance** | 40-65% | • Notes-organizing is not effective  
  • Lack of understanding on details |

Here is an example exam essay question and the answers shown with different levels of proficiency (Table 3):

Q: The first enzyme in the Calvin cycle is the most abundant biological catalyst on earth.
   a. What is the name of this enzyme?
   b. What reaction(s) does it catalyze?
   c. What reaction in photosynthesis would the enzyme ribulose-5-phosphate kinase (or phosphoribulokinase) be used?

Table 3: Example answers for exam essay question

| High-performance | a. RuBisCO: Ribulose-1,5-bisphosphate Carboxylase/Oxygenase  
  b. Within the carboxylation phase of the Calvin cycle, it catalyzes:  
  ribulose-1,5-bisphosphate + CO2 → 2 molecules of 3-phosphoglycerate  
  During respiration, RuBisCO also catalyzes:  
  ribulose-1,5-bisphosphate + O2 → 3-phosphoglycerate + 2-phosphoglycolate  
  c. The enzyme phosphoribulokinase would be used during the regeneration phase of the Calvin cycle. ATP is needed for rearrangements to convert glyceraldehyde-3-phosphate back into ribulose-5-phosphate. The name kinase suggests the use of ATP to provide energy for this reaction. |
| Medium-performance | a. RuBisCO  
  b. It catalyzes the carboxylation reaction in the light dependent part of the Calvin cycle, turning the 5-carbon sugar into 3-carbon sugars with the help of light energy and CO2. It can also perform oxylation if too much O2 is present causing |
photorespiration.
c. Ribulose-5-phosphate kinase would be used at the end of the reaction to refresh
the 5-carbon sugar ribulose from 2 portion of the 3-carbon sugars used in the other
parts of photosynthesis.

| Low-performance | a. The enzyme is RuBisCO.  
|                 | b. The reaction catalyzed is carboxylation.  
|                 | c. Ribulose-5-phosphate kinase would be used to catalyze the ATP-dependent phosphorylation. |

In general, high-performing students are able to articulate their answers with ample details and accuracy. One strategy they often use is to organize their notes using figures and bullet points to include details that can be easily visualized. It will be interesting to see whether this strategy is effective on medium- and low-performing students.

3.5 Attendance and Grade

Lastly, I analyzed the class attendance using clicker data to see whether it has any effect on grade. The average attendance of A and B students is about the same, whereas that of C and D students are much lower. These data suggested that strategies to increase attendance might facilitate learning especially for low-performing students.

![Figure 5: Correlation between class attendance and grades](image)

Figure 5: Correlation between class attendance and grades
IV. REFLECTION / PLANNED CHANGES

Being my first time teaching this course, participation in the Peer Review of Teaching Project is extremely helpful in every stage of the process. The three memos on ‘Learning Objectives’, ‘Course Activities’, and ‘Analysis of Learning’ provided an effective framework for planning, executing, and assessing the course. It helped me define measurable course objectives and align them to the ASBMB standards, design appropriate class activities to achieve these objectives, and use various assessment tools to evaluate learning and to identify areas for future improvement. Suggestions and feedbacks from the PRTP leaders and the other participants are invaluable for the development of this course.

From student feedback, one complaining is about the half-online half-in-class format. I also felt this is probably not the most effective way to teach a content-dense course. I plan to reorganize the online-content and leave more class-time for practicing effective study strategies and problem-solving. As shown in 3.4, high-performance students have figured out the strategies that worked best for them. While I recommended those strategies to the class, not all students were thrilled to give them a try. It would be possible to utilize the class time to guide students to exercise the strategies, and they may find some actually work for them as well. Problem-solving skills can also be developed in a social-learning environment where students are physically present in the classroom.

A tool I’d like to try is to use team management system like CATME to facilitate students to form groups in the classroom. There is extensive evidence in the literature that states the benefit of group learning. I used the iClicker response system this semester, and the data has shown the effectiveness on learning. However, I noticed that quite a few students sit by themselves in the class and didn’t really participated group discussion. Using CATME to assign groups intentionally might help those students to get involved. This may also help increase attendance when students bond to each other within the group, which in turn leads to better performance as shown in Figure 5.

As for assessment, I used weekly assay questions for practicing problem-solving, and four exams for summative assessment. Previously in this course online weekly quizzes were used as formative assessment. I didn’t use the quizzes this semester because of the textbook change that requires updating of the quiz bank, and the limited time available for making that ready. I will work with another instructor to update and use these quizzes, as it’s an effective tool for students to practice and for assessment that doesn’t require additional grading.

Lastly, I would like to continue the conversation with students from different backgrounds, understand how they learn, and identify approaches that are effective for teaching and learning of this course. I plan to look into literature for validated survey questions that can formalize the process, or resources that can help develop the survey. This could serve as an evidence-based start point for further developing the course to become more learner-centered for student success.
APPENDIX I: American Society for Biochemistry and Molecular Biology (ASBMB)  
Foundational Concepts and Skills

### Society Learning Goals

**Foundational Concept: Energy is required and transformed in biological systems**

- **What is the nature of biological energy?**
  Many forms of energy are involved in biological processes: light, chemical, conformational, mechanical, and gradients. These forms can be understood in terms of the principles of thermodynamics. Energy is utilized for diverse purposes, such as the work required to synthesize biomolecules, create electrical and chemical gradients, perform mechanical work or stored within biomolecules.

- **How do enzymes catalyze biological reactions?**
  Enzymes, which can be proteins or RNA, are macromolecules with catalytic functions. They do not alter reaction equilibria; instead, they lower the activation energy barrier of a particular reaction allowing it to proceed more rapidly. Key concepts of enzyme kinetics are typically defined in terms of the initial rate of product formation, \( V_{max} \) and various catalytic kinetic parameters, such as \( V_{max} \), or \( K_{cat} \) and \( K_{m} \), which are either mathematically defined for enzymes that follow Michaelis-Menten kinetics or defined empirically for more complicated enzyme models.

