Training Workshop for Life Sciences TAs
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Features of Inquiry-based Labs[1]

The primary feature of an inquiry-based lab is that students experience science as an experimental process that gives priority to explanations based on evidence. Students will

1. Learn essential concepts and information in biology, including content, lab skills, procedures, and methods.
2. Think analytically and critically about experimental design
3. Take responsibility for their own learning in a way that is engaging and meaningful to them.
4. Experience the collaborative nature of science as they negotiate with peers and communicate their explanations.
5. Give Priority to explanations based on evidence.
6. Witness the thrill of discovery and uncertainty in biology.

Examples of Approaches to Labs

Inquiry-Based Labs	NOT Inquiry-based Labs
Students are asked to bring in two soil samples and are challenged to generate a hypothesis about the microbes in the soil samples and design an experiment to test it.	Students are instructed how to make 10-fold dilutions of soil samples and apply each solution to a culture medium. After incubation, students count the number of colonies on each plate and calculate the number of culturable organisms in the sample.
Students are asked to generate a hypothesis about the effect of the environment of the life cycle of a plant and test it.	Students are told to plant seeds and fertilize with a dilution series of fertilizer, then measure the effect on plant height, number of leaves, and number of seeds.
Students are given an unhealthy plant and asked to determine the cause of its symptoms.	Students are given a protocol to inoculate a plant with a known pathogen. A week later, they identify the correct disease symptoms and re-isolate the pathogen.
Students are given two seed stocks: one parent and its progeny. Students are challenged to generate a hypothesis about the second parent's genotype and design an experiment to test it.	Students are instructed to cross two true-breeding lines of fruit flies, then identify the correct genotype and phenotype of the progeny.
Students choose a single organism (bacterium or fungus) and are charged with its care for a semester. At the end of the project, they are responsible for returning a pure culture of the pet, describing its interactions with other organisms and in the environment, characterizing it, and identifying it.	Students are given 10 microorganisms plus a list of 20 diagnostic media and told to determine the correct identity of each microorganism.

[1] Un-cooking the Lab: How to Convert a Traditional "Cookbook" Lab into an Inquiry-based Lab. Sarah Lauffer, Co-Director HHMI New Generation Program for Scientific Teaching. UW Madison. http://newgenerationprogram.wisc.edu

5E Instructional Scheme for Inquiry Teaching[2]

Roger Bybee developed the 5-E instructional scheme in the early 1990's as a means of easily creating a good student-centered lesson. It is made up of five basic sections, although sections can be repeated within a lesson as needed to cover the required material.

Each new topic is introduced with an appropriate ENGAGE. This is a brief activity, question, demonstration or film "snippet" that whets the students' appetite and gets their attention focused on the topic. A new engage should be done for each different topic that is introduced within a lesson, or when a topic must be continued during another class period.

Once the students have seen or done the engage, they are asked to EXPLORE the topic in groups. This might be a lab activity in which the students develop questions and attempt to answer them, or it may include several challenge questions that encourage the students to think in depth about the topic at hand.

After students have had time to explore the topic and to develop answers, they are asked to EXPLAIN these answers to the class. Teams take turns sharing their results, whether they have done an experiment or worked through a question. Different team members are encouraged to present the group's material so all students participate in the discussion. At this point, the professor can also clear up misconceptions and misinformation to ensure that students understand the material.

Once the groups have had a chance to explain the information in their own words, and have a clear understanding of the material, they ELABORATE on the topic. They may do further laboratory work, do research, give presentations or simply discuss more complex questions within their groups. This allows them to build a deeper understanding and to relate this information to other material covered in the class.

Finally, the professor must EVALUATE student comprehension of the topic. Evaluation can take numerous forms, including standard quizzes or tests, written assignments, oral presentations, student self-evaluations or observations of student participation in group activities. Rubrics given to the students at the beginning of the lesson can help to clarify expectations of grading requirements.

The 5-E model aids the professor in maintaining a smooth flow during a class by giving a simple outline for developing class procedures. It reduces time spent on unrelated topics and helps keep student groups on task. It also aids in developing better understanding of the material by encouraging students to explore new information before the explanation.

ENGAGE – use to motivate the class in the topic
EXPLORE – encourages the students (in teams) to examine the topics
EXPLAIN – allows students to describe to others what their team discovered
ELABORATE – permits students to expand on the topic
EVALUATE – provides the students with a means of assessing what's learned

[2] Reproduced from Holly J. Travis and Thomas R. Lord. Best Practices in College Science Teaching from the Society of College Science Teachers.

Creative Ways to Engage Students

Experienced instructors have discovered that it although it is difficult to come up with a "zinger" to engage students every time a class meets or that their "zinger" falls flat sometimes, intriguing activities at the beginning of class are still a terrific way to set-up the lesson for the students. ENGAGE activities should create interest, generate curiosity, raise questions or elicit responses that uncover what the students know or think about the concept topic. (Think about what the electricity lab made you do.) Most of the ENGAGES fit into on of five categories:

1. **Short video clips** (snippets of not more than 2 minutes) that introduces the lesson topic. (video of a baby being born)
2. **Discrepant Event** (unpredicted outcome) that introduces the lesson topic (when discussing charge, have students play with static electricity)
3. **Surprising Fact** that introduces the lesson topic (when discussing large numbers [i.e. world population], let students know it would take 32 years to count to a billion by ones [counting one number per second])
4. **Silly Joke** to introduce a lesson ("in today's class on Gas Laws you'll learn about Charles Law, Boyles Law, and Coles Law" [at Coles Law, state: "finally chopped cabbage mixed with mayonnaise always tastes good."
5. **Learning Objective** to introduce a lesson (when teaching photosynthesis say: "at the end of class you'll be able to tell me how many molecules of sugar and water are needed to produce a molecule of sugar")

We're going to watch a videotape now of how the lab was run without this type of ENGAGE activity, Your assignment for next week is to try to think of an activity that you could do to ENGAGE the students in the lab.

Common Situations Encountered in Groups[5]

Consider each of the situations below. Circle the 5-6 you think most common.

1. Student who confidently presents ideas that are incorrect yet goes unchallenged by the group.
2. Student who misses class or regularly comes late and requires class time for the more conscientious students to fill him (or her) in on what was missed.
3. Unprepared student who routinely comes to class but doesn't contribute to group discussions or projects.
4. Likeable talkative student who is unaware that he (or she) frequently interrupts others and dominates discussion thereby preventing contributions from other members of the group.
5. Student who readily understands the material but is not particularly interested in sharing that knowledge with other group members.
6. Student who thinks inquiry learning is not a good way to learn and deliberately or unconsciously disrupts the process.
7. Quiet student who has good thoughts to contribute but never seems to get the attention of the group.
8. Students whose friendship outside of class creates a subgroup that frequently breaks off from the main group in lab discussion.
9. Student who, due to illness of some other reason misses a week or more of classes.
10. Group that gets along well and is satisfied with a superficial procedural understanding and doesn't seem to be aware or interested in a deeper conceptual understanding.
11. Student who has difficulty focusing on course material and frequently ends up discussing sports, the campus social scene or the previous night's TV show.
12. Student who ignores or puts down group members that have a different cultural background, racial background, or physical appearance.
13. Student who doesn't listen or seem to understand the points made by other group members.
14. Group that can't make progress without assistance, and show signs of frustration (and perhaps resentment) when the TA doesn't provide the information desired.
15. Group in which the disparity in the abilities of members makes communication of concepts difficult. Student who directs all of his (or her) questions to the TA.
16. Students who do all of the necessary work, but do not seem to enjoy discussing problems and related concepts with each other.

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[5] White, H. (2005). "Preparing Peer Facilitators for Cooperative Learning Groups." Presentation at the Annual Conference on Case Study in Science held in Buffalo, NY on October 7-8, 2005, hosted by the National Center for Case Study Teaching in Science, State University of New York at Buffalo.

The Role of Questioning in Inquiry Instruction: Your Job is to Pause, Listen, then Nudge[4]

The biggest challenge instructors face when implementing inquiry instruction is how to encourage and lead students to develop an understanding of what they are doing without telling them what to do. This is particularly challenging because it fights the natural tendencies of both the teacher and student. We as teachers define our job as helping students learn, and it is hard for us to realize that students don't learn by being told facts but rather by figuring out solutions to problems with some guidance and explanation from a teacher rather than total disclosure. Students may not be accustomed to learning this way and may still define the role of an instructor as someone who is there to "teach" them the facts and then test them by simply asking them to regurgitate these memorized facts. In inquiry instruction, we aren't interested in their ability to memorize, but rather to their ability to think, plan, and solve problems. And face it –thinking is hard work. Expect your students to resist.

We've provided help for you by placing questions in the lab manual for students to use to guide their thought processes. Your job will be to listen to the student's questions about those guiding questions and nudge them toward solving their own questions.

Instead of obeying your reflex to just tell them the answer, pause for 2-3 seconds and ask yourself, "Does this student have the ability to answer her own question?"

If the answer is "no", it could be for two reasons:

1. Students are asking some procedural or technical question like how to use a piece of equipment, so your job is to help them locate that information in their manual or in the room. Try to demonstrate this to the whole class at one time.
2. The student may lack some basic background knowledge, your job is ask further questions to help you figure out where they are getting confused and make some suggestions about how to find out this information. You may need to remind them of material in their textbook or class notes.

If the answer is "yes", then your job is to help them get on track to answering their own question using a prompt.

1. Sometimes a prompt is just re-phrasing the question back to the student to help them to clarify exactly what they are asking. Take for example this question, "Do we need to take measurements using the spec?" Ask them, "What are you measuring? How do you want to use this data? When you write up your results how will you back up any claims that you make?"

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[4] Douglas Llewellyn. (2005). "Managing the Inquiry Classroom" in *Teaching High School Science Through Inquiry*. Pages 104-109. Corwin Press. Thousand Oaks California.

2. Encourage students' confidence by suggesting that they recall previously learned information. For example, "Last week when we tested the iodine concentrations, what were you trying to determine?"

