Pre-Instructional Assessment of the Basic Chemical and Molecular Literacy of Biochemistry Students

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Background

Despite the fact that students beginning our year-long undergraduate biochemistry course have already completed year-long courses in general chemistry, organic chemistry, and introductory biology, many still struggle with fundamental chemical and biological concepts that they have previously encountered in their pre-requisite coursework (1). Some students, for example, seem to lack an intuitive understanding of reversible equilibrium reactions, especially when considered at a quantitative level, even though acid/base chemistry is a staple of general chemistry courses. Also, many students are surprisingly deficient in their knowledge of the basic structural and chemical properties of amino acids, even though these fundamental building blocks of proteins are typically "covered" in introductory biology and organic chemistry courses. Because many biochemical concepts derive in some fundamental way from more basic chemical concepts, we have started to investigate the possible sources and remedies for the conceptual issues that students find problematic. With the ultimate goal of helping students overcome these conceptual hurdles, we currently administer online assessment quizzes during the first week of instruction in order to identify and track the sources of their misconceptions.

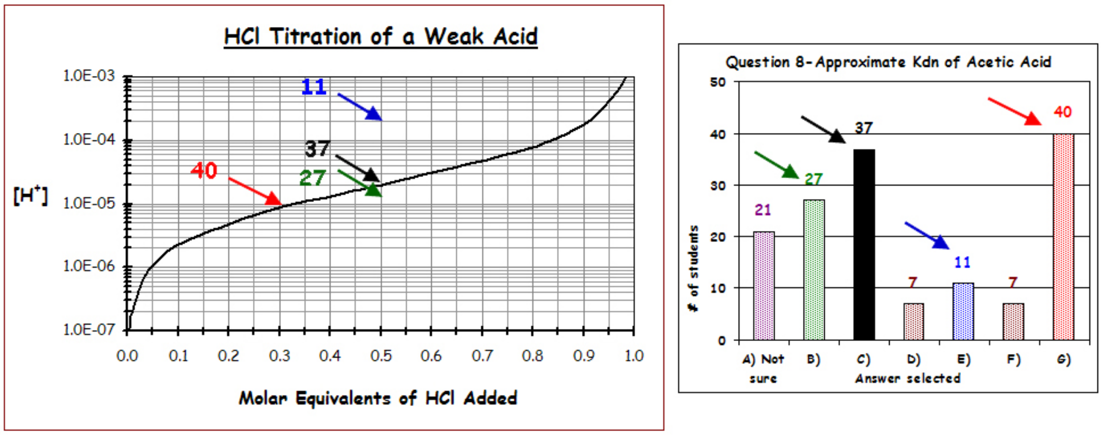
Pre-Instructional Assessment Quizzes

"Pre-instructional" assessments serve several purposes. 1) They help us evaluate the basic chemical and molecular literacy of our students in terms of their mastery of fundamental concepts that are important for understanding more specialized biochemical concepts. For example, a conceptual mastery of simple reversible equilibrium binding reactions (e.g., weak acid/base reactions) is essential for conceptual understanding of more complex reversible reactions that involve multivalent ligand binding systems (e.g. O_2 transport by hemoglobin). 2) The results from these assessments help us identify common misconceptions and problem areas that subsequent instruction may need to address. 3) These assessments also serve to "put students on notice" early on in the course that they will be expected to learn the material at a conceptual level in order to effectively answer questions on our three <u>open-notes</u>, <u>open-book</u> examinations that emphasize data analysis and problem-solving, rather than rote memorization. 4) Finally, the highly varied student responses to the conceptual questions posed on these assessments underscore the need for vetted biochemical concept inventories that are pedagogically integrated with more fundamental chemical and biological concept inventories.

Assessing Basic Chemical Literacy

Because biological organisms survive by responding "reflexively" to the chemistry of their environments – be it for the purpose of taking up nutrients, releasing waste products, or modifying behavior to improve survival – it is essential for students to understand the basic concepts of reversible equilibrium chemistry (1). Such concepts are typically introduced in general chemistry courses in the context of weak acid/base chemistry. Thus, several of our pre-instructional assessment questions pose problems related to the qualitative and quantitative analysis of such reactions. One sample question is shown in Fig. 1 below. Here students are presented with a typical weak acid titration curve and they are asked to select a value from several choices that most closely corresponds to the equilibrium dissociation constant based on the experimental titration curve shown.