### Society Sample Learning Objectives

- **Society Sample Learning Objectives**

<table>
<thead>
<tr>
<th>Society Sample Learning Objectives</th>
</tr>
</thead>
<tbody>
<tr>
<td>Compare and contrast biologically relevant forms of energy (e.g. kinetic energy versus potential energy, energy stored in bonds versus potential energy of concentration gradients).</td>
</tr>
<tr>
<td>Identify and explain instances when energy is converted from one form to another.</td>
</tr>
<tr>
<td>Write a general chemical reaction and the corresponding mathematical expression that approximates its equilibrium constant (( K_c )).</td>
</tr>
<tr>
<td>Explain the relationship between equilibrium constants and reaction rate constants.</td>
</tr>
<tr>
<td>Apply knowledge of basic chemical thermodynamics to biologically catalyzed systems.</td>
</tr>
<tr>
<td>Account for energy changes in the intermediate steps that define a biological process and predict the spontaneity of the overall process or an intermediate step.</td>
</tr>
<tr>
<td>Explain the properties of biomolecules with high-energy transfer potential that make them suitable as energy currency.</td>
</tr>
<tr>
<td>Identify the factors contributing to the activation energy of a reaction.</td>
</tr>
<tr>
<td>Explain transition state stabilization.</td>
</tr>
<tr>
<td>Calculate the rate enhancement of an enzyme-catalyzed reaction.</td>
</tr>
<tr>
<td>Explain what a substrate is in terms of an enzyme-catalyzed reaction.</td>
</tr>
<tr>
<td>Differentiate between the activation energy, the free energy and standard free energy of a reaction.</td>
</tr>
<tr>
<td>Use kinetic parameters to compare enzymes.</td>
</tr>
<tr>
<td>Distinguish the different forms of catalytic inhibition and explain how and why they differ.</td>
</tr>
</tbody>
</table>
### How is energy of chemical processes coupled in metabolic pathways?

Biochemical systems couple energetically unfavorable reactions with energetically favorable reactions. These reactions can be part of catabolic pathways where complex substances are broken into simpler ones with the release of energy or anabolic pathways where complex molecules are synthesized with an input of energy.

<table>
<thead>
<tr>
<th>Question</th>
<th>Answer</th>
</tr>
</thead>
<tbody>
<tr>
<td>Quantitatively model how catalyzed reactions occur and calculate kinetic parameters of enzymes from experimental data.</td>
<td>Explain how catalytic parameters vary as one varies substrate or enzyme concentration.</td>
</tr>
<tr>
<td>Interpret the physical meaning of various kinetic parameters and describe the underlying assumptions and conditions (such as steady state or equilibrium) on which different parameters depend.</td>
<td>Discuss the concept of Gibbs free energy and how to apply it to chemical transformations.</td>
</tr>
<tr>
<td>Explain how endergonic and exergonic pathways can be coupled and how this applies to metabolism.</td>
<td>Calculate the overall ΔG for a coupled reaction given the ΔG values for the component reactions.</td>
</tr>
<tr>
<td>Explain the simplifying assumptions made in biochemistry that are consistent with physiological conditions and make &quot;biochemical standard conditions&quot; (steady state) different from the standard conditions (equilibrium conditions) normally referred to in chemistry.</td>
<td>Explain the simplifying assumptions made in biochemistry that are consistent with physiological conditions and make &quot;biochemical standard conditions&quot; (steady state) different from the standard conditions (equilibrium conditions) normally referred to in chemistry.</td>
</tr>
<tr>
<td>Predict how perturbing a system affects the actual free energy (both mathematically and conceptually).</td>
<td>Explain evolutionary conservation of key metabolic pathways.</td>
</tr>
<tr>
<td>Explain differences in energy use and production in different cells and different biological systems.</td>
<td>Explain the role of gene duplication in the evolution of energy production and utilization by different organisms.</td>
</tr>
</tbody>
</table>

### Foundational Concept: Macromolecular Structure Determines Function and Regulation

<table>
<thead>
<tr>
<th>What factors contribute to the size and complexity of biological macromolecules?</th>
<th>Discuss the diversity and complexity of various biologically relevant macromolecules and macromolecular assemblies in terms of evolutionary fitness.</th>
</tr>
</thead>
<tbody>
<tr>
<td>Macromolecules are made up of basic molecular units. They include the proteins (polymers of amino acids), nucleic acids (polymers of nucleotides), carbohydrates (polymers of sugars) and lipids (with a variety of modular constituents). The biosynthesis and degradation of biological macromolecules involves linear polymerization, breakdown steps (proteins, nucleic acids and lipids) and may also involve branching/debranching (carbohydrates). These processes may involve multi-protein complexes (e.g. ribosome, proteasome) with complex regulation.</td>
<td>Discuss the basic units of the macromolecules and the types of linkages between them. Compare and contrast the processes involved in the biosynthesis of the major types of macromolecules (proteins, nucleic acids and carbohydrates). Compare and contrast the processes involved in the degradation of the major types of macromolecules (proteins, nucleic acids and carbohydrates). Understand that proteins are made up of domains and be able to discuss how the protein families arise from duplication of a primordial gene.</td>
</tr>
</tbody>
</table>

### What factors determine structure?

Covalent and non-covalent bonding govern the three dimensional structures of proteins and nucleic acids which impacts function. The amino acid sequences observed in nature are highly selected for biological function but do not necessarily adopt a unique folded structure. The structure (and hence function) of macromolecules is governed by foundational principles of chemistry such as: covalent bonds and polarity, bond rotations and vibrations, non-covalent interactions, the hydrophobic effect and dynamic aspects of molecular structure. The sequence (and hence structure and function) of proteins and nucleic acids can be altered by alternative splicing, mutation or chemical modification. Sequences (and hence structure and function) of macromolecules can evolve to create altered or new biological activities.

<p>| Recognize the repeating units in biological macromolecules and be able to discuss the structural impacts of the covalent and non-covalent interactions involved. | Discuss the composition, evolutionary change and hence structural diversity of the various types of biological macromolecules found in organisms. Discuss the chemical and physical relationships between composition and structure of macromolecules. Compare and contrast the primary, secondary, tertiary and quaternary structures of proteins and nucleic acids. Use various bioinformatics approaches to analyze macromolecular primary sequence and structure. Compare and contrast the effects of chemical modification of specific amino acids on a three dimensional structure of a protein. Compare and contrast the ways in which a particular macromolecule might take on new functions through evolutionary changes. Use various bioinformatics and computational approaches to compare primary sequences and identify the impact of conservation and/or evolutionary change on the structure. |</p>
<table>
<thead>
<tr>
<th>How are structure and function related?</th>
</tr>
</thead>
<tbody>
<tr>
<td>Macromolecules interact with other molecules using a variety of non-covalent interactions. The specificity and affinity of these interactions are critical to biological function. Some macromolecules catalyze chemical reactions or facilitate physical processes (e.g. molecular transport), allowing them to proceed in ambient conditions. These processes can be quantitatively described by rate laws and thermodynamic principles, (e.g. collision theory, transition state theory, rate laws and equilibria, the effects of temperature and structure and chemical reactivity, Coulomb’s Law, Newton’s laws of motion, energy and stability, friction, diffusion, thermodynamics, and the concept of randomness and probability).</td>
</tr>
<tr>
<td>Use mechanistic reasoning to explain how an enzyme or ribozyme catalyzes a particular reaction.</td>
</tr>
</tbody>
</table>

