

# Supplemental Material

*CBE—Life Sciences Education*

Loertscher *et al.*

## Focus Group Interviews April 2013

### Receptor Binding

Students will be given the figure below to look at (removed for publication). Questions will be asked orally; students will not receive the list of questions to read.

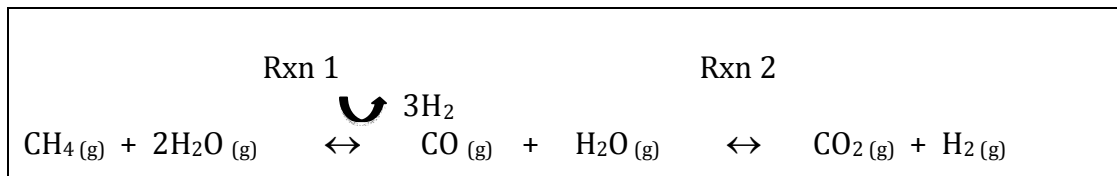
1. Describe the scenario depicted in the figure in your own words.
2. What happens once the steroid is bound to the receptor? Wait for student responses then ask: Are there possibilities that are not shown in the picture?
3. Once the hormone-receptor complex is formed, will it make its way into the nucleus intact?
4. Once the hormone-receptor complex is in the nucleus, will it bind the chromatin? Wait for student responses then ask: If it binds the chromatin, where will it bind?
5. In drawings of cellular events, some aspects are well represented and others are not. What are some of the shortcomings of this picture? In what ways does it differ from reality?
  - a. Ask about equilibrium arrows if students don't bring this up.
  - b. Ask about amounts of steroid hormone and steroid receptor if students don't bring this up.
6. What determines whether the steroid hormone binds to the steroid receptor?

## **Multiple Equilibria**

Students will be given the following prompt and chemical reactions. They will not be given the questions to read.

1. If the goal is to maximize  $\text{H}_2$  production with a continuous supply of water and methane
  - a. What will happen if  $\text{H}_2$  is removed?
  - b. What will happen if  $\text{CO}_2$  is removed?
  - c. Are the reactions at equilibrium?
2. What will happen to the system at equilibrium if  $\text{CH}_4$  is removed? Prompt students to discuss all reagents in the system (especially  $\text{CO}_2$ ) if they don't bring it up.
3. Assume the system is at equilibrium. What will happen if:
  - a. step 1 is blocked
  - b. step 2 is blocked
4. How many  $\text{CH}_4$  and  $\text{H}_2\text{O}$  molecules are depicted in the reaction above? Is that the amount in the reaction vessel?

The industrial process for the production of hydrogen is shown below. It uses fossil fuels, methane and steam to generate hydrogen.



**Transforming Undergraduate Biochemistry Education NSF-DUE-1224868**  
**Interview Protocol for Institution 1**  
**Fall Semester 2013**

Interviews will be conducted in a focus group format with 4-8 students per group and will be recorded. Each interview will last one hour with two different focus group interviews scheduled for October 1, 2013. Interviews will investigate student understanding of a total of four concepts related to biochemistry. Each focus group session will investigate two of these concepts. Investigation of student understanding of these concepts will be probed using a semi-structured approach. Questions provided below for each concept will guide the flow of the discussion, but additional clarifying questions may be used based on student responses. Student may be provided an image to look at, but will not be provided interview questions (questions will be asked orally). In addition to questions pertaining to biochemical concepts, student will be asked their major and year in school (junior, senior, etc). Interviews will be conducted primarily by Dr. Jennifer Loertscher and Dr. David Green of Seattle University.

Focus Group A: Concepts 1 and 4 (visual)

Focus Group B: Concepts 2 (visual) and 3

## CONCEPT 1: EQUILIBRIUM

1. What comes to mind when you hear the term equilibrium?
2. Are reactions in biochemistry reversible? How do you know?
  - a. What do you mean by reversible?
  - b. If yes, why?
  - c. If no, why not?
  - d. What do you think about reversibility for a reaction with a  $K_{eq} = 1$  versus a  $K_{eq} = 10^{10}$ ?
3. What effect do enzymes have on reactions?
  - a. What is their effect?
  - b. How do enzymes relate to reversibility?
4. Are reactions in the body at equilibrium?
  - a. If no, why
  - b. If yes, explain what you mean. What are the necessary criteria for equilibrium? How do these constraints relate to cellular conditions (intended to probe understanding of steady state)?
5. How do cells/organisms differ from a reaction in a flask with regard to equilibrium?
6. Is understanding equilibrium and applying it to biochemistry difficult? If so, how or why?