Q8



This is an acid/base titration plot for a weak acid.

Which value below best approximates the **dissociation constant, K_{dn},** for the ionizable proton of a weak acid?

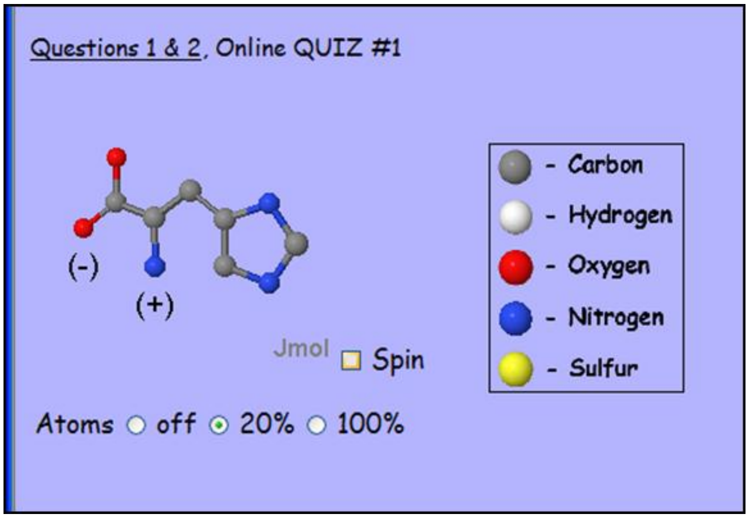
- A) I am not sure that I have enough information to answer this question 21
- B) 1.5×10^{-5} ← 27
- C) 2×10^{-5} ← 37
- D) 1×10^{-4} 7
- E) 2×10^{-4} ← 11
- F) 1.1×10^{-4} 7
- G) 1×10^{-5} ← 40

Figure 1. Online pre-instructional assessment question in which students are presented with the acid titration curve of a weak acid and several possible choices for the equilibrium dissociation constant. The numbers and histogram bars indicate how many students out of 151 made the specific selections indicated, with choice (**C**) being the correct value.

Surprisingly, only 37 of 151 students correctly identified the value for the equilibrium constant (choice C, 2×10^{-5}). The incorrect choices made by the remaining students possibly reveal certain misconceptions that some students have in terms of interpreting titration data and/or determining specific values from semi-logarithmic data plots (1). We are planning to evaluate specific "distracters" for questions like this in future studies (2) with the hope of solidifying our understanding of what types of misconceptions plague students in their failure to understand fundamental concepts that they most likely have encountered already in their general chemistry courses.

Assessing Basic Molecular Literacy

Understanding the underlying structures that dictate the architecture of living organisms is obviously a key component of biochemical knowledge. Such knowledge ultimately hinges on a basic understanding of the properties of organic molecules, as typically introduced in organic chemistry courses. However, many students seem to lack an intuitive understanding of such structures. Therefore, several of our pre-instructional assessment questions involve the analysis of simple “abbreviated” or “stripped down” organic structures like that shown in Fig. 2. This abbreviated structural image corresponds to one of the ionization states of histidine and it is accompanied by two questions, as shown at the right of the figure. Both questions essentially ask students to make educated deductions about this structure based on their knowledge of organic chemistry. Note that the structure for this question is rendered as a static 2-D image but students can also view a dynamic interactive 3-D image, which pops up after clicking on a URL. The 3-D image, is rendered using the *JMol* browser plugin for molecular imaging and students can easily manipulate the image by moving the mouse for more complete viewing of the structure.



Question 1

How many **double covalent bonds** are implied by this structure? (Enter an <u>integer</u> for your answer.)

Question 2

How many **covalently bound hydrogen atoms** are implied by this structure? (Enter an <u>integer</u> for your answer.)

Figure 2. “Stripped-down,” abbreviated image of one of the ionized structures of histidine. Shown are the relative placements and connections between carbon, oxygen, and nitrogen atoms. The associated hydrogen atoms are not shown, and no distinction is made here between possible single or double covalent bonds linking the atoms in this model.