<table>
<thead>
<tr>
<th>What is the role of noncovalent intermolecular interactions?</th>
</tr>
</thead>
<tbody>
<tr>
<td>The interactions between macromolecules and other molecules rely on the same weak, noncovalent interactions that play the major role in stabilizing the three-dimensional structures of the macromolecules themselves. The hydrophobic effect, ionic interactions and hydrogen bonding interactions are prominent. The structural organization of interacting chemical groups in a binding site or an active site lends a high degree of specificity to these interactions. The specificity and affinity of these interactions are critical to biological function.</td>
</tr>
<tr>
<td>Discuss the impact of specificity or affinity changes on biological function and any potential evolutionary impact.</td>
</tr>
</tbody>
</table>

<table>
<thead>
<tr>
<th>How is macromolecular structure dynamic?</th>
</tr>
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<tbody>
<tr>
<td>Macromolecular structure is dynamic over a wide range of time scales, and the dynamic structural changes, large and small, are often critical for biological function. Small changes can come in the form of localized molecular vibrations that can facilitate the access of small molecules to interior portions of the macromolecule. Large conformational changes can come in the form of the motions of different macromolecular domains relative to each other to facilitate catalysis or other forms of work. Proteins can contain intrinsically unstructured domains. The lack of structure in solution may facilitate a function in which interactions must occur promiscuously with several other molecules. The dynamic structure of macromolecules enables rapid changes that impact the homeostasis of biochemical and molecular biological processes.</td>
</tr>
<tr>
<td>Discuss the time scales of various conformational effects in biological macromolecules and design appropriate experiments to investigate ligand induced changes in conformation and dynamics.</td>
</tr>
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</table>

<table>
<thead>
<tr>
<th>How is the biological activity of macromolecules regulated?</th>
</tr>
</thead>
<tbody>
<tr>
<td>The biological activity of macromolecules is often regulated in one or more of a variety of hierarchical ways (e.g. inhibitors, activators, modifiers, synthesis, degradation and compartmentalization).</td>
</tr>
<tr>
<td>Compare and contrast various mechanisms for regulating the function of a macromolecule or an enzymatic reaction or pathway.</td>
</tr>
</tbody>
</table>

| Predict the effects of mutations on the activity, structure or stability of a protein and design appropriate experiments to assess the effects of mutations. |

| Propose appropriate chemical or chemical biology approaches to explore the localization and interactions of biological macromolecules. |

| Discuss how mutations of a duplicated gene generate functional diversity. |

| Evaluate chemical and energetic contributions to the appropriate levels of structure of the macromolecule and predict the effects of specific alterations of structure on the dynamic properties of the molecule. |

| Calculate enzymatic rates and compare these rates back to cellular or organismal homeostasis. |

| Discuss various methods that can be used to determine affinity and stoichiometry of a ligand-macromolecule complex and relate the results to both thermodynamic and kinetic data. |

| Critically assess contributions to specificity in a ligand-macromolecule complex and design experiments to both assess contributions to specificity and test hypotheses about ligand specificity in a complex. |

| Discuss the basis for various types of enzyme mechanisms. |

| Predict the biological and chemical effects of either mutation or ligand structural change on the affinity of binding and design appropriate experiments to test their predictions. |

| Discuss the interactions between a variety of biological molecules (including proteins, nucleic acids, lipids, carbohydrates and small organics, etc.) and describe how these interactions impact specificity or affinity leading to changes in biological function. |

| Discuss the relationship between the temperature required for denaturation (T_{m}) and macromolecular structure. |

| Predict the effects of either mutation or ligand structural change on the affinity of binding and design appropriate experiments to test their predictions. |

| Critically discuss the evidence for and against the roles of dynamics in macromolecular function. |

<p>| Discuss potential roles for disordered regions of proteins. |</p>
<table>
<thead>
<tr>
<th>How is structure (and hence function) of macromolecules governed by foundational principles of chemistry and physics?</th>
<th>How are a variety of experimental and computational approaches used to observe and quantitatively measure the structure, dynamics and function of biological macromolecules?</th>
</tr>
</thead>
<tbody>
<tr>
<td>The structure (and hence function) of macromolecules is governed by the foundational principles of chemistry (including covalent bonds and polarity; bond rotations and vibrations; hydrogen bonds and non-covalent interactions; the hydrophobic effect; dynamic aspects of molecular structure; collision theory; transition state theory; rate laws and equilibria; the effects of temperature and structure and chemical reactivity) and physics (including Coulomb’s Law; Newton’s laws of motion; energy and stability; friction; diffusion; thermodynamics; and the concept of randomness and probability).</td>
<td>A variety of experimental and computational approaches can be used to observe and quantitatively measure the structure, dynamics and function of biological macromolecules. Equations can be derived from models and used to predict outcomes or analyze data. Data can be analyzed statistically to assess the correctness of the model and the reliability of the data.</td>
</tr>
<tr>
<td>Relate basic principles of rate laws and equilibria to reactions and interactions and calculate appropriate thermodynamic parameters for reactions and interactions. Explain how a ligand, when introduced to a solution containing a macromolecule to which it can bind, interacts with the macromolecule. Explain, using basic principles, the effects of temperature on an enzyme catalyzed reaction. Discuss the dynamic properties of a macromolecule using foundational principles of physics.</td>
<td>Propose a purification scheme for a particular molecule in a mixture given the biophysical properties of the various molecules in the mix. Either propose experiments that would determine the quaternary structure of a molecule or interpret data pertaining to tertiary and quaternary structure of molecules. Explain how computational approaches can be used to explore protein-ligand interactions and discuss how the results of such computations can be explored experimentally. Compare and contrast the computational approaches available to propose a three dimensional structure of a macromolecule and discuss how the proposed structure could be validated experimentally. Analyze kinetic or binding data to derive appropriate parameters and assess the validity of the model used to describe the phenomenon.</td>
</tr>
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</table>

**Foundational Concept: Information storage and flow are dynamic and interactive.**

**What is a genome?**

A genome is an organism’s complete set of DNA, including all of its genes. Each genome contains all of the information needed to build and maintain that organism. Some noncoding sequences enable our cells to produce different amounts of proteins at different times. For example, control sequences contain instructions to tell the cell how to switch genes on and off. Other noncoding sequences are part of genes but do not directly code for proteins. These are thought to help the cell generate a number of different proteins from one gene. More than half of the DNA in our genome is made up of repeated sequences, which appear to stabilize chromosomes; noncoding regions may have a role in spacing out the coding sequences so that they can be activated independently.

Define what a genome consists of and how the information in the various genes and other sequence classes within each genome is used to store and express genetic information.