Sometimes you will be confronted with students who have the opposite problem; they won't ask enough questions and are happily not working toward the goal of the lab. These students need to be nudged with questions. Good questioning skills are the most important factor for successful implementation of inquiry labs. Here are some suggestions from Douglas Llewellyn in his book, "Teaching High School Science Through Inquiry."

Questioning Techniques

1. ***Avoid chorus questions***

   Chorus or group response questions are those questions the teacher asks to which anyone can shout out an answer. When teachers ask chorus questions to anyone and everyone to answer, they often get inappropriate answers. Suppose an earth science teacher asks a question, "What type of rock is limestone?" The entire class responds, "Sedimentary." Did all the students really answer correctly? Did some students quietly or to themselves answer, "Metamorphic?" The teacher doesn't know. It is nearly impossible to determine, through a chorus or class response, how many students actually know the answer to a question. Other students may answer correctly when they hear the correct answer from the class.

   As an alternative to chorus questions, pose questions to an individual student, not the entire class.

2. ***Think about when to use a student's name before posing a question***

   Teachers can place the student's name either before or after a question. Each has its own specific purpose. By placing the student's name before the question, as in "Josh, explain the atomic exchange in a double replacement reaction," all the other students may "shut down" as soon as they know that Josh, not them, has to answer the question. This immediately takes the rest of the class "off the hook."

   Another option is to pose the question, follow it with a pause of 3-5 seconds, and then state the name of the student you wish to call upon.

   During that brief amount of time, all students have to think of the answer, because they don't know who will be called upon. The brief pause invites students to actively think about an answer, rather than the first student to raise his or her hand. By placing the student's name at the end of the question, *all* the students are kept "on the hook" a little longer. Pausing also gives students a chance to understand the question – not all students grasp the essence of a question immediately or at the same time.

3. *Apportion questions equally and equitably by gender.*

4. *Avoid "guess what I'm thinking of" questions*

Teachers often pose questions with a particular desired response in mind. When this happens and the teacher does not get the answer he or she is looking for, the teacher may, through facial expressions or body language, indicate a "wrong" answer and call on another student until the "correct" answer is given. All the answers provided by the students may make sense from the standpoint of the students who provided the responses; however, they just aren't the responses the teacher is searching for. Teachers should not ignore "wrong" answers.

Most often, when a student gives a wrong answer, it point to a misconception the student has. Good inquiry teachers are just as concerned with "wrong" answers as they are with "right answers.

5. *Avoid repeating student answers*

When a teacher poses a question and a student provides a correct response, what happens next? Usually, the teacher (a) responds by saying "Okay," (b) says nothing and goes on to another student, (c) provides feedback for the correct response, or (d) repeats the student's answer. Far too often, you will hear the teacher repeating the answer a student gives. Some teachers say they do it out of habit, while others say that students talk too softly for the rest of the class to hear. In either case, by repeating students' answers, teachers reinforce the notion that students do not have to speak up because the teachers will always repeat, in a louder voice, what they said. In this situation, the teacher is the conduit of the conversation. All the conversation goes "through" the teacher.

Repeating student answers also communicates to the class that the students do not have to listen to other students' responses, just what the teacher says.

Consider this as an alternative.

Teacher:	"What are the three types of rock?" [Pause] Gino?
Gino:	[Speaking softly] "Sedimentary, metamorphic, and igneous."
Teacher:	[Pointing to a student across the room] "Michael, did you hear that answer?"
Michael:	"No."
Teacher:	[Allowing a pause]
Gino:	[Speaking louder this time so Michael can hear him] "Sedimentary, metamorphic, and igneous."

With enough practice and consistent use, students will rise so they will respect each other's contributions, thus creating a community of learners.

6. *Rephrase a question when a student can't provide an answer*

Not all questions that teachers pose result in immediate answers. There are times when students may have the background knowledge for the concept but just don't understand the question being asked. Frequently, the tendency for the teacher is to repeat the question as originally stated or ask the same question to a different student. Neither of these options models good questioning strategies.

When a student cannot answer a question, first consider re-phrasing it. The question may make sense to the teacher but not the student.

Second, consider asking another student to rephrase the question to the class.

It might be that the manner in which the teacher asks the question does not make sense to the students. Sometimes students are great at "translating" teacher questions into forms that their peers can understand.

Third, don't be so quick to let the students off the hook by calling on someone else. Continue to rephrase the question to provide prompts to help the student answer the question.

If the teacher goes on to another student, he or she communicates to the class that student can avoid answering just by claiming, "I don't know."

7. *Follow up a student's response by asking for supporting details*

After posing a question and receiving a correct response, what do you do next? The teacher has several alternatives:

She could go on and ask another student another question.

She could ask the first student to support the answer with additional supporting details.

She could follow up the student answer with the question, "Why do you think that?"

Or she could ask a second student to respond to the first student's answer.

Depending on the situation, any of these alternatives may be appropriate. In creating a classroom culture of inquiry, consider the importance of interstudent communication where students react and respond to other student's answers. This encourages everyone to be active listeners and respect other participant's points of view.

8. *Don't interrupt a student's answer in the middle of the response*

Too often, a teacher poses a question that a student begins to answer correctly, and realizing the answer is correct, the teacher interrupts the student in the middle of her answer and provides further elaboration of the response. Over time, this communicates to students that their opinions are not as important as the teacher's.

When a student provides an answer to a question, be patient and wait until she completes her response.

Doing this will encourage the student to give a complete, thoughtful response and encourage higher-order thinking skills at the analysis and synthesis levels.

9. *Move about the classroom when asking questions.*
A teacher's position in a classroom can have a profound effect on student participation in answering questions. When a teacher positions himself in the front of the class, the tendency is to acknowledge students in the immediate area, also being the front of the class. A teacher can enhance his questioning skills by walking about the room during a discussion-based lesson and consciously calling on students across the room.

Try calling on a student while you are standing behind her and encourage the student to answer and make eye contact with the other students in the classroom, not you.

This helps students respond to each other rather than directly to the teacher, encouraging the development of a community of learners.

10. *Avoid rhetorical questions that require students to confess to the class that they do not understand a particular concept.*
Questions that fall into this category usually include the following:

- Does everyone understand that?
- Who doesn't understand what I just said?
- Isn't that right?
- Who didn't get that down?
- Who doesn't get it?

11. *Plan three to four discussion questions in advance to direct the conversation and stimulate critical thinking skills.*
By choosing levels of questions that require higher-level thinking skills (application, analysis, and synthesis), the teacher prompts the classroom discussion to challenge students' thinking. For example:

- What is the phenotypic proportion of offspring for a cross ***dumpy*** X ***wild-type*** if the dumpy trait is sex-linked? (application)
- What is the relationship in a stream between the oxygen levels and health of the organisms? (analysis)
- Given the data collected, how can you determine if the stream would be considered healthy? (synthesis)

Careful planning of classroom questions can foster an inductive thinking model of whole-class discourse. As inquiry-based teachers hone their questioning skills, they provide opportunities to internalize learning, motivate students to challenge their models and thoughts, and provide thoughtful, engaging discussions around topics that are relevant to students.

Teaching Assistant - Inquiry Observation Protocol (TA-IOP)

BACKGROUND INFORMATION

Name of Evaluator ___________________ Announced Observation? ________

Date of Class ________________________ Topic of Exercise __________________

Start time ___________________________ End Time _____________________

Name of TA ________________________ Prior Experience ________________

OBSERVATIONS

Time (mins)	Use the spaces below to take descriptive notes of your observations. Provide specific examples of exchanges that demonstrated the TA's pedagogical skills, classroom management skills, content knowledge, and preparation.
0-15	
15-30	
30-45	
45-60	

1hr- 1hr15	
1hr15- 1hr30	
1hr30- 1hr45	
1hr45- 2hr	

This instrument is to be completed during/following observation of laboratory classroom instruction. Refer to the specific examples you noted in your observations (previous pages) that demonstrate each of the items. Use the numerical scale as follows: 0 = not observed, 1 = observed rarely (once or twice), 2 = observed occasionally (3-4 times), 3 = observed often (>50%), 4 = observed throughout (>75%)

PEDAGOGICAL SKILLS	
1. The TA asked questions that elicited student responses built on the students' own ideas rather than the TA leading students to answer a specific way. **Example of a question that worked:** After showing students a graph of data displaying unexpected results the TA asks, "How would you interpret the results?" **Why did it work?** Asks students to analyze their expectations/thoughts, mesh these idea with inconsistencies presented before them, and analyze and evaluate data, rather than just telling the students what the graph indicates. **Example of a question that didn't work as well:** "What's wrong with this data?" **Why did this not work as well?** TA is leading them, telling them a little about what they should be looking for or analyzing rather than letting it be student-instigated.	0 1 2 3 4 Provide examples below:
2. The TA encouraged students to reflect upon (explain in their own words) how they learned something/came up with an answer (metacognition). **Example of a question that worked:** Students ask a TA why they got unexpected results and the TA responds, "First tell me what you got and then tell me what you did to get these results." **Why did it work?** Asks students to first state their results and then retrace and verbally explain (i.e. reflect) how they got them; Reflecting on their methodology often leads students to answer their own questions because it forces them to think out what they did and how they did it (and therefore where they went wrong). **Example of a question that didn't work as well:** Students ask a TA why they got unexpected results and TA responds "It seems to me based on what you wrote that you forgot your control, so redo the experiment with a control and see what kind of results you get." **Why did this not work as well?** TA is identifying the problem and instructing students how to fix it. Students don't have to do any thinking to solve the situation, identify other possible errors, etc.	0 1 2 3 4 Provide examples below:
CLASSROOM MANAGEMENT	
3. The TA provided a holistic view of the lab. **Example of a strategy that worked:** TA opens the beginning of lab with a brief summary of what will take place in lab as whole and then provides detail about each lab activity: "Today we are working with enzymes, and we'll complete three activities about how enzymes do their jobs. The first looks at XXXX, and at the end of the activity you should be able to XXX. This sets up the next activity on YYYYY, etc.	0 1 2 3 4 Provide examples below:

Why did it work? Students have an overall view of the lab topic and how the lab will run, but they are also clear on how each activity is connected to the rest. **Example of a strategy that didn't work as well:** TA begins the lab by stating "We are working on enzymes today and by the end of lab you should have the following complete to turn in to me." **Why did this not work as well?** TA is providing a broad outlook of lab and what is due at the end, ignoring connections that should be made between activities.	
4. The TA regularly checked on group interactions to ensure a collaborative working environment where all students were contributing equally. **Example of a strategy that worked:** While students are working on activities, TA observes group interactions to see how work is being completed. TA also checks in with each group to inquire what roles each team member is playing: "Who is doing the timing in this experiment? Who is writing down results?" **Why did it work?** Students are reminded that everyone should be participating equally in the lab. **Example of a strategy that didn't work as well:** TA talks with members of one or two out of five groups, but only visually observes the remaining groups. **Why did this not work as well?** TA has not reached all groups to check how work has been divided amongst members. This may communicate to students that TA is not concerned with equal work loads, so some students may continue to do all the work while others do little.	0 1 2 3 4 Provide examples below:
5. The TA managed the progress of groups, ensuring that they finished tasks and redirected them if they were "struggling." **Example of a strategy that worked:** While students are working on activities, TA checks with each group to see how much progress they have made and where they might be stuck. TA also asks a "check-in" question to make sure they are completing the work and looking ahead: "This looks like a good idea. How many replicates will you run?" **Why did it work?** Students are shown that TA is concerned about their group's progress and are given an opportunity to ask questions. Students are also held accountable for how they will finish the experiment in the allotted time. **Example of a strategy that didn't work as well:** TA visually observes the groups, only checking on those that are clearly struggling. **Why did this not work as well?** TA has not made efforts to verbally discuss progress with students. This may communicate to students that TA is not concerned with them understanding the lab and completing work and therefore may lead to lower effort on students' part.	0 1 2 3 4 Provide examples below:

CONTENT KNOWLEDGE	
6. The TA had a solid grasp of the subject matter content inherent in the lesson and could apply it to real-world situations. **Example of a teaching strategy that worked:** TA asks "After reading the article in the New York Times comparing the abilities of children and chimps to imitate, you read some letters to the editor. In one letter, the author wrote about "unschooling": a child-led form of homeschooling. Has anyone ever heard of this term? Can you give me an example?...Pause…The best example I can think of is this lab! You are experiencing traditionally taught science laboratories in a non-traditional way where YOU often figure out the science instead of me teaching it to you in a lecture or you following a series of steps to get an answer." **Why did this work?** TA used an unfamiliar term and is able to draw a direct comparison to the students themselves.	0 1 2 3 4 Provide examples below:
7. The TA acted as a resource person, working to support and enhance student investigations. **Example of a strategy that worked:** As TA checks on groups' progress, he states "This experiment looks pretty good, but don't forget that there are other reactants available to work with on the table. How could they help your investigation?" **Why did this work?** TA recognizes and compliments current progress while encouraging students to look beyond their current work and possibly enhance their experimental results **Example of a strategy that didn't work as well:** Student has only used 3 of 5 solvents on lab bench for experiment and asks TA if she should use the rest. TA responds "Well, I'm not really sure why they are there so I'd say don't use them. I'm sure what you did is fine." **Why did this not work as well?** TA communicates to student that he does not understand all possible variables in the experiment and how students should utilize them.	0 1 2 3 4 Provide examples below:
PREPARATION	
8. The TA presented information that was accurate. **Examples of inaccuracies:** 1) TA has lectured on material that she later realizes had some inaccuracies. For instance, she gives the incorrect end products of photosynthesis; 2) incorrect methods to dilute solvents; 3) incorrect identification of organism on slide.	0 1 2 3 4 Provide examples below:
9. The TA selected teaching strategies that made content understandable to students. **Example:** TA wants to explain "denaturation." She draws a flower on the board, representing an enzyme. She explains: "Let's say this flower is an enzyme. If we put this flower in an environment that it wasn't used to, such as really high heat, what might happen? It will wilt." She redraws the flower, this time crumpled and wilted. "This is what happens when you put enzymes in unfavorable conditions such as high heat; they break apart and lose their shape."	0 1 2 3 4 Provide examples below:

Why did this work? TA uses a simple example to explain a more complex scientific concept. **Example of a strategy that didn't work as well:** Student asks who in the real world would want to isolate specific genes. TA replies an in-depth description of his master's research project. **Why did this not work as well?** TA is giving a real life example, but it is too detailed and complicated for the general connection that the student is trying to make. A connection to a larger picture would work better (i.e. someone interested in trying to find a specific genetic link to Alzheimer's disease).	
10. The TA covered all that was required in the time allotted.	0 1 2 3 4 What are some reasons why the TA was not able to cover everything?
STUDENT BEHAVIORS	
11. Students were actively engaged in thought-provoking activity and stayed on task. **Examples of off task behavior observed:** text messaging, talking about social events, talking on the phone, head down on desk/sleeping	0 1 2 3 4 Provide examples below:
12. Most student questions were reflective (asking about *why* they were doing something) rather than procedural (*how* they were doing it). **Example of reflective question:** Student states "I don't understand why we are measuring how long a behavior occurs instead of the number of times a behavior occurs." **Example of procedural question:** Student states "I don't understand how to adjust the temperature setting on the water bath."	0 1 2 3 4 Provide examples below:
13. Students actively shared ideas and problem solving strategies, including how they learned and what they learned with each other, rather than turning to the TA for corroboration. **Example:** Students are given a set of materials and need to design an experiment on how to measure the amount of starch hydrolyzed in a given solution. Students begin by discussing/debating with one another how they are going to conduct the experiment, rather than waiting for the TA to tell them or searching for the answer in their lab manuals.	0 1 2 3 4 Provide examples below:

POST-LESSON PEER INTERVIEW QUESTIONS

1. What do you think went well in the lab?

Answer:	Observers suggestions:

2. Can you give an example of an interchange you had with the students that you felt went particularly well? Why did it work well?

Answer:	Observers suggestions:

3. What did you feel did not go well with the class?

Answer:	Observers suggestions:

4. What is the reason you think these problems happened?

Answer:	Observers suggestions:

5. How would you modify your teaching next time to deal with this problem?

Answer:	Observers suggestions:

6. Are there any materials or instructions you felt would have helped you better prepare to teach this lab?

Answer:	Observers suggestions:

7. If you could teach this same class over again, what would you do differently? (In particular any interactions you had with the students during class.)

Answer:	Observers suggestions:

Graduate Teaching Assistant Evaluation
Life Sciences Program and Department of Zoology and Physiology

GA Name: Date of evaluation:

Course: Teaching Topic:

Evaluated by:

1. General class or lab observations. *Did lab begin and end on time? Was it a good use of the time? What was the general attitude of the students? Were they engaged?*

2. GA interactions with students. *Were students encouraged to actively participate in lab? Were students asking questions? How did the GA respond to the questions? Was there mutual respect between students and GA?*

3. GA oratory skills. *Was the GA loud enough? Did they pace their speaking appropriately?*

4. Lecturing. *Did it appear the GA was comfortable with the lecture material? Was the lecture well organized? Did they attempt to engage the students?*

5. Preparedness. *Was the GA comfortable with the material and lab activity? Was it apparent the GA had practiced?*

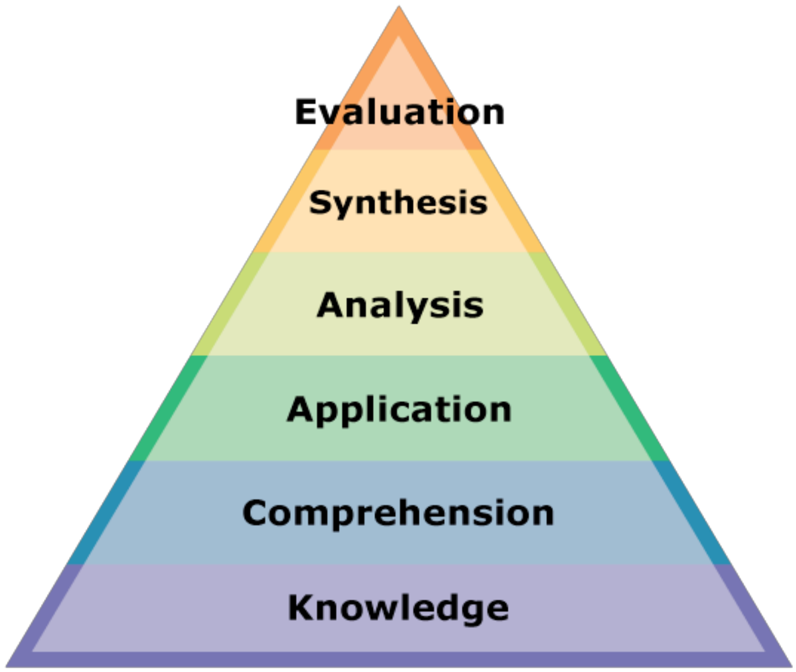
6. GA attitude in prep meetings. *Does the GA take notes and appear engaged? Do they actively participate in the meetings?*

7. Reliability, responsibility, and time management. *Did the GA attend all scheduled meetings including grading sessions and attend lecture? Was the GA prepared and ready for meetings and teaching lab? Were they regularly asking last minutes questions or favors?*

8. Overall impression of the GA.

9. Would you request this GA again to teach your lab?

Bloom's Levels and Associated Verbs



Knowledge: arrange, define, duplicate, label, list, memorize, name, order, recognize, relate, recall, repeat, reproduce, state

Comprehension: classify, describe, discuss, explain, express, identify, indicate, locate, recognize, report, restate, review, select, translate

Application: apply, choose, demonstrate, dramatize, employ, illustrate, interpret, operate, practice, schedule, sketch, solve, use, write

Analysis: analyze, appraise, calculate, categorize, compare, contrast, criticize, differentiate, discriminate, distinguish, examine, experiment, question, test

Synthesis: arrange, assemble, collect, compose, construct, create, design, develop, formulate, manage, organize, plan, prepare, propose, set up, write

Evaluation: appraise, argue, assess, attach, choose, compare, defend, estimate, judge, predict, rate, core, select, support, value, evaluate

Sample Exam

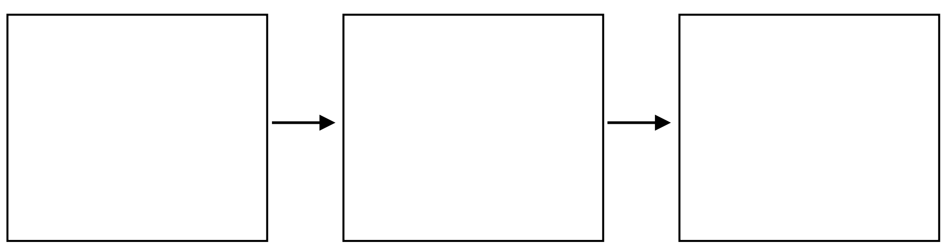
In groups, examine and discuss the questions below and determine which Bloom's level each question represents. Be prepared to defend your answers.

1. Ebola is an infectious disease.

   T F

2. You are a scientist and are identifying species of fungi in the field. You come upon a fungus that appears to have a symbiotic relationship with a tree, where the fungal mycelium has grown around and within the cells of the tree's roots. Which type of mycorrhizal fungi have you found, and how do you know this?
   a. Ectomycorrhizae, because the mycelium has penetrated the cells of the tree.
   b. Ectomycorrhizae, because it is the only type of fungus that can form a symbiotic relationship.
   c. Endomycorrhizae, because the mycelium has penetrated the cells of the tree.
   d. Endomycorrhizae, because it is the only type of fungus that can form a symbiotic relationship.

3. In the three boxes below, illustrate how evolution could occur through natural selection in a population of tuberculosis. Then, describe what is taking place in each step. In your description, include the following terms: ***resistant***, ***mutation, natural selection, evolution, susceptible,*** and ***suitable trait.***



4. ***The Scenario:*** Tera is a 4th grade student in your classroom. She believes that the antibacterial dish soap that her mom uses at home does not inhibit bacteria from growing on their dishes. Her theory is that plain water will have the same affect as the dish soap. She sets up an experiment, dips 3 paper dots in the dish soap, and then arranges them on a nutrient agar Petri dish that has been swabbed with *E. coli*. She waits two days, and then measures the width of no-growth around each of her paper dots. She comes to class really excited and tells you that her theory was proven wrong, and that the dish soap really did inhibit bacterial growth!

   The Question: What mistakes can you find in this scenario? Please list the mistakes that you have identified in the space below.

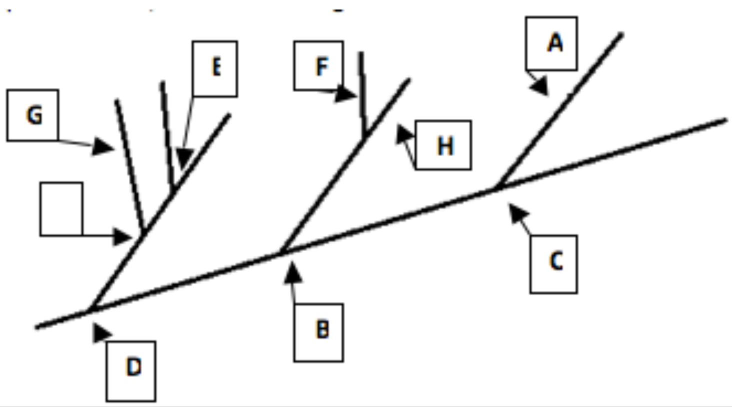
5. Briefly describe phagocytosis.

6. You hypothesize that one particular potato variety, the "lumper" variety, will grow well at low elevations. Design an experiment to test the affects of varying elevation on potato populations. Do not forget to include the components we have discussed all semester regarding proper experimental protocol.

7. Scientists identified resistance genes in a potato from South America, where farmers have preserved the genetic variation of potatoes by growing many cultivated varieties alongside the potato's wild cousins. Despite the warnings of evolution and history, much agriculture continues to depend on genetically uniform crops that have been genetically engineered to exhibit desired traits.

   Would you recommend genetically modifying potatoes that are presently grown in the U.S. to be resistant to such diseases as *Phytophthora infestans*? Why or why not?

For question 8, refer to the diagram below.



8. What would happen if the positions of F and H were flipped?
   a. All relationships would remain the same.
   b. F would become more related to A.
   c. Node B would represent a more derived group.
   d. The length of time between F and H would increase.
   e. Nodes I and E would also flip positions.

9. Protists feed by one of three methods:
   (1) ingesting packets of food
   (2) absorbing organic molecules directly from the environment
   (3) performing photosynthesis

   For one of these methods, describe an example seen in lab. Name the organisms and the structures they used during this feeding event.

10. If a hydra lost its nematocysts, what could be one possible outcome?

Lab Report Rubric – LIFE 1010 General Biology

	2 pts.	**1.5 pts.**	**1 pts.**	**0.5 pts.**	**Score**
Writing	Format follows course guidelines for the lab report. Report was proof read and no obvious errors are present. Writing includes complete sentences and is easily understood.	Minor errors in formatting, grammar, and spelling. Overall message is easily understood.	Frequent errors in formatting, grammar, and spelling. Some incomplete sentences are present and the flow of ideas is at times difficult to follow. Format is inconsistent.	Numerous grammatical and spelling errors – the lab report was not proof read. Flow of ideas is difficult to follow. Format and style are inappropriate for the assignment and do not follow the course guidelines.	
	4 pts.	**3 pts.**	**2 pts.**	**1 pts.**	**Score**
Title and Introduction	A descriptive title is included that clearly represents the main experimental question or finding. The introduction contains necessary background information from relevant sources to introduce the research question and the information is translated into student's own words. Purpose of the experiment, research question, hypotheses (both null and alternative), and predicted outcome are clearly stated.	A descriptive title is included that clearly represents the main experimental question or finding. The introduction refers to some necessary background information but does not completely support the research questions. Purpose, research question, hypotheses, and predictions are stated.	The title does not make clear what the main experimental question is. The introduction does not provide adequate overview of the research question, and/or research question, hypotheses, or predictions are missing.	The title is generic (e.g. Lab Report 1) or missing. Little to no background information is provided. The report is missing several pieces of introductory information including purpose, research question, hypotheses, and predictions.	
	2 pts.	**1.5 pts.**	**1 pts.**	**0.5 pts.**	**Score**
Methods	The methods for collecting data are clearly described – someone who has never done this before could read the methods and easily duplicate the data collection. Methods are written in past tense, in paragraph form and not as a list of steps like in a cookbook. A description of the controls and replications are included.	A few minor steps are missing but all of the important steps are included. Methods are written in paragraph form. A description of the controls and replications are included.	A few important steps in the methods are missing. Methods are written in paragraph form.	Procedures for data collection are unclear and missing important steps. Methods are not written in paragraph form.	
	4 pts.	**3 pts.**	**2pts.**	**1 pts.**	**Score**
Results	The results from the experiment and the associated analyses are thoroughly described but are not interpreted. Any trends, outliers, suspect data points, or interesting relationships are identified (but not interpreted). Figures are referred to in the text using figure numbers.	The results are missing descriptions of a few minor pieces of the data collected or analyzed. Any trends, outliers, suspect data points, or interesting relationships are identified (but not interpreted). Figures are referred to in the text using figure numbers.	A few major descriptions of the data or analyses are missing. Trends, outliers, data points, or interesting relationships are missing. Figures are not referred to in the text.	No basic description of the data or the analyses. Trends, outliers, data points, and interesting relationships are all missing. Figures are not referred to in the text.	

	6 pts.	4 pts.	2 pts.	1 pts.	Score
Discussion	The results are correctly interpreted and related to the research questions, hypotheses, and predictions. Hypotheses (both null and alternative) are accepted or rejected with a clear explanation. The results are compared to previous research cited in the discussion. Errors in the experiment are identified and their implications are discussed, as are modifications or improvements that should be made in future research. Relevant additional research questions arising from the result are posed and further studies are suggested. Clear understanding of the results and experiment is evident.	Most of the results are correctly interpreted and related to the research questions, hypotheses, or predictions. Hypotheses are accepted or rejected with at least a minimal explanation. Results are compared to previous research. Errors in the experiment are identified, as are modifications or improvements that should be made in future research. At least one research question arising from the result is posed and further studies are suggested. Clear understanding of the results and experiment is evident.	Some of the results are correctly interpreted. Results are superficially compared to previous research. Hypotheses are accepted or rejected but no explanation is provided. Errors in the experiment or improvements are discussed. Additional research questions and future studies suggested are not relevant. Partial understanding of the results and experiment is evident.	Results are incorrectly interpreted or discussion is incomplete. Hypotheses are not addressed. No errors or modifications are identified. No additional research questions or future studies are suggested. There is an overall lack of understanding of the results.	
	3 pts.	**2 pts.**	**1 pts.**	**0.5 pts.**	**Score**
Citations	Each in-text citation is included in the Literature Cited section and vice versa. In-text citations are formatted correctly. No direct quotes are used, and all work cited is paraphrased appropriately. Literature Cited is formatted correctly according to course guidelines.	Minor errors in formatting but all other requirements are followed. No direct quotes are used, and all work cited is paraphrased appropriately.	A few formatting errors for in text citations or literature cited. An in-text citation or citation in the Literature Cited is missing. No direct quotes are used, and all work cited is paraphrased appropriately.	Format and style are inappropriate for the assignment and do not follow the course guidelines. Direct quotes are used or work is not paraphrased appropriately.	
	4 pts.	**3 pts.**	**2 pts.**	**1 pts.**	**Score**
Figures and Tables	The figures/tables are correctly displayed. Each figure/table is labeled (e.g. Fig. 1). Figure axes are correctly labeled and include units. Columns and rows are clearly labeled in tables. A clear description is given as a caption for the figure or table (i.e. a reader could look only at the table/figure and understand the data). Figures/tables are clear, organized, easy to read, and follows the format for the course guidelines.	The figures/tables are correctly displayed but have minor problems. Minor issues with formatting but otherwise all formatting requirements are met.	Some mistakes with the figures/tables. Inappropriate format is used for the graphs (e.g. line vs bar). Important information is missing from the caption. Some labels are missing.	Figures/tables contain significant errors that lead to incorrect interpretation or results. Labels are missing and formatting is incorrect and does not follow guidelines.	
				TOTAL Points =	

WORDS AND PHRASES FOR PROMPT AND RUBRIC DESIGN

Developed by the SBE Design Team, Northern Colorado BOCES

Instruction Verbs for Five Levels of Thinking				
KNOWLEDGE/ COMPREHENSION	APPLICATION	ANALYSIS	SYNTHESIS	EVALUATION
list	use	inspect	plan	rate
repeat	show	inventory	create	score
record	apply	examine	design	choose
relate	employ	diagram	program	value
locate	interpret	analyze	manage	select
review	operate	compare	arrange	assess
restate	sketch	contrast	compose	estimate
describe	schedule	relate	propose	appraise
discuss	illustrate	question	set up	evaluate
explain	translate	test	collect	revise
recognize	demonstrate	measure	assemble	judge
identify	dramatize	differentiate	prepare	debate
define		distinguish	construct	oppose
report		calculate	formulate	defend
name		experiment	organize	criticize
recall			connect	
tell				

FOUR LEVELS OF DIFFERENCE IN DEGREE		
DEGREES OF UNDERSTANDING	DEGREES OF FREQUENCY	DEGREES OF EFFECTIVENESS
▪ thorough/complete ▪ substantial/extensive ▪ minimal/general ▪ partial/some misunderstanding	▪ nearly always/always ▪ often/frequently ▪ sometimes/occasionally ▪ rarely/almost never/ never	▪ highly effective ▪ effective ▪ moderately effective ▪ minimally effective/ ineffective

Descriptors for Weaker Performance Levels

- recognizes and describes briefly
- incomplete attempt
- with some errors
- without complete understanding
- generally explains
- general, fundamental understanding
- uses a single method
- represents a single perspective
- identifies few connections
- without drawing accurate conclusions
- without explaining the reason
- presents confusing statements and facts
- without demonstrating complete understanding of the characteristics
- with limited details
- demonstrates beginning understanding
- has a general sense
- with inaccuracies
- takes a common, conventional approach
- overlooks critical details
- relies on single source
- vague or incomplete description
- unable to apply information in problem solving
- does not perceive a pattern
- presents concepts in isolation
- omits important details, facts, and/or concepts
- no evidence of future projections

Descriptors for Stronger Performance Levels

- thoroughly understands and explains
- efficient, thorough solution
- without errors
- thorough, extensive understanding
- provides new insight
- thorough mastery of extensive knowledge
- uses multiple methods
- represents a variety of perspectives
- draws complex connections
- draws logical conclusions which are not immediately obvious
- clearly explains the reasoning
- provides clear, thorough support
- demonstrates complete understanding of all the characteristics
- in elaborate detail
- sophisticated synthesis of complex body of information
- shows an impressive level of depth
- with precision and accuracy
- takes an original, unique, imaginative approach
- provides comprehensive analysis
- uses multiple sources
- thorough explanation of critical analysis
- solves problem by effective application of information
- identifies an abstract pattern
- relates concepts using a variety of factors
- thorough presentation of important details, facts, and concepts
- predicts future changes

Difficult Situation Scenarios

Scene 1

You are the lab instructor for LIFE 1010, General Biology, at the University of Wyoming. You begin your class as you always do until a student arrives a few minutes late and makes a bit of a disruption as she enters the room and finds her seat. As you continue on with the lab you begin to suspect that your late student may be under the influence. Your suspicions are confirmed after you encounter the student one on one and can smell alcohol on them. What do you do if the student becomes very disruptive and distracting to the class? What would you do if the student were not disruptive?

Scene 2

You are teaching a night lab for LIFE 2023, Plant and Fungal Biology, that meets for three hours each week. It's the middle of the semester and you have a good relationship with each of your students; you know everyone by name. One particular student in your class seems to be very friendly to you. You start to notice that this student is feeling that you are no longer his teacher but his friend. At first you don't worry about this but something happens. A problem arises when the student skips an entire lab period without sending you any notice. In the next lab period you ask the student where they were. He tells you that his fraternity had a flag football game and he had to go to it because he plays. He continues to tell you that his attendance in the game was REQUIRED because he is actively pledging the fraternity this semester. If he had skipped the game then he would be out of the fraternity. You start to tell the student that his first priority is school not flag football but he interrupts you and tells you that not only was he required to go to the game by his fraternity but it was also the championship game. What do you do about this student? Clearly he is pressuring you because he feels some sort of connection with you. He even tries to make you feel guilty by playing the "I thought you were cool" card. How do you deal with this "friend"? What would you do if you were downtown at the Buckhorn Bar on a Friday night, and this student comes in the door and is very excited to see you because you are one of his favorite TA's? How would you handle the situation if he offers to buy you a beer?

Scene 3

One morning you are holding office hours when one of your student's parents comes in. The parent is quite irate with you and is upset that their daughter is not doing well in your LIFE 1002, Discovering Science, lab. The parent blames you for their daughter's poor performance and wants to know why you are singling out their daughter. You continue to talk to the irate parent and find out that the student has told them a very different version of what you view the problem to be. How do you deal with the upset parent? What plan of action do you see will best resolve this situation?

Scene 4

You are a TA in LIFE 1020, Life Science for elementary education majors, and are dealing with sensitive topics (ie: genetic engineering, evolution, etc.). After grading the first assignment, a student accuses you of insulting their beliefs because of comments you made on their assignment. You are certain that you have not behaved in an insulting manner, and feel that the accusation is untrue. From your perspective your comments were intended to help them understand the topic. How would you handle this situation? What would you do if during class one day, some of your students begin a debate about one of the controversial topics that was introduced in the course? You realize that the students' personal views are very different from each other, and perhaps from your own, and the students are becoming very passionate about the issue. How do you foster a discussion that does not affect you or the students ethically?

Scene 5

During one of the LIFE 1003, Current Issues in Biology, labs that you are teaching you notice that two of the written lab reports that were turned in are very similar. You had discussed plagiarism at the beginning of the semester and had mentioned that although the students were working in lab groups during their experiments, their reports were to be written individually. The two reports that you are grading have almost the same text with the exception of a few words and the rearrangement of a few paragraphs. How would you handle this situation? What if, upon confronting one of the two students, they claim that they had given their report to the other student because they said they needed help writing their discussion section? Should both students be dealt with in the same manner?

Scene 6

You have really enjoyed teaching your lab section for LIFE 2022, Animal Biology, however there is one lab table that is continually disruptive in class. You have asked them repeatedly to not talk while you are talking and to respect others around them, yet they still continue to talk during lab. After lab one day two students from another lab group approach you and mention that they are having difficulties concentrating in class due to the disruptive table. What would you tell these two students? How would you handle the disruptive students? If the problem persists, what would you do?

Scene 7

The day before the final lab report is due for LIFE 1010, a frantic student shows up at your office. Last week in lab, she neglected to copy down the raw data from her group's experiment, and she was depending on her lab partner to email her the information after class. Now, with just one day left to finish her paper, she says she has not been able to get in touch with her partner and so she has not yet begun to write her report. You have on your desk a completed lab report from another student in the class that contains all of the data she would need. How would you respond to the student?

Things to do Before Class Begins: A Checklist[3]

All this stuff should be in the syllabus, but if you can't find it, contact your lab coordinator to find out:

- The goals of the course
- When the class meets
- Where the class meets
- What to do about absent students
- What to do about make-ups
- How you can obtain the textbook for the course
- How you can obtain a course syllabus
- How you will deal with withdrawals
- How your hours are spent for the week
- The course requirements concerning grading and deadlines for work
- The level and range of abilities for students who take this course
- What kinds of assignments you will be responsible for creating and evaluating
- What students are expected to learn as a result of your teaching

Check the room you will be teaching to make sure you have all the necessary materials to teach

Talk to GLAs who have taught the course before to find out about their experiences with the course.

Find out what help you can expect with Xeroxing or getting supplies.

How to be a Successful Teacher: Empathy and Enthusiasm

Educational psychologists studying student evaluations found two major factors that correlated with high student perceptions of the quality of their instructor (empathy and enthusiasm). How can you build rapport the first day?

- In order to set up a supportive environment, start the first day with activities that break the ice and get students used to speaking in front of groups. Successful instructors offer personal information to get the ball rolling.
- It's important to make sure students know that you respect their thoughts and you are interested in finding out about their knowledge, but are in control of how the discussion moves. Do this through learning their names and using successful discussion practices. Say things like, "That's an interesting idea, tell me more."

[3] Acitelli, L.K. (Ed.) (1989). *A Guidebook for University of Michigan Teaching Assistants*. Ann Arbor, MI: The Center for Research on Learning and Teaching, University of Michigan.

- ❖ Non-verbal cues can help foster a good rapport. Nodding and smiling while students ask questions, keeping eye contact with whomever is speaking, walking toward the person who is speaking, walking around the room during a discussion, stand by students who have not contributed to the discussion, proximity may draw them in.

Ways to Deal with Nervousness

- ❖ **Practice**: doing all or part of your presentation aloud several times will make you feel more confident. Do at least one dry run in front of an audience, even it is your dog.
- ❖ **Prepare**: go to the classroom you'll be in and familiarize yourself with it and its equipment.
- ❖ **Visualize**: imagine a positive response from your students.
- ❖ **Make a strong start**: start with something easy to remember, ask a question, tell a story, or pose a problem.
- ❖ **Concentrate on ideas**: focus on the ideas you want to get across and not on the nervousness. Think about your student's needs and not your own.
- ❖ **Use Audiovisual Aids**: it can be particularly reassuring to have it written on the board.
- ❖ **Assume a Confident Attitude**: Remember, to your class, your nervousness may appear to be enthusiasm.
- ❖ **Write down a few questions to ask the class during your presentation**: it will help you remember to include them. Also when asking questions pause, give them a minute to think!

Emergency Protocol for LIFE Labs

Minor injury – shallow cut/scrape

If a student sustains a minor injury requiring basic first aid (i.e. a band-aid), there are first aid kits on the front counters in both lab prep rooms in Biological Sciences (142/143, 144/145), on the side counter in Aven Nelson 223, and in the biology cabinets in Physical Sciences 237.

Eye injury

There is also an eye wash station at the back sink in each room in Biological Sciences. If the eye wash station is needed, please also contact either Student Health or Ivinson Memorial for additional care.

Significant injury or illness – deep cut, student passes out, seizure, etc.

If a student is injured or becomes ill during lab and the student needs medical attention contact:

1. Student Health (8-5 PM) 766-2130
2. Ivinson Memorial (night labs) 742-2142
3. 911

Hazardous chemical spills, fires, explosions, etc.

Call 911 immediately.

With any injuries or emergencies, please contact a lab coordinator immediately after helping student:

- Brianna Wright: [redacted]
- Carly Jordan: [redacted]
- Liz Flaherty: [redacted]
- Diane Gorski: [redacted]

For locked buildings or safety problems, please contact Campus Security at (766-5179)

Please enter your lab coordinator's cell phone number, student health, and campus security numbers into your cell phone.

Do Graduate Teaching Assistants Benefit from Teaching Inquiry-Based Laboratories?

DONALD FRENCH AND CONNIE RUSSELL

Although the debate about the balance between research and teaching at the university level has yet to be settled (Brand 2000), it is indisputable that a principal role of the research university is to teach students to do research (Gonzàlez 2001). Because learning takes place most rapidly when students are actively involved in the learning process (Leonard 1989), students should learn how to do research not by listening or reading about it, but by doing it. This has been the basis of graduate education for decades and, increasingly, the path taken at the undergraduate level as well (Gonzàlez 2001). Moreover, it has been stated that people learn as much as 95 percent of what they teach (Uno 1999), which, if true, makes teaching the most effective of all learning activities. If this is so, does it not follow that graduate students, who commonly serve as teaching assistants (GTAs), benefit from teaching others how to do research?

Graduate students are encouraged to make presentations about their research to get feedback about their work. In many institutions, they may also have the opportunity to mentor undergraduates who are involved in research projects. However, graduate students have another opportunity to learn about research while teaching about research—through inquiry-based laboratories taught at the introductory level.

For many years, the mainstay of the undergraduate laboratory experience has been the "verification-style" laboratory, in which students demonstrate a concept, already taught in lecture, by following a set of instructions and comparing the results to a known outcome. Essentially, in such labs there is only one correct result, and both the instructor and the astute student typically know the result beforehand. In these labs, it is actually the designer of the laboratory who is "doing the science," for it is the instructor who has selected the hypothesis or generalization to be tested, designed the experiment, carefully delineated the protocol, selected the variables and their values, and predicted the outcome. The students simply follow the steps, fill in the tables, and answer questions. Students view the laboratories as "busy work" with the goal of simply filling in worksheets—much like their high school experience. The GTAs clarify the steps and correct the mistakes. GTAs receive no intellectual stimulation from essentially repeating what is in the lab manual and merely checking answers against a key provided by a faculty member or lab coordinator. It is not surprising that the students and the GTAs may not value this experience.

Inquiry-based laboratories provide a different experience. Although there are variations of inquiry-based instruction (e.g., open-ended, guided, challenge), they share all or most of the following characteristics: Inquiry-based instruction places more emphasis on the students as scientists. It places the responsibility on the students to pose hypotheses, design experiments, make predictions, choose the independent and dependent variables, decide how to analyze the results, identify underlying assumptions, and so on. Students are expected to communicate their results and support their conclusions with the data they collected. In inquiry-based labs, the concepts behind the experiments are deduced during the lab; the results are unknown beforehand, although pre-

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dictable, because the students designed the experiments. Results that do not support the students' hypotheses are not viewed as a failure but as an opportunity for the students to rethink any misconceptions in their understanding of concepts (Uno 1990, Leonard 1991).

If this sounds like the process of science as scientists conduct it, it should. It may also sound like the projects that are conducted in graduate courses or toward the end of an upper-division biology course. Inquiry-based labs are also becoming common in introductory-level and midlevel classes, and thus are producing laboratories that follow the guidelines described in the National Science Education Standards (NRC 1996, Howard and Boone 1997, Adams 1998, Siebert and McIntosh 2001). However, many GTAs were not enrolled in such labs as undergraduates and thus are unfamiliar with them. Despite different types of GTA training (Rushin et al. 1997), GTAs often begin teaching the laboratories with only limited training and little time to become socialized into the ranks of instructors conducting such inquiry-based courses (Shannon et al. 1998). They are therefore unfamiliar with the potential of inquiry-based labs to teach both the student and themselves about conducting research.

Is it better for those who plan careers in research to minimize their involvement in teaching so as to concentrate on doing research, or can teaching inquiry-based labs complement other activities through which GTAs learn to conduct research? McPherson (2001) has argued that most beginning graduate students confuse "hypothesis" and "prediction." Isaak and Hubert (1999) point out that, although it is important for graduate students to learn the scientific method, the first opportunity for many to do so is during their thesis or dissertation research. However, given that most graduate students begin teaching before this stage and that inquiry-based labs mirror the scientific process, perhaps teaching in inquiry-based laboratories offers GTAs an additional opportunity to practice their scientific skills before conducting their research. We examined this proposition through surveys that asked GTAs whether teaching in an inquiry-based laboratory influenced their research skills.

Laboratory and graduate teaching assistant descriptions

The GTAs who participated in this study taught in a laboratory that is part of a large-enrollment, mixed-majors, introductory biology course that was redesigned to include inquiry-style laboratories. Before each lab, students read a short story that describes a general situation and presents a general question. They also perform activities in the Zoology Department's Learning Resources Center (LRC) to become familiar with relevant concepts and equipment. The students then prepare planning forms on which they identify a more specific question, propose a relevant hypothesis, and design an experiment to test it. In lab, each group of three students agrees on a hypothesis to test, decides on an experimental design, selects equipment and procedures from those described in the reference portion of the laboratory manual (French 2000), conducts the experiment, and writes a report. The GTA's role is to review the planning forms; Socratically guide students to the information they need; help students revise hypotheses, experiments, predictions, and conclusions; and facilitate experiments and report writing.

GTAs at our institution work 20 hours per week. Those who are assigned to the introductory biology course typically teach three laboratories (9 contact hours) and hold office hours in the LRC for 2 hours per week. The GTAs also grade the prelabs, planning forms, and lab reports. Because the university prohibits first-year graduate students who lack teaching experience from teaching freshmen (Mills and Hyle 2001), these GTAs perform support duties that include working in the LRC and circulating through the three simultaneous laboratory sections to assist groups or attend to needs such as equipment failures or supply shortages. Thus, we had three general types of GTAs: experienced (GTAs who had taught the course prior to this study), new (GTAs who may have taught previously but were teaching this course for the first time), and rookies (inexperienced, first-year graduate students who were assigned to support duties).

GTA instruction

During an orientation training session (1.5 days) at the beginning of the semester, the GTAs learn about procedures and policies, underlying teaching philosophy, and pedagogy involved in the lab. GTAs grade sample papers using a standardized evaluation scheme, conduct their own experiments, and write their own reports. During the training lab, experienced GTAs model the teaching method; new and rookie GTAs participate as students. When they conduct the labs, the GTAs are encouraged to

- act as research advisors
- avoid lecturing at the beginning of class
- refrain from general announcements and instead contact each group separately
- answer questions with questions that direct the students
- help students find relevant sections in the lab manual to answer procedural questions
- observe students as they write and offer suggestions to them through questions

During the semester, the GTAs and the lab coordinator meet weekly to discuss procedures and grading, learn to use equipment, and exchange other needed information. Led by a senior GTA, they discuss the acceptable and unacceptable hypotheses and predictions that students might propose in the week's lab and the potential controls and factors that have contributed to success or failure of past experiments.

Assessment

Each semester from fall 1999 to spring 2001, we asked the GTAs, prior to the orientation training session, to answer questions concerning their previous teaching experience, their plans to conduct their classes, and what effect they thought teaching the course would have on their research (box 1). At the end of every semester, we asked the GTAs to complete a questionnaire, anonymously, which included open-ended questions regarding their perceptions of how teaching the inquiry-based course had influenced their teaching or research skills (box 1).

We pooled the responses to both surveys for all semesters and analyzed them following the qualitative analysis procedures of Rubin and Rubin (1995). The analysis involved coding responses to define common issues by assigning summary phrases of text to these various issues and then reevaluating and clustering the related issues into major themes. In reporting results, we selected direct quotes to illustrate examples of coded themes. Unless otherwise stated, all quotes were from different GTAs.

Because the postsemester surveys were returned anonymously and because we did not distinguish between new and rookie GTAs, we divided the GTAs' responses into two categories: experienced (those who taught the inquiry-based course previously) and inexperienced (those who were rookie or new GTAs). Some of the experienced GTA surveys were from previously inexperienced GTAs, but because of GTA reassignment, attrition, or graduation, no GTA answered the survey more than once as an experienced GTA.

Box 1. GTA survey questions

Presemester questions

1. Please list your teaching experience.
2. Do you have any intention to teach after you earn your degree? At what level?
3. Do you think that teaching this lab will have any effect on how you conduct your research?

Postsemester questions

1. Is this the first time you taught this course?
2. How has teaching these laboratories improved your ability to explain the process of science?
3. In what ways might teaching these laboratories have had a positive effect on your ability to plan your research?
4. In what ways might teaching these laboratories have improved?
5. In what ways might teaching these laboratories have improved your grasp of scientific method?
6. In what ways might teaching these laboratories have improved your grasp of experimental design?

Note: The actual survey forms include other questions not relevant to this discussion. Those questions have been omitted.

GTA perceptions

Presemester questions. When experienced GTAs were asked what they thought their role in conducting the laboratory would be, they generally gave longer responses than did inexperienced GTAs, and they focused more on aspects of pedagogy or the process of science rather than on "helping students to understand concepts" or on classroom management issues.

Additionally, experienced GTAs tended to portray themselves as facilitators or guides rather than as presenters of information, the role that inexperienced GTAs described. Statements such as "I rely on students asking questions, and then I answer with a simpler question that leads them to their answers" from an experienced GTA stand in stark contrast to statements from an inexperienced GTA, such as "I intend to cover the areas thoroughly and accurately while maintaining control of the classroom." Experienced GTAs felt that a "brief (typically 5–10 minutes) lecture at the beginning of each lab, to clarify procedures or complicated processes" was necessary as often as did inexperienced GTAs. However, casual observations by the lab coordinator throughout the semesters and unsolicited student comments on teaching evaluations indicated that experienced GTAs were less likely to exceed the 10 minutes. Experienced GTAs were more likely to begin class with brainstorming sessions or other nonexpository interactions.

In answer to whether they felt that teaching this lab would affect how they conduct their research, only 19 of 35 respondents anticipated a positive effect (binomial test, $p > .5$). Thus, before they experienced inquiry-based laboratories, GTAs did not perceive that this style of teaching would have any effect on their ability to do research. Respondents who anticipated a positive effect cited improvement in their understanding of the process of science, the importance of controls, and so on. For example, one (inexperienced) GTA replied that "this lab will make me more conscious of the scientific method in my own work, as well as providing me with more experience in experimental design," while another (experienced) stated, "Of course, teaching this course reminds you of how important it is to be a participant in producing *good* science/sound science and presenting your findings in a manner which others can understand."

Of the 16 GTAs who did not think that teaching the lab would positively affect their research, only one was an experienced GTA. Three of these 16 GTAs, who may have misinterpreted the question, cited concern with time constraints on their research—"I will have to arrange my schedule to avoid time conflicts"—while the rest were ambivalent or gave no explanation about how teaching the course might affect their research.

End of semester questions. When asked how they might improve student performance, GTAs emphasized helping to guide students to a better understanding of how to "do science," particularly in generating good, testable hypotheses and in addressing critical research issues. Both the answers to the survey questions and comments by experienced GTAs during the weekly meetings repeatedly emphasized that a key factor in student success was the quality of the students' hypotheses—causal, falsifiable, testable, within constraints of the lab, and leading to specific, quantitative predictions. None of the answers to the survey questions addressed helping students with content issues.

Most GTAs (91 percent) also thought that teaching this course had greatly improved their abilities to explain the process of science. The following comments typify this feeling:

- "Every week trying to explain to people who have absolutely *no clue* about science in a way they can grasp the concept only improves our skills."
- "I have wholeheartedly embraced the scientific methods after seeing the students' so-called experiments. Controls are very very important."
- "It forces you to have a more thorough understanding of the concepts. It forces you to think about them from more than one perspective."

It appears that GTAs favor inquiry-style instruction after their experiences in teaching inquiry-based labs, with just a single student favoring only a verification-style of instruction (table 1). Because the responses of the experienced and inexperienced groups of GTAs were not entirely independent and the sample sizes were small, we could not compare these directly. However, more experienced GTAs (those who had taught at least two semesters of inquiry-based labs) significantly favored inquiry over the other possibilities combined ($p < 0.05$), while inexperienced GTAs (those who had only been involved in the inquiry-based lab for one semester) did not ($p > 0.25$). It remains to be seen whether this lack of significant preference among inexperienced GTAs reflects the small sample size or their more limited experience with this teaching style.

In contrast to their presemester opinion, when asked how teaching the course had effected their research, a significant majority of both inexperienced ($p < 0.005$) and experienced ($p < 0.025$) GTAs perceived a positive influence (table 1). GTAs mentioned improvements in their grasp of scientific method and experimental design and in their ability to communicate effectively, for example,

> Teaching this lab probably clarified a lot of aspects of research for me by forcing me to put everything in simpler terms in order for the students to understand it, such as exactly how to write a hypothesis and justify it, how they should present their results and interpret them, and how to write a scientific paper in general.

GTAs specifically mentioned that teaching in these labs made them more aware of the need to "keep it simple [and to] start with a clear problem and objective and build from it." One GTA mentioned that the labs "showed me what *not* to do, helped me to learn to think of *all* variables for an experiment while designing it," and, according to another, "helped me re: my research design, hypothesis formation, and also my writing!" Finally, another GTA commented that as a result of the labs "I find myself thinking more critically of my own work because these simple but very important principles [of scientific method] have been so well enforced from teaching." The importance to GTAs of writing good hypotheses and predictions and of designing a good experiment was also apparent in the weekly meetings. Guiding themselves, the GTAs chose to spend almost all their meeting time critiquing the merits of good and bad hypotheses and related experiments and predictions. They worked together to develop and calibrate a common grading scheme for hypotheses and elected to practice using the equipment on their own time.

Benefits of inquiry-based labs for GTAs

Many colleges and universities are following the lead of K–12 institutions by adopting the National Science Education Standards (NRC 1996, Siebert and McIntosh 2001) and emphasizing inquiry-style instruction in laboratories, many of which are taught by graduate students. When assigned to an inquiry-based course, GTAs must increase the depth and breadth of their knowledge in response to the uncertainty of not having a single, tested procedure to follow. GTAs' workloads thus increase, because they now have to be better prepared to deal with the wide range of student experiments and because grading reports consumes more time than does grading practicals, quizzes, or worksheets. Because the goal of a GTA is to earn a degree, which requires doing research, time

Table 1. Responses of experienced and inexperienced GTAs after teaching in the inquiry-based lab.

		Perceived effect on instructional strategy				Perceived effect on graduate research			
Teaching experience	Number	Favors inquiry	Favors traditional	Favors combination	Nonresponsive	Positive	Negative	Mixed	Nonresponsive
Experienced	12	9	0	2	1	10	1	1	0
Inexperienced	15	9	1	5	0	11	0	1	3
Total	27	18	1	7	1	21	1	2	3

Note: The responses grouped as "nonresponsive" were either blank or could not be categorized.

spent teaching inevitably reduces potential time to do research. Taking an inquiry-based lab helps the students learn science (Leonard 1997), but does teaching this lab benefit the GTAs?

The statement that we learn 95 percent of what we teach (Uno 1999) usually refers to scientific techniques, facts, and concepts. However, if the focus of teaching switches from emphasizing facts to emphasizing the process of science, then it should follow that graduate students would learn how to do science (research) better by teaching inquiry-based labs. In our labs, the GTAs helped the students write good hypotheses, select techniques, and design experiments. They evaluated the students' results, judged the validity of their conclusions, critiqued their writing, and helped them find references. Essentially, GTAs engaged in all the research activities that they will do in pursuit of their graduate degrees and as supervisors at universities or in companies or government agencies. In fact, during the training sessions at the beginning of the semester, the GTAs are told to think of themselves as research advisors to seven student research teams per lab and to think about how they would like their research advisor to treat them. While teaching, GTAs are constantly forced to think about and clearly articulate what it means to conduct research properly.

In describing a model for graduate research training, Isaak and Hubert (1999) described the need for graduate students to make a transition from memorizing the content presented to them to thinking creatively, developing original ideas, and communicating effectively. They further characterize new graduate students as inexperienced researchers who are learning to apply the scientific method while developing the attributes of creativity, critical thinking, and rigorous testing of experimental design. Finally, Isaak and Hubert note that graduate students' research is often detrimentally affected by their lack of understanding of how to apply scientific method and of the relationship between hypotheses, prediction, and methods, a theme reiterated by McPherson (2001). Do the GTAs think that teaching inquiry-based labs contributes to their ability to do research? As we predicted, GTAs (inexperienced) unfamiliar with inquiry-based instruction did not initially recognize the relevance to their research. By the end of a semester, however, a significant number of responding GTAs did. Thus, it is important that faculty encourage GTAs to take advantage of the opportunity to learn from this experience.

If teaching an inquiry-based lab has some effect on graduate student research skills, then, in addition to their general perception that it does, we would predict that GTAs would make specific references to the components described above by Isaak and Hubert (1999) or McPherson (2001), and they did. Some commented directly that they saw how it improved their ability to do research. Others simply mentioned that they were more aware of the need for clear communication of ideas and methods and the importance of well-formed hypotheses. Some of the GTAs' descriptions of how best to conduct the laboratory paralleled the maturation of their understanding of the process of science as they gained experience and began to make the transition from student to researcher. For example, one description of the GTA's role changed from "help students apply what is being taught in lectures and make sure that the material taught in the lectures and labs is understood" (emphasis on memorization and repetition of facts) to "providing the students with an opportunity to construct their own ideas and concepts" (emphasis on creativity and critical thinking) as this particular GTA gained more experience in teaching inquiry-based labs. This type of change reflects the kind of shift discussed by Isaak and Hubert (1999) in their model.

Why is it that not all of the GTAs reported a positive influence? Some had less experience teaching in this manner, and rookies did not have any experience with being responsible for a lab. Some GTAs had nearly finished their degrees or were more focused on a specific research project and therefore perceived little impact on their research. When asked if teaching this course had changed one's approach to research, one doctoral GTA replied, "I haven't really changed the way I think about research, but I've got a more diverse research background than most people, and I'm fairly set in my ways." That a graduate student already felt set in his or her ways should concern those of us who think that the experience as a GTA plays a large role in shaping a college professor.

Most college and university science faculty have spent part of their time during graduate school teaching laboratories. While many GTAs view this situation as an opportunity to gain valuable teaching experience, others view it simply as a means to support their graduate studies (Milner-Bolotin 2001). Unfortunately, graduate students may sometimes be encouraged to think that teaching is of secondary importance to research (Boyer 1990, Shannon et al. 1998, Nyquist et al. 1999) by their advisors (Milner-Bolotin 2001), supervisors, and peers (Notarianni-Girard 1999).

Inquiry-based teaching is a new style to most GTAs. It requires more time and practice and can be frustrating. However, teaching inquiry-based labs involves critiquing experimental design, evaluating arguments, interpreting and solving problems, and other skills not developed in verification-style labs. These skills should be important to graduate students whose primary, if not exclusive, career goal is research. It is worth noting that our research shows that, although GTAs have to teach inquiry-based labs for more than one semester before they show a significant preference for this method, GTAs recognize its value to them as researchers by the end of one semester. Therefore, faculty should encourage their graduate students who are supported by a teaching assistantship to teach inquiry-based laboratories.

Teaching and research may be considered separate domains, because the emphasis on imparting factual knowledge, common in teaching, has little in common with the process of science embodied by research. However, just as the line between undergraduate and graduate education in terms of research and mentorship has changed (Gonzàlez 2001), so too has the balance between learning facts and learning the process of science at the introductory level.

On the basis of the benefits to undergraduates, previous studies have supported converting from verification-style laboratories to inquiry-based ones. That GTAs may be gaining valuable scientific training while teaching inquiry-based laboratories provides further support for a push to change the way in which laboratories are taught.

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References cited

Adams DL. 1998. What works in the nonmajors' science laboratory. Journal of College Science Teaching 28: 103–108.

Boyer EL. 1990. Scholarship Reconsidered: Priorities of the Professoriate. Princeton (NJ): Carnegie Foundation for the Advancement of Teaching.

Brand M. 2000. Changing faculty roles in research universities using the pathways strategy. Change 32: 42–45.

French DP. 2000. Investigating Biology: A Laboratory Resource Manual. 3rd ed. Orlando (FL): Harcourt Brace.

Gonzàlez C. 2001. Undergraduate research, graduate mentoring, and the university's mission. Science 293: 1624–1626.

Howard RE, Boone WJ. 1997. What influences students to enjoy introductory science laboratories? Journal of College Science Teaching 26: 383–387.

Isaak DJ, Hubert WA. 1999. Catalyzing the transition from student to scientist—a model for graduate research training. BioScience 49: 321–326.

Leonard WH. 1989. Ten years of research on investigative laboratory instruction strategies. Journal of College Science Teaching 18: 304–306.

———. 1991. A recipe for uncookbooking laboratory investigations. Journal of College Science Teaching 21: 84–87.

———. 1997. How do college students learn science? Pages 5–21 in Siebert ED, Caprio MW, Lyda CM, eds. Methods of Effective Teaching and Course Management for University and College Science Teachers. Dubuque (IA): Kendall/Hunt Publishing.

McPherson GR. 2001. Teaching and learning the scientific method. American Biology Teacher 63: 242–245.

Mills MR, Hyle AE. 2001. No rookies on rookies: Compliance and opportunism in policy implementation. Journal of Higher Education 72: 453–477.

Milner-Bolotin M. 2001. Creating community among the graduate teaching assistants: Benefits, challenges, and lessons learned. Journal of Graduate Teaching Assistant Development 8: 65–70.

[NRC] National Research Council. 1996. National Science Education Standards. Washington (DC): National Academy Press.

Notarianni-Girard D. 1999. Transfer of training in teaching assistant programs. Journal of Graduate Teaching Assistant Development 6: 119–147.

Nyquist JD, Manning L, Wulff DH, Austin AE, Sprague J, Fraser PK, Calcagno C, Woodford B. 1999. On the road to becoming a professor: The graduate student experience. Change 31: 18–29.

Rubin HJ, Rubin IS. 1995. Qualitative Interviewing: The Art of Hearing Data. Thousand Oaks (CA): Sage Publications.

Rushin JW, De Saix J, Lumsden A, Streubel DP, Summers G, Bernson C. 1997. Graduate teaching assistant training. American Biology Teacher 59: 86–90.

Shannon DM, Twale DJ, Moore MS. 1998. TA teaching effectiveness. Journal of Higher Education 69: 440–466.

Siebert ED, McIntosh WJ, eds. 2001. College Pathways to the Science Education Standards. Arlington (VA): National Science Teachers Association Press.

Uno GE. 1990. Inquiry in the classroom. BioScience 40: 841–843.

———. 1999. Handbook on Teaching Undergraduate Science Courses: A Survival Training Manual. Orlando (FL): Harcourt Brace.

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Article

Biology in Bloom: Implementing Bloom's Taxonomy to Enhance Student Learning in Biology

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We developed the Blooming Biology Tool (BBT), an assessment tool based on Bloom's Taxonomy, to assist science faculty in better aligning their assessments with their teaching activities and to help students enhance their study skills and metacognition. The work presented here shows how assessment tools, such as the BBT, can be used to guide and enhance teaching and student learning in a discipline-specific manner in postsecondary education. The BBT was first designed and extensively tested for a study in which we ranked almost 600 science questions from college life science exams and standardized tests. The BBT was then implemented in three different collegiate settings. Implementation of the BBT helped us to adjust our teaching to better enhance our students' current mastery of the material, design questions at higher cognitive skills levels, and assist students in studying for college-level exams and in writing study questions at higher levels of Bloom's Taxonomy. From this work we also created a suite of complementary tools that can assist biology faculty in creating classroom materials and exams at the appropriate level of Bloom's Taxonomy and students to successfully develop and answer questions that require higher-order cognitive skills.

INTRODUCTION

Most faculty would agree that academic success should be measured not just in terms of what students can remember, but what students are able to do with their knowledge. It is commonly accepted that memorization and recall are lower-order cognitive skills (LOCS) that require only a minimum level of understanding, whereas the application of knowledge and critical thinking are higher-order cognitive skills (HOCS) that require deep conceptual understanding (Zoller, 1993). Students often have difficulty performing at these higher levels (Zoller, 1993; Bransford *et al.*, 2000; Bailin, 2002). In the past decade, considerable effort has been directed toward developing students' critical-thinking skills by increasing student engagement in the learning process (Handelsman *et al.*, 2004). An essential component of this reform is the development of reliable tools that reinforce and assess these new teaching strategies.

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Alignment of course activities and testing strategies with learning outcomes is critical to effective course design (Wiggins and McTighe, 1998; Sundberg, 2002; Ebert-May *et al.*, 2003; Fink, 2003; Tanner and Allen, 2004; Bissell and Lemons, 2006). Students are motivated to perform well on examinations; therefore, the cognitive challenge of exam questions can strongly influence students' study strategies (Gardiner, 1994; Scouller, 1998). If classroom activities focus on concepts requiring HOCS but faculty test only on factual recall, students quickly learn that they do not need to put forth the effort to learn the material at a high level. Similarly, if faculty primarily discuss facts and details in class but test at a higher cognitive level, students often perform poorly on examinations because they have not been given enough practice developing a deep conceptual understanding of the material. Either case of misalignment of teaching and testing leads to considerable frustration on the part of both instructor and student. Though considerable attention has been given to changing our classrooms to incorporate more active-learning strategies, not enough attention has been placed on how to better align assessment methods with learning goals. Indeed, one of the most significant ways to impact the quality of student learning is through the improvement of our assessments (Entwistle and Entwistle, 1992).

How can we better assess our assessment methods? One approach is to use Bloom's Taxonomy of cognitive domains (Bloom *et al*., 1956), hereafter referred to as "Bloom's." Bloom's is a well-defined and broadly accepted tool for categorizing types of thinking into six different levels: knowledge, comprehension, application, analysis, synthesis, and evaluation. A revised version of Bloom's (Anderson *et al*., 2001) further subcategorizes the original taxonomy and converts the different category titles to their active verb counterparts: remember, understand, apply, analyze, create, and evaluate. Bloom's has been used widely since the 1960s in K–12 education (Kunen *et al*., 1981; Imrie, 1995) but has seen only limited application in selected disciplines in higher education (Demetrulias and McCubbin, 1982; Ball and Washburn, 2001; Taylor *et al*., 2002; Athanassiou *et al*., 2003).

Although Bloom's lends itself to wide application, each discipline must define the original classifications within the context of their field. In biology, Bloom's has been used to design rubrics for evaluating student performance on introductory biology exams (Bissell and Lemons, 2006), develop formative assessment questions at the appropriate cognitive level (Allen and Tanner, 2002), and inform course design (Allen and Tanner, 2007). Nonetheless, there is significant need for more comprehensive assessment tools that undergraduate biology instructors can easily use to assess student learning, guide development of teaching strategies, and promote student metacognition in the biological sciences.

We have developed the Blooming Biology Tool (BBT; Table 1), which can be used to assess the Bloom's Taxonomy level of questions on biology-related topics. The BBT evolved out of a study we were asked to participate in that required us to rank more than 600 biology exam questions from a wide variety of sources including MCAT, GRE, and AP biology exams, as well as introductory biology and first-year medical school courses (Zheng *et al*., 2008). Here we present a detailed description of the BBT and complementary materials for use by college and university faculty and students. We also highlight how we implemented the BBT and associated learning activities in a variety of educational settings. We found the BBT a useful guide for faculty

Table 1. Blooming Biology Tool

	Knowledge[1]	Comprehension[1]	Application[1]	Analysis	Synthesis	Evaluation
	LOCS[2]	LOCS[2]	LOCS[2] HOCS[3]	HOCS[3]	HOCS[3]	HOCS[3]
Key skills assessed	**IDENTIFY, RECALL,** list, recognize, or label	**DESCRIBE** or explain in your own words, re-tell, or summarize	**PREDICT** an outcome using several pieces of information or concepts; use information in a new context	**INFER**; understand how components relate to each other and to the process as a whole	**CREATE** something new using/combining disparate sources of information	**DETERMINE