Questions 1 and 2 above were administered in pre-instructional assessments during the first week of our biochemistry course in two successive academic years (2004 and 2005). As indicated by the arrows in Fig. 3, only <u>48 of 151</u> students in 2004 (A) and <u>75 of 171</u> students in 2005 (C) correctly answered Question 1 by entering **3** for the number of double bonds which can reasonably be inferred from this abbreviated covalent structure. Students with incorrect answers submitted values that ranged from as low as **1** double bond to as high as **8** double bonds. For Question 2, only <u>13 of 151</u> students in 2004 (B) and <u>12 of 171</u> students in 2005 (D) correctly entered a value of **8** for the number of covalently bonded hydrogen atoms implied by the abbreviated structure. Students with incorrect answers submitted values ranging from as low **0** to as high as **27** for the number of covalently bonded hydrogen atoms implied by this structure.

Results from cross-analysis of the student responses are shown in Fig. 4. In this case, only **8** of **154** students submitted *correct* answers for *both* assessment questions, i.e., that the abbreviated structure of the ionized histidine molecule implies <u>3 double bonds</u> *and* <u>8 covalently bound hydrogen atoms</u> in this structure. Many students incorrectly selected 9 covalently bound hydrogen atoms, which is not too surprising since the positive charge indicated on the structure implies the existence of a noncovalently bound hydrogen ion. However, the extremely wide range of answers submitted for both questions by this group as a whole is alarming because is suggests that many students were either just guessing or had very little idea about how to answer these questions.

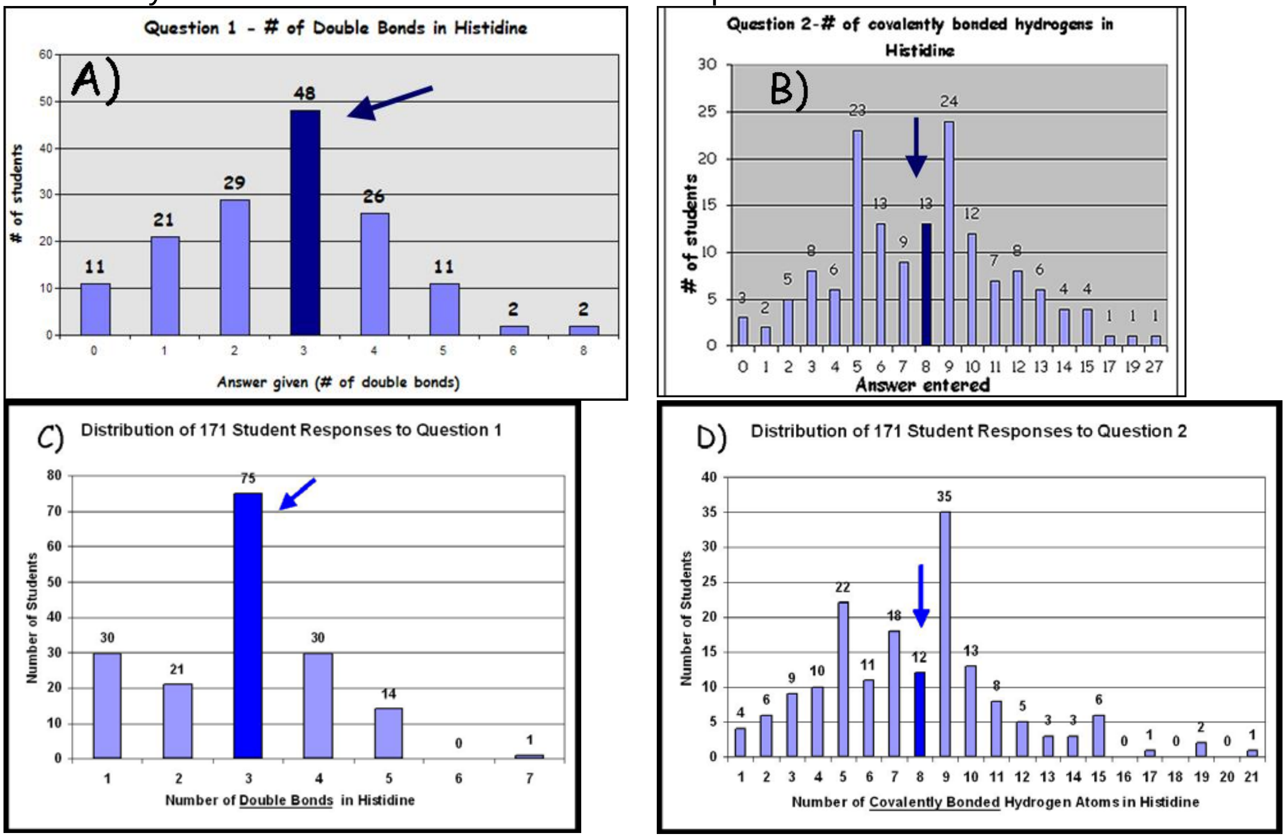


Figure 3. Comparisons between the distributions of student responses to pre-instructional assessment Questions 1 and 2, as described in Figure 2. These assessments were administered during the first week of our biochemistry course in two successive years, 2004 (**A** and **B**) or 2005 (**C** and **D**).

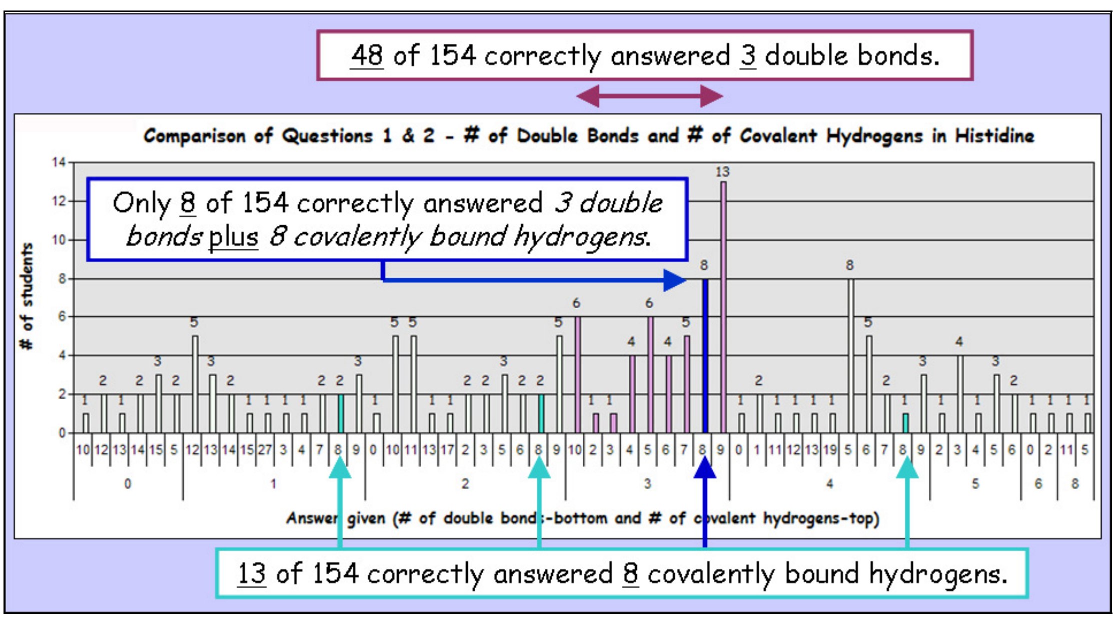


Figure 4. Co-distribution of the student responses to the Questions 1 & 2 shown in Fig. 2. Of **154** students, **13** correctly selected *8 covalently bound hydrogen atoms* (vertical arrows) while **48** correctly selected *3 double bonds* (horizontal double arrow). However, only **8** students correctly answered *both* questions (horizontal single arrow).

Summary

The wide range and extent of incorrect student responses to basic, conceptually linked questions like these strongly suggests that our assumptions about what students <u>know</u> when starting out in our course are seriously at odds with what they <u>demonstrably know</u> or are able to <u>reconstruct</u> from their pre-requisite coursework. Conceptual discontinuities such as these obviously present major impediments to effective learning and instruction. A partial remedy for these issues would be to develop integrated concept inventories that explicitly link basic concepts in chemistry and biology to important concepts in biochemistry. By melding fundamental concepts in this way, students would be more likely to build skill sets that constitute what cognitive psychologists sometimes refer to as "expert knowledge." This is knowledge that is "sensitive to patterns of meaningful information;" that is "highly organized in deeply integrated schemas;" and that is "readily accessible when needed because it contains information about when it will be useful." (4) The tiered blending of concepts between the physical, chemical, biological and biochemical sciences ultimately demands that instruction and, more importantly, the pedagogy used in all of these disciplines be integrated in terms of sound conceptual approaches to learning.

Acknowledgements

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