Discuss how the genome is organized and packaged in prokaryotes and eukaryotes.

Discuss tools used to study expression, conservation and structure of an organism at the genome level.

Explain the role of repetitive and non-repetitive DNA and how its relative abundance varies from prokaryotes to eukaryotes.

**How does the nucleotide sequence of the gene lead to biological function?**

The information contained in the nucleotide sequence of a genome is organized into various elements, including coding regions, which contain three base codons coding for amino acids, which are transcribed to messenger RNA. The messenger RNA is translated to

Explain the role of repetitive and non-repetitive DNA and how its relative abundance varies from prokaryotes to eukaryotes.

Explain the process of gene regulation connecting how extracellular signals can result in a change of gene expression.

Discuss how genes are organized and contrast the different approaches used in prokaryotic and eukaryotic organisms.
<table>
<thead>
<tr>
<th><strong>How do genomes transmit information from one generation to the next?</strong></th>
<th>Explain how mRNA processing occurs and how splicing affects the diversity of gene products in eukaryotic organisms.</th>
</tr>
</thead>
<tbody>
<tr>
<td>The primary concern of cell division is the maintenance of the original cell’s genome. The genomic information that is stored in chromosomes must be replicated, and the duplicated genome must be separated cleanly between cells. Somatic cell lines are diploid (2n chromosome complement), and mitotic division normally results in two daughter cells, each with chromosomes and genes identical to those of the parent cell. Germ cells, called gametes, are haploid (having the haploid or the n chromosome complement) and reproduce by meiosis.</td>
<td>Explain the differences of mitosis and meiosis and relate them to the process of cellular division.</td>
</tr>
<tr>
<td>Illustrate how DNA is replicated and genes are transmitted from one generation to the next in multiple types of organisms including bacteria, eukaryotes, viruses and retroviruses.</td>
<td>Apply the concepts of segregation and independent assortment to traits inherited from parent to offspring and discuss how they increase genetic variation.</td>
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<tr>
<td>State how the cell ensures high fidelity DNA replication and identify instances where the cell employs mechanism for damage repair.</td>
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<tr>
<td>Explain what a mutation is at the molecular level, how it arises and how it could potentially affect the organism from gene expression to fitness.</td>
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<tr>
<td>Relate how the cell cycle and genome maintenance are coordinated and how disruptions in this coordination could affect the organism.</td>
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<tr>
<td>List events that result in genomic instability and explain how the cell responds to restore order and stability.</td>
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<tr>
<td>Construct relationships between chromosome and cellular structures (e.g. telomere, centromeres and centrosomes) and explain how these structures are responsible for and/or involved in genomic stability.</td>
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</table>

**Foundational Concept: Discovery requires objective measurement, quantitative analysis, and clear communication.**

| **What is the scientific process?** | Accurately prepare and use reagents and perform the required experiments. |
| The process of science combines creative ideas, experimentation, and data analysis. Scientists develop a hypothesis, design and conduct appropriate experiments. Experimental results are analyzed and data interpreted using appropriate quantitative modeling and simulation tools. | When presented with an observation, develop a testable and falsifiable hypothesis. |
| When provided with a hypothesis, identify the appropriate experimental observations and controllable variables. Determine averages and standard deviations to relate the significance of experimentally obtained data. Use equations and models to predict outcomes of experiments. Use appropriate equations to analyze experimental data and obtain parameters. | |

<p>| <strong>What skills are needed to access, comprehend and communicate science?</strong> | Identify, locate and use the primary literature. |
| Scientists access, assess and use available information and present data in an appropriate context in a variety of ways at different levels. | Use databases and bioinformatics tools. |
| When provided with appropriate background information, identify consistencies and inconsistencies. Explain the big picture aspects of current challenges in the molecular life sciences. Use visual and verbal tools to explain concepts and data. Translate science into everyday examples. | |
| Explain the importance of and keep an accurate laboratory notebook. Given a case study, identify both scientific and societal ethical aspects. Explain cross-disciplinary concepts such as modularity, energy, modeling scientific phenomena, change over time and the differences between stochastic and deterministic phenomena. Access and interpret safety information and conduct lab work. | |</p>
<table>
<thead>
<tr>
<th>Underlying Concept: Evolution</th>
<th>safely and ethically. Give and take directions to be an effective team member.</th>
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</table>
| **What is the significance of evolution?**  
Evolution is genetic change within a population over time. Understanding evolutionary processes and the supporting evidence is an integral part of the molecular life sciences. It explains many present day issues, such as crop availability and pesticide resistance in agriculture, vaccine and drug development in medicine and regulatory mechanisms in cellular, developmental and behavioral biology. | Describe evolution as genetic change in a population over time.  
Analyze preexisting and novel data and relate the findings in light of evolution.  
Relate evolution to concepts in biochemistry and molecular biology. |
| **What are the mechanisms of evolution?**  
Many mechanisms may drive evolution. These include mutation, migration (gene flow), genetic drift (change from generation to generation) and natural selection. | Explain how mechanisms of evolution cause variation within a population.  
Distinguish between random and nonrandom evolutionary processes.  
Demonstrate their understanding of the mechanisms of evolution to relevant issues, such as antibiotic resistance, the occurrence of genetic disorders or cancer therapeutics. |
| **How is natural selection a key evolutionary mechanism?**  
Evolution by natural selection results from differential reproductive success, where individuals with certain heritable traits are more successful. The fitness of an individual and its genotype is directly determined by its relative reproductive success. The fittest individuals will pass their genes to more offspring, driving the evolution of the population. In this way, the population becomes better-suited (adapted) to its environment. Multiple lines of evidence support evolution by natural selection, including the fossil record, homologies and direct observation in laboratory and field studies. | Describe the process of natural selection.  
Distinguish between individual fitness and adaptation of populations.  
Explain how selection of phenotypes affects genotype transmission.  
Synthesize and evaluate supporting evidence for the theory of natural selection. |
| **What is the molecular basis of evolution?**  
Organismal traits are determined at the genetic and epigenetic level. Molecular modifications at these levels may determine the RNA and protein expression patterns in a cell, influencing the phenotype of the organism. Genetic modifications can also arise from the acquisition of new genetic material via processes such as horizontal gene transfer, endosymbiosis and viral vector transfer. Transmission of these heritable alterations may lead to changes in the genetic composition of a population, thereby driving evolution. | Explain how cells can acquire new genetic material.  
Explain how mutations and epigenetic changes influence gene expression, structure and function of gene products and the fitness of an organism.  
Using genetic information, categorize organisms and establish phylogenetic relationships. |