Ask only if time:

7. Organisms maintain glucose at near constant levels. How do you think that happens?

## CONCEPT 2: INDIVIDUAL VERSUS POPULATIONS OF MOLECULES

1. Imagine you have a protein called X that can bind to two different small molecules A and B.
  - a. What do protein X, A and B look like in the cell? Can you sketch a picture of what you imagine?
  - a. How many copies of each are there in the cell?
  - b. What configurations are possible for these three to associate with each other in the cell?
  - c. Are A and B always bound to protein X?
  - d. If A and B are bound to one molecule of protein X in the cell, what is true about other copies of protein X in the cell?
  - e. Biochemists often ask questions like “How much A is bound to protein X”. What do they mean? Do they mean that more than one molecule of A is bound to a single molecule of protein X?
  - f. What determines how many molecules of protein X within a cell are bound to A and/or B?
2. ***If previous question goes quickly, ask this. If not, move on the next question:*** When biochemists say that oxygen binds hemoglobin, what do they mean? What is the reality in the cell?
3. Consider the following questions:
  - a. Give an example of when you have focused on an individual molecule in biochemistry class.
  - b. Give an example of when you have focused on populations of molecules in biochemistry class.
  - c. Expert biochemists think that considering both individual and populations of molecules is important for understanding biochemistry. What comes to mind when you think of individual versus populations of molecules in biochemistry?
4. Is understanding the distinction between individual and populations of molecules and applying these ideas to biochemistry difficult? If so, how or why?

### CONCEPT 3: INTER AND INTRAMOLECULAR INTERACTIONS - CONCEPTUAL

1. What comes to mind when we mention intermolecular interactions? **Use the term *intermolecular forces* if they don't recognize "interactions"**.
2. For the ones you mentioned, can you describe the chemistry of the interactions occurring?
3. What are situations or examples in biological systems in which these interactions take place? Is it possible for these interactions to take place within one molecule?
4. Does equilibrium play a role in these interactions? If so how and give an example, if not why not?
5. Is understanding intermolecular interactions and applying them to biochemistry difficult? If so, how or why?

Ask these only if time:

6. Are you familiar with biological regulation? If so can you give an example that you are familiar with.
7. Do intermolecular interactions play a role in your regulation example?



**CONCEPT 4: INTER AND INTRAMOLECULAR INTERACTIONS - VISUAL**  
**PROVIDE COPIES of IMAGE FOR STUDENTS TO VIEW**

1. Draw where inter or intramolecular interactions are happening in this picture. Name the kind or kinds of interactions if you can.
2. Is there anything that is missing from this picture as shown?
3. For the interactions you mentioned, can you describe the chemistry of the interactions occurring?
4. ***Ask if not covered through image analysis above:*** What are situations or examples in biological systems in which these interactions take place?
5. Does equilibrium play a role in these interactions? If so how and give an example, if not why not?
6. Is understanding intermolecular interactions and applying them to biochemistry difficult? If so, how or why?

Ask these only if time:

7. Are you familiar with biological regulation? If so can you give an example that you are familiar with.
8. Do intermolecular interactions play a role in your regulation example?

**Interview Protocol use for Institutions 2-5  
Fall Semester 2013**

**CONCEPT 1: EQUILIBRIUM**

8. What comes to mind when you hear the term equilibrium?
9. Are reactions in biochemistry reversible? How do you know?
  - a. What do you mean by reversible?
  - b. If yes, why?
  - c. If no, why not?
  - d. What do you think about reversibility for a reaction with a  $K_{eq} = 1$  versus a  $K_{eq} = 10^{10}$ ?
10. What comes to mind when you hear the term steady state?
  - a. What about steady state in a biological context (ask if does not arise above)
  - b. How are steady state and equilibrium similar?
  - c. How are they different?
11. Are reactions in the body at equilibrium?
  - a. If no, why
  - b. If yes, explain what you mean. What are the necessary criteria for equilibrium? How do these constraints relate to cellular conditions?
12. How do cells/organisms differ from a reaction in a flask with regard to equilibrium?
13. Is understanding equilibrium and applying it to biochemistry difficult? If so, how or why?

## CONCEPT 2: INDIVIDUAL VERSUS POPULATIONS OF MOLECULES

5. Imagine a weak acid solution. What molecules are in this solution? How many of each are there?  
*[Use HA as an example if needed]*
6. A chemist may say that an acid solution exhibits 50% dissociation. What does that mean?
  - a. What are the possible forms of molecules in this solution? *Looking for HA and A<sup>-</sup>, may get that above.*
  - b. Sketch a molecular view of this population of molecules.
  - c. Are acid molecules always protonated or deprotonated?
  - d. What determines the extent to which the acid molecules in the population are protonated?
  - e. What would you observe if you tracked one individual molecule over an extended period of time?
  - f. Is pH a characteristic of an individual molecule or a population of molecules? Explain. Does an individual molecule have a pH?
7. Give an example of a macroscopic property (prompt melting point if they don't come up with anything). Do individual molecules have macroscopic properties?
8. When biochemists say that oxygen binds hemoglobin, what do they mean? What is the reality in the cell?
9. Consider the following questions:
  - a. What comes to mind when you hear the term "population of molecules"?
  - b. Give an example of when you have focused on an individual molecule in biochemistry class.
  - c. Give an example of when you have focused on a population of one kind of molecule in biochemistry class.
10. Is understanding the distinction between individual and populations of molecules and applying these ideas difficult? If so, how or why?