<table>
<thead>
<tr>
<th>Underlying Concept: Homeostasis</th>
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</table>
| **What is the biological need for homeostasis?**  
Biological homeostasis is the ability to maintain relative stability and function as changes occur in the internal or external environment. Organisms are viable under a relatively narrow set of conditions. As such, there is a need to tightly regulate the concentrations of metabolites and small molecules at the cellular level to ensure survival. To optimize resource use and to maintain conditions, the organism may sacrifice efficiency for robustness. Breakdown of homeostatic regulation can contribute to the cause or progression of disease or lead to cell death. | Describe why maintenance of homeostasis is advantageous to an organism.  
Define homeostasis in a biochemical context to both scientifically trained and lay audiences.  
Describe how homeostatic pathways and mechanisms have been conserved throughout evolution  
Appraise the costs and benefits of different homeostatic mechanisms to an organism.  
Relate different environmental factors necessitating homeostasis to a specific adaptation. |
| **How are steady state processes and homeostasis linked?**  
A system that is in a steady state remains constant over time, but that constant state requires continual work. A system in a steady state has a higher level of energy than its surroundings. Biochemical systems maintain homeostasis via regulation of gene expression, metabolic flux and energy transformation but are never at equilibrium. | Explain that a system at chemical equilibrium (or just equilibrium) is stable over time, but no energy or work is required to maintain that condition.  
Apply the principles of kinetics to describe flux through biochemical pathways.  
Discuss a metabolic pathway in terms of equilibrium and Le Chatelier’s principle.  
Relate the laws of thermodynamics to homeostasis and explain how the cell or organism maintains homeostasis.  
Model how perturbations to the steady state can result in changes to the homeostatic state.  
Propose how resources stored in the homeostatic state can be utilized in times of need. |
<p>| <strong>How is homeostasis quantified?</strong> | Describe experiments discussing how signaling and |</p>
<table>
<thead>
<tr>
<th>How is homeostasis controlled?</th>
<th>How do cells and organisms maintain homeostasis?</th>
</tr>
</thead>
<tbody>
<tr>
<td><strong>Homeostasis</strong> is maintained by a series of control mechanisms functioning at the organ, tissue or cellular level. These control mechanisms include substrate supply, activation or inhibition of individual enzymes and receptors, synthesis and degradation of enzymes, and compartmentalization. The primary components responsible for the maintenance of homeostasis can be categorized as stimulus, receptor, control center, effector and feedback mechanism.</td>
<td><strong>Homeostasis</strong> in an organism or colony of single celled organisms is regulated by secreted proteins and small molecules often functioning as signals. Homeostasis in the cell is maintained by regulation and by the exchange of materials and energy with its surroundings.</td>
</tr>
<tr>
<td>Discuss how chemical processes are compartmentalized in the organism, organ and the cell.</td>
<td>Describe how the cell and organism store resources (both in terms of stored energy and chemical building blocks) for times of need and how they mobilize these resources.</td>
</tr>
<tr>
<td>Explain why biochemical pathways proceed through the intermediates that they do (gradual oxidation or reduction) and why pathways share intermediates.</td>
<td>Integrate homeostasis from the cellular to the organismal level. In other words, students should be able to describe how a complex metazoan can have both a cellular and organismal response to maintain homeostasis.</td>
</tr>
<tr>
<td>Summarize the different levels of control (including reaction compartmentalization, gene expression, covalent modification of key enzymes, allosteric regulation of key enzymes, substrate availability and proteolytic cleavage) and relate these different levels of control to homeostasis.</td>
<td>Compare and contrast homeostasis in different organisms.</td>
</tr>
<tr>
<td>Compare the temporal aspect of different control mechanisms (e.g. how quickly phosphorylation occurs versus changes in gene expression).</td>
<td>Describe homeostasis at the level of the cell, organism or system of organisms and hypothesize how the system would react to deviations from homeostasis.</td>
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</tbody>
</table>
BIOC 321: Elements of Biochemistry Syllabus  
Spring 2019

Instructor:  Dr. Jing Zhang  
jzhang24@unl.edu  
N106 Beadle  
Office Hour: Please email to schedule a meeting time


Lectures:  Tue\textsuperscript{1} & Thu 9:30 to 10:45 am. Rm. E103 Beadle Center

Prerequisite:  A BIOS or LIFE course and Chem 251 or 255

Note that the laboratory for Biochemistry 321 is a separate one-credit course. This laboratory (BIOC 321L) is optional and not required for credit in BIOC 321.

Course Objectives:
Upon completion of this course, a successful student will be able to:

- recognize the structures of a defined set of important biochemical molecules. This will include the following:

<table>
<thead>
<tr>
<th>Molecules</th>
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<tbody>
<tr>
<td><strong>Amino Acids:</strong> all 20 common amino acids</td>
</tr>
<tr>
<td><strong>Lipids:</strong> Selected saturated &amp; unsaturated fatty acids, triacylglycerol, Phosphatidyl-choline, -ethanolamine, -serine and -glycerol, Phosphatidic acid</td>
</tr>
<tr>
<td><strong>Carbohydrates:</strong> monosaccharides (D-glucose, D-mannose, D-galactose, D-ribose, D-fructose) &amp; disaccharides (maltose, lactose, sucrose)</td>
</tr>
<tr>
<td><strong>Nucleic acids:</strong> Nucleotides and nucleoside forms of ribo- and deoxyribo- nitrogen bases</td>
</tr>
<tr>
<td><strong>Metabolites:</strong> Intermediates in Glycolysis &amp; in citric acid cycle (TCA)</td>
</tr>
</tbody>
</table>

- Apply the principles of thermodynamics to compare different forms of biological energy
- Explain the mechanisms on how enzymes catalyze biological reactions, and interpret the kinetic parameters including Vmax, Km, and Kcat

\textsuperscript{1} For most Tuesdays, there will be an online, rather than in-class lecture.
• Discuss how structure determines function and regulation of the macromolecules
• Compare and contrast the processes involved in the biosynthesis and degradation of the macromolecules
• Explain how genetic information is stored, transmitted, and maintained from one generation to the next in prokaryotes and eukaryotes
• Explain the role of evolution and homeostasis in the structure and function of biological molecules and organisms
• Relate biochemistry to everyday examples and apply biochemical principles to explain phenomena in different context

Activities:

This course will be delivered in a blended format. After the initial week, most Tuesday lectures will be online. It is expected that students will read the appropriate sections of the text prior to viewing the online lectures, and answer an online essay question that will be graded. Thursday lectures will be in-class, and students must read the text and answer an online essay question that will be graded as well. Clicker questions will be used to practice foundational concepts during in-class lectures.

Homework assignments are given for every lecture selected from the end-of-chapter problems of the text. The goal is to help you understand the material and prepare for the exams. You can find the keys at the end of the book so they are not going to be graded.

Each of the lectures will have PowerPoint slides available, but we also suggest that you outline the material to make sure you understand which topics are really important, and compile a list of key vocabulary terms. We also strongly encourage you to form study groups of five to eight students who can meet weekly. Students in study groups learn the material at a deeper level than students who study alone and usually score better on exams.

Typical Weekly Activities (except surrounding exams):

• Read book chapters and view online lecture
• Tuesday: Listen to online lecture
• Friday Midnight: Deadline for submitting Essay(s) related to Tuesday online lecture (3 pts)
• Thursday 9:30am: Attend in-class lecture
• Sunday Midnight: Deadline for submitting Essay(s) related to Thursday lecture (3 pts)
• Homework: practice on assigned end-of-chapter problems (not graded)

The weekly essays will be worth 3 points each, a total of 63 points. In-class Clicker questions will have 1 point (as bonus point) for participation per class, a total of 11 bonus points. In addition, there are 2 in-class worksheets worth a total of 7 points.

Examination Format:
There will be a total of Four (including the FINAL) examinations. Each Exam is worth 40 points. These examinations will contain:

- 15 multiple choice questions (1 point each = 15 points)
- 5 short answer questions (3 points each = 15 points)
- 2 essay questions (5 points each = 10 points)

There will be a review session during the lecture prior to each exam. The Final Exam is not comprehensive, but mandatory. Only pencils, pens, and erasers are allowed to be taken to the examination seats. Personal items such as backpacks, coats, cell phones (turned off) and books should be placed on the floor at the sides of the room. Calculators will not be required.

**Grading:**

*Graduating seniors are not excused from the Final Examination or any of the other course requirements.*

The grading is based on the 230 points from the weekly essays (Total 63 pts) plus the four exams (Total 160 pts). Two in-class worksheets are worth 7 points in total. Clickers give you another 11 bonus points. If one of the questions on an examination is determined to be defective, all students will receive credit for that question. **NO curving on the Final Grade.**

<table>
<thead>
<tr>
<th>Item</th>
<th>Points (out of 230 total)</th>
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<tbody>
<tr>
<td>Weekly Essays 21 x 3pts</td>
<td>63</td>
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<tr>
<td>4 Exams</td>
<td>160</td>
</tr>
<tr>
<td>2 In-class Worksheets</td>
<td>7</td>
</tr>
<tr>
<td>Clicker Questions</td>
<td>11 (Bonus Points)</td>
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<tr>
<th>Percent %</th>
<th>Total Points</th>
<th>Final Grade</th>
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<tbody>
<tr>
<td>90</td>
<td>207-230</td>
<td>A</td>
</tr>
<tr>
<td>86</td>
<td>197-206</td>
<td>A-</td>
</tr>
<tr>
<td>82</td>
<td>188-196</td>
<td>B+</td>
</tr>
<tr>
<td>78</td>
<td>179-187</td>
<td>B</td>
</tr>
<tr>
<td>74</td>
<td>170-178</td>
<td>B-</td>
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<tr>
<td>70</td>
<td>161-169</td>
<td>C+</td>
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<td>66</td>
<td>151-160</td>
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<td>62</td>
<td>142-150</td>
<td>C-</td>
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<td>58</td>
<td>133-141</td>
<td>D+</td>
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<td>54</td>
<td>124-132</td>
<td>D</td>
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<tr>
<td>50</td>
<td>115-123</td>
<td>D-</td>
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<tr>
<td>&lt; 50</td>
<td>&lt; 115</td>
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Policy on Missed Examinations:

If a student fails to take a scheduled examination and is able to provide a valid excuse with supporting documentation, the instructor will provide an accommodation. We expect to be notified of any issue prior to the start of an exam.

Valid excuses for not taking an examination include the following:

- Illness, documented by a signed statement from a physician in the University Health Service or in private practice.
- A request from another University professor to excuse a student because of a conflict with the student's participation in other University courses or officially sponsored activities.
- Extenuating circumstances, such as death or serious illness of a member of the student's immediate family. Documentation may be required. Weddings, vacations, and quasi-University functions are not extenuating circumstances.

OTHER COURSE POLICIES AND INFORMATION

Academic Dishonesty: Academic dishonesty is not tolerated by Department of Biochemistry faculty and should not be tolerated by biochemistry students. While there are obviously different degrees of dishonest behavior, they are all an indication that a student should probably not pursue a professional career.

- Department of Biochemistry Policy: Students are expected to adhere to guidelines concerning academic dishonesty outlined in Article III.B of the University’s Student Code of Conduct http://stuafs.unl.edu/ja/code/. Students are encouraged to contact the instructor for clarification of these guidelines, if they have questions or concerns. The policy, including the procedure in place for alleged violation of the policy, can be found at the Department of Biochemistry website http://biochem.unl.edu

- Considerations for Students:
  - Falsification of research data or its deliberate misinterpretation is a serious offense.
  - Cheating on an examination or assignment is an obvious form of academic dishonesty.
  - Plagiarism\(^2\) is more complex and may be the result of sloppiness, rather than an intentional attempt to deceive. Anything that you present (thesis, examination, lab or book report, etc.) that is under your name should be entirely your own work unless so indicated and appropriately cited. This includes ideas as well as specific quotations, artwork and figures.
  - For lab reports, it may be appropriate to work with fellow students on data analysis and presentation, but each student should provide independent presentation of results and discussion.

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\(^2\) Plagiarize: to steal and pass on (the ideas or words of another) as one's own; use (a created production) without crediting the source; to commit literary theft; present as new and original an idea or product derived from an existing source.

For papers, it may be acceptable to discuss with faculty and other students about the scope of the project, but the research and the narrative are expected to be your original work. When you turn in something with your name on it, the reader assumes that this is your original work unless indicated otherwise.

IF YOU ARE CAUGHT CHEATING ON AN EXAMINATION, YOU WILL RECEIVE AN F GRADE FOR THE COURSE. UNL’S POLICIES CONCERNING GRADE APPEALS WILL BE FOLLOWED.

Diversity: The University of Nebraska–Lincoln does not discriminate based on gender, age, disability, race, color, religion, marital status, veteran’s status, national or ethnic origin, or sexual orientation.

Emergency Response:
- **Fire Alarm (or other evacuation):** In the event of a fire alarm: Gather belongings (Purse, keys, cellphone, N-Card, etc.) and use the nearest exit to leave the building. Do not use the elevators. After exiting notify emergency personnel of the location of persons unable to exit the building. Do not return to building unless told to do so by emergency personnel.
- **Tornado Warning:** When sirens sound, move to the lowest interior area of building or designated shelter. Stay away from windows and stay near an inside wall when possible.
- **Active Shooter**
  - **Evacuate:** if there is a safe escape path, leave belongings behind, keep hands visible and follow police officer instructions.
  - **Hide out:** If evacuation is impossible secure yourself in your space by turning out lights, closing blinds and barricading doors if possible.
  - **Take action:** As a last resort, and only when your life is in imminent danger, attempt to disrupt and/or incapacitate the active shooter.
- **UNL Alert:** Notifications about serious incidents on campus are sent via text message, email, unl.edu website, and social media. For more information go to: http://unlalert.unl.edu.
- **Additional** Emergency Procedures can be found here: http://emergency.unl.edu/doc/Emergency_Procedures_Quicklist.pdf

Special Needs:
Students with disabilities are encouraged to contact the instructor for a confidential discussion of their individual needs for academic accommodation. It is the policy of the University of Nebraska-Lincoln to provide flexible and individualized accommodation to students with documented disabilities that may affect their ability to fully participate in course activities or to meet course requirements. To receive accommodation services, students must be registered with the Services for Students with Disabilities (SSD) office, 132 Canfield Administration, 472-3787 voice or TTY.

Secrets to Success:
- Biochemistry is cumulative; study every week. It takes the instructor approximately three hours to prepare a one-hour lecture. You must make a commitment to budget an appropriate amount of time for this course. Peruse the chapters before the appropriate lectures and then read them again following the lectures.
• Treat biochemistry as a foreign language (it is!); study vocabulary and practice using it in sentences. If you can't use the proper vocabulary, you haven't really learned the material.
• **Form a study group and work with others.** You need to verbalize biochemical concepts to really master them. The most effective study groups involve students with different majors. Find a group of students with schedules such that they can meet every week.
• If you don't understand something, ask questions. Send questions to the instructor using the Discussion Board so that they can be answered for everyone. The instructors will give students as much help as they require. If you need help, drop in or make an appointment.

**Biochemistry 321 Learning Outcomes:**

1. Explain the relationship between Gibbs free energy change (ΔG) and chemical equilibrium (K\(^\text{eq}\)) and how enzymes make chemical reactions happen rapidly enough to sustain life.
2. Define anabolism and catabolism in general terms and identify common metabolites used by both.
3. Write out the general structure of amino acids and short polypeptides.
4. Define the four different levels of protein structure.
5. Discuss how the different levels of protein structure provide different biochemical and physiological functions for myoglobin and hemoglobin.
6. Outline the Michaelis-Menten model for enzyme kinetics and how the same data can be analyzed by Lineweaver-Burk plots to analyze inhibition.
7. Demonstrate knowledge of non-polar and polar lipids and how the latter contribute to the structure of biological membranes.
8. Describe how membrane proteins have different structures from soluble proteins and how they contribute to solute transport across membranes.
9. Explain how membrane transport systems are involved in digestive processes like acidification of the stomach and absorption of glucose from the blood.
10. Draw the structures of the common mono- and disaccharides.
11. Describe the entry of glucose into either anabolism or catabolism in the cell.
12. Explain the importance of electrons and redox in the coupling of catabolism and anabolism.
13. Review the enzymes and intermediates in glycolysis.
14. Differentiate between anaerobic and aerobic glycolysis.
15. Review the enzymes and intermediates in the citric acid cycle.
16. Outline oxidative phosphorylation and describe how oxidative energy is converted into ATP.
17. Compare and contrast the regulatory mechanisms of glycolysis and gluconeogenesis.
18. Describe the basic ways in which enzyme activity can be modulated in the cell.
19. Provide an overview of photosynthesis, including explaining the role of water in the process and movement of “fixed CO\(_2\)” into mainstream metabolism.
20. Define the structures of nucleotides and deoxyribonucleotides and draw the basic structure of a polynucleotide.
21. Describe the basic structure of B-form DNA and explain why base pairing is the basis for the genetic code.
22. Explain the meaning of ‘semiconservative replication’ in the context of DNA and the basics of DNA replication.
23. Explain how RNA is synthesized.
24. Describe the role of the *lac* operon in the life of *E. coli*.
25. Describe the mechanism of gene transcription in eukaryotes, showing how the production of the final mRNA differs from that which occurs in prokaryotes.
26. Describe the mechanisms of protein synthesis in prokaryotes.
APPENDIX III: GRADING RUBRICS FOR ESSAY AND SHORT ANSWER QUESTIONS

Example Short Answer Question with rubric & explanation of rubric points

Short Answer Question: What is the role of hydrophilic amino acid residues in the formation and stability of tertiary structure of globular proteins?
1. They tend to be positioned on the outside of tertiary structure and increase solubility.
2. They can interact with other hydrophilic amino acids to cause electrostatic attraction or hydrogen bonding.
3. These contacts and their attraction stabilize the tertiary structure.

Explanation
- This answer has 3 aspects to the rubric (or 2 if #2 & #3 are combined into one).
- Major scoring is pretty objective (± 0.1); subtle scoring is subjective (± 0.05).
- The major scoring deviations can change as the number of aspects change. Example: 2 vs 3 vs 4 aspects, so the rubric will need to have different cut-offs.

<table>
<thead>
<tr>
<th>Percent Score</th>
<th>Range</th>
<th>Rubric</th>
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| 1.0           | Excellent   | • Shows a thorough understanding of the question - Addresses all aspects of the question  
                 • Shows an ability to analyze, evaluate, compare, and/or contrast  
                 • Supports essay with relevant facts, examples, and details  
                 • Writes a well-developed answer. Consistently demonstrating a logical and clear organization |
| 0.9           | Very Good   | • All aspects correct, small error(s) in explanation/examples  
                 • Shows a clear understanding of the question - Addresses most aspects  
                 • Shows some ability to analyze, evaluate, compare, and/or contrast  
                 • Includes relevant facts, examples, and details, but *may not support all aspects of the question evenly*  
                 • Writes a well-developed answer, consistently demonstrating a logical and clear plan of organization |
| 0.8           | Good        | • One aspect is incorrect & most of explanation/examples are correct  
                 • Presents a general understanding of the question  
                 • Addresses most aspects of the question or all aspects *in a limited way*  
                 • Uses vague and/or inaccurate information to address the question |
| 0.7           | Average     | • 50% on aspects correct & partial correct explanations/examples  
                 • Has vague or missing information  
                 • Lacks analysis or evaluation beyond stating vague and/or inaccurate facts  
                 • Uses little or no accurate or relevant facts, details, or examples  
                 • Does show some knowledge of biochemistry |
| 0.6           | Weak        | One aspect is correct AND explanations/examples are incorrect |
| 0.5           | Poor        | Relevant information to content, but all aspects & explanations are incorrect |
| 0.2-0.4       | Jibber-Jabber | Answer makes little sense & nothing is applicable |
| 0             | No Answer   | No answer provided |
APPENDIX IV: EXAMPLE OF EXAMS

**Essay Questions**
Each question is worth 5 points and answer should be approximately 1 to 2 paragraphs. Use the relevant biochemical vocabulary to provide an answer.

**Essay 1:**
The first enzyme in the Calvin cycle is the most abundant biological catalyst on earth.

a. What is the name of this enzyme?
b. What reaction(s) does it catalyze?
c. What reaction in photosynthesis would the enzyme ribulose-5-phosphate kinase (or phosphoribulokinase) be used?

**Essay 2:**
The structure shown in the image below represents components found in the DNA replication fork.

(a) Identify the two structures labeled as 1 and 2.
(b) What role does each of these components play in DNA replication?
(c) Account for differences that lead to different processes/structures found on the two newly formed DNA double helices.
Short Answer Questions
Each question is worth 3 points and should be answered with two or three sentences.

SA1: Describe the two-step biological process of nitrification.

SA2: (a) Explain what complementary base pairing is.
(b) A DNA double helix was sequenced and found to contain 12% cytosine. Calculate the percentage of each of the other bases in the double helix.

SA3: Transcription produces an mRNA transcript by copying a coding segment of DNA. The image shows three different strands.
(a) Identify which strand is the mRNA transcript, which is the template strand and which one is the coding strand.
(b) Explain the differences between template and coding strands.
SA4:  a) Is tyrosine an essential amino acid if the diet contains phenylalanine?  
b) Would tyrosine be an essential amino acid in a patient with a phenylalanine hydroxylase deficiency?  
Explain your answers.

SA5:  (a) Identify the molecule in the image.  
(b) Describe the reaction that synthesizes this molecule from its constituent components. Be sure to specify the enzyme that catalyzes the reaction.
Multiple Choice Questions

MC1: Which of the following statements about the mechanism of the Calvin Cycle is correct?
   a) The Calvin cycle enzymes are more reactive if there is a decrease in light intensity
   b) In the Calvin cycle rubisco adds CO$_2$ to ribose-5-phosphate
   c) The Calvin cycle is a metabolic pathway by which plants convert CO$_2$ and water into carbohydrates
   d) In the Calvin cycle rubisco adds CO$_2$ to 3-phosphoglycerate

MC2: Which of the following statements about photosynthesis is correct?
   a) Carbohydrates are the source of electrons in photosynthesis.
   b) CO$_2$ is the source of electrons in photosynthesis.
   c) Water is the source of electrons in photosynthesis.
   d) NADH is the source of electrons in photosynthesis.

MC3: Which pair of components from oxidative phosphorylation and photophosphorylation seems to have similar functions and locations with respect to the membrane?
   a) Complex I and Photosystem I
   b) Complex II and Photosystem II
   c) Ubiquinone and ferredoxin
   d) Cytochrome c and plastocyanin
   e) NADH and water

MC4: Which of the following enzymes is involved in nitrogen fixation?
   a) Nitrogenase
   b) Nitrite reductase
   c) Nitrate reductase
   d) Urease
   e) Glutamate dehydrogenase

MC5: Which of the following statements is correct, according to Chargaff’s rules?
   a) All DNA molecules contain the same proportions of A, C, G and T.
   b) Single-stranded RNA molecules contain the same amount of A and U.
   c) In double-stranded DNA, the amount of T equals the amount of C.
   d) In double-stranded DNA, the amount of G equals the amount of C.
   e) In double-stranded DNA, the amount of A equals the amount of C.
MC6: Identify the names of the following structures in the order they appear in the image:

(a)  
- Thymine, Uracil, Cytosine

(b)  
- Uracil, Cytodine, Thymine

(c)  
- Cytosine, Thymine, Uracil

(d)  
- Uracil, Thymine, Cytosine

(e)  
- Cytosine, Uracil, Thymine

MC7: A histone gene is mutated such that a positively charged amino acid is substituted with a negatively charged one. What is the most likely result?

a) Binding of histone to DNA is not affected.

b) Histone will bind DNA less well.

c) Histone will bind DNA better.

d) Gene expression will be inhibited.

MC8: The replication forks at an origin of replication in prokaryotes move:

a) In the same direction.

b) In opposite directions.

c) Toward the origin.

d) In the 5’ to 3’ direction.

e) In the 3’ to 5’ direction.

MC9: Nucleotides are linked by:

a) ionic bonds.

b) phosphoanhydride bonds.

c) phosphodiester bonds.

d) peptide bonds.

e) hydrogen bonds.

MC10: What type of enzyme removes damaged DNA segment?

a) Nuclease.

b) Primase.

c) Polymerase.

d) Helicase.
MC11: A biochemist isolated a gene from a eukaryotic cell and the corresponding mRNA for research. Upon comparison, the mRNA is found to contain 589 fewer bases than the DNA sequence. Which statement is correct?
   a) The mRNA is made from a DNA template and should be the same length as the gene sequence.
   b) The mRNA contains only exons; the introns were removed.
   c) The mRNA should contain more bases than the DNA sequence because bases flanking the gene are also transcribed.
   d) There is not enough evidence for deducing a conclusion.

MC12: A DNA strand with the sequence 5'-ACGTATCCGA-3' is transcribed. What is the sequence of the resulting mRNA molecule?
   a) 5'-TGCATGGCU-3'
   b) 5'-UGCAUGGCU-3'
   c) 5'-ACGUAUCCGU-3'
   d) 5'-ACGTATCCGA-3'
   e) 5'-UGCATGGCU-3'

MC13: What is the significance of the figure?
   a) It shows the anti-codon region of mRNA.
   b) It shows one of the two mechanisms for transcription termination.
   c) It shows the Shine-Dalgarno sequence on mRNA.
   d) It shows stem-loop structure used to initiate translation.
   e) It shows the binding site for the ribosomes.

MC14: Which of the following mRNA sequences might cause binding of an fMet-tRNA?
   a) 5'-ATCAUCGCGA-3'
   b) 5'-CGAAUCCGCU-3'
   c) 5'-AACCGUUACG-3'
   d) 5'-UUACGAUGCC-3'
   e) 5'-CCGUAAGCUA-3'

MC15: The codon is found _____ while the anticodon is found _____.
   a) on the proteins of the ribosome; in the mRNA
   b) in the mRNA; on the RNA of the ribosome
   c) on the tRNA; on the RNA of the ribosome
   d) on the tRNA; in the mRNA
   e) in the mRNA; on the tRNA