### CONCEPT 3: INTER AND INTRAMOLECULAR INTERACTIONS

8. What comes to mind when we mention intermolecular interactions? Use the term intermolecular forces if they don't recognize "interactions".
9. For the ones you mentioned, explain what causes these interactions to occur.
  - a. May need to probe understanding of the following:
    - i. Are these attractions or repulsions?
    - ii. What is a dipole?
    - iii. What is an induced dipole?
    - iv. How are these interactions similar and different?
10. Do charges play a role in these interactions? If so, how?
11. What are situations or examples in biological systems in which these interactions take place? Is it possible for these interactions to take place within one molecule?
12. Look at the representation of a monomeric protein. If this protein were inside a cell (as it usually is), what do you not see in this picture?
13. Is understanding intermolecular interactions and applying them difficult? If so, how or why?

# 8-month follow-up evaluation

## Final text

This is a two-part survey.

The first part relates to the NSF-funded **Minneapolis workshop** in June 2013.

The second part asks for feedback related to the **findings** arising from three faculty workshops and from focus groups with 46 students from five different institutions around the USA.

Thanks for participating!

Jenny Loertscher, Vicky Minderhout, Jennifer Lewis, David Green

### PART ONE: LONGITUDINAL FEEDBACK

I am primarily a:  biochemist  biologist  chemist  other, please specify \_\_\_\_\_

	STRONGLY DISAGREE	DISAGREE	NEUTRAL	AGREE	STRONGLY AGREE
1. Since the workshop, I have been mindful of concepts that are “ <b>troublesome</b> ” for my students (e.g. ones that appear alien, counterintuitive, incoherent, etc.).	SD	D	N	A	SA
2. Since the workshop, I have been mindful of concepts that are “ <b>irreversible</b> ” for my students (i.e. once learned, they are typically not unlearned).	SD	D	N	A	SA
3. Since the workshop, I have been mindful of concepts that are “ <b>transformative</b> ” for my students (i.e. ones that alter students’ thinking about my discipline).	SD	D	N	A	SA
4. Since the workshop, I have been mindful of concepts that are “ <b>integrative</b> ” for my students (i.e. ones that bridge concepts within and between disciplines, revealing hidden connections).	SD	D	N	A	SA

If you have done anything differently in your class(es) in response to the considering the four characteristics of threshold concepts, described above, give one or two short examples. If the examples relate specifically to one of the four characteristics, specify which one.

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5. Since the workshop, I have been mindful of the role of **language and definition** in (mis)understanding scientific concepts. (Referred to as “signification” in the workshop.)

SD            D            N            A            SA

If this has led you to do anything differently in your class(es), give a short example.

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6. Since the workshop, I have been mindful of the role of **graphic representation** in (mis)understanding scientific concepts.

SD            D            N            A            SA

If this has led you to do anything differently in your class(es), give a short example.

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7. I have stayed in contact with other workshop participants whom I didn't previously know.

SD            D            N            A            SA

- 8. What has stuck with you most about this workshop?** Feel free to comment on any aspect of the workshop, for example, content, process, participants, facilitators, etc.

- 9. Any further comments?**

## PART TWO: FEEDBACK ON BIOCHEMISTRY THRESHOLD CONCEPTS (first page)

We have selected **five** threshold concepts for future development of instructional and assessment materials.

These five were chosen using an iterative process including three faculty workshops and focus groups with 46 students from five different institutions around the USA.

*NOTE: This list is not an exhaustive list of threshold concepts, simply the concepts to be explored in this NSF study.*

**For concepts 1 through 5 below, knowledge statements are provided below.**

**Keeping in mind of the problem of “signification” (the issue of identifying the meanings of terms, as discussed at the start of the MN workshop), your task is to assign a name to describe each set of knowledge statements.**

**If it is helpful, feel free to use terminology in the knowledge statements as part of your names for the concepts.**

### CONCEPT 1

- Reactions and interactions in biological systems are dynamic and reversible
- Directionality of processes depends on relative concentrations of reactants and products available
- Observable flux is the net result of forward and reverse processes
- Enzymes control rates of forward and reverse reactions
- Enzyme activity is highly regulated

**a. What would you call Concept 1?** \_\_\_\_\_

### CONCEPT 2

- Interactions occur because of the electrostatic properties of molecules. These properties can involve full, partial, and/or momentary charges.

**b. What would you call Concept 2?** \_\_\_\_\_

### CONCEPT 3

- Interactions in biological systems almost always take place in aqueous solution
- Bulk interactions in an aqueous system have an entropic component
- Enthalpic and entropic contributions are responsible for biological structure

**c. What would you call Concept 3?** \_\_\_\_\_

### CONCEPT 4

- The tendency towards equilibrium drives biological processes
- Change in free energy is the chemical driver behind biological processes

- By providing a direct, physical link between a thermodynamically favorable reaction with a thermodynamically unfavorable one, enzymes enable biological systems to drive a normally unfavorable reaction by coupling it to one with a large and favorable free energy change
- Enzymes affect reaction rate, yet do not affect equilibrium position

**d. What would you call Concept 4?** \_\_\_\_\_

#### CONCEPT 5

- Living organisms constitute open systems, which constantly exchange matter and energy with their surroundings, yet net concentrations remain relatively constant over time. This dynamic, yet outwardly stable condition is referred to as a steady state.
- “Steady” is not synonymous with “chemically stable.” Concentrations are determined by kinetic, rather than thermodynamic, factors. Hence, biological systems do not exist in a state of chemical equilibrium.
- If an organism reaches chemical equilibrium, its life ceases. Consequently, organisms have evolved extensive regulatory systems for maintaining steady state conditions.

**e. What would you call Concept 5?** \_\_\_\_\_



PART TWO: FEEDBACK ON BIOCHEMISTRY THRESHOLD CONCEPTS (second page)

We'd now like you to compare your ideas with our own labels for these concepts.

CONCEPT 1

- Reactions and interactions in biological systems are dynamic and reversible
- Directionality of processes depends on relative concentrations of reactants and products available
- Observable flux is the net result of forward and reverse processes
- Enzymes control rates of forward and reverse reactions
- Enzyme activity is highly regulated

In the last section of this survey, you called this concept "XXXXX."

We have called it "**Biochemical flux**"

	STRONGLY DISAGREE	DISAGREE	NEUTRAL	AGREE	STRONGLY AGREE
<b>g. To what extent do you agree with our label?</b>	SD	D	N	A	SA

Any further comments (especially if you disagree) \_\_\_\_\_

CONCEPT 2

- Interactions occur because of the electrostatic properties of molecules. These properties can involve full, partial, and/or momentary charges.

In the last section of this survey, you called this concept "XXXXX."

We have called it "**Interactions (physical basis)**"

<b>h. To what extent do you agree with our label?</b>	SD	D	N	A	SA
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Any further comments (especially if you disagree) \_\_\_\_\_

CONCEPT 3

- Interactions in biological systems almost always take place in aqueous solution
- Bulk interactions in an aqueous system have an entropic component
- Enthalpic and entropic contributions are responsible for biological structure

In the last section of this survey, you called this concept "XXXXX."

We have called it "**Interactions (biological structure)**"

<b>i. To what extent do you agree with our label?</b>	SD	D	N	A	SA
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Any further comments (especially if you disagree) \_\_\_\_\_

CONCEPT 4

- The tendency towards equilibrium drives biological processes
- Change in free energy is the chemical driver behind biological processes
- By providing a direct, physical link between a thermodynamically favorable reaction with a thermodynamically unfavorable one, enzymes enable biological systems to drive a normally unfavorable reaction by coupling it to one with a large and favorable free energy change
- Enzymes affect reaction rate, yet do not affect equilibrium position

In the last section of this survey, you called this concept "XXXXX."

We have called it "**Free energy**"

**j. To what extent do you agree with our label?**                      SD                      D                      N                      A                      SA

Any further comments (especially if you disagree) \_\_\_\_\_

CONCEPT 5

- Living organisms constitute open systems, which constantly exchange matter and energy with their surroundings, yet net concentrations remain relatively constant over time. This dynamic, yet outwardly stable condition is referred to as a steady state.
- "Steady" is not synonymous with "chemically stable." Concentrations are determined by kinetic, rather than thermodynamic, factors. Hence, biological systems do not exist in a state of chemical equilibrium.
- If an organism reaches chemical equilibrium, its life ceases. Consequently, organisms have evolved extensive regulatory systems for maintaining steady state conditions.

In the last section of this survey, you called this concept "XXXXX."

We have called it "**Steady state**"

**f. To what extent do you agree with our label?**                      SD                      D                      N                      A                      SA

Any further comments (especially if you disagree) \_\_\_\_\_

**k. Any further general comments on these five threshold concepts?**

**OPTIONAL:**

Your name: \_\_\_\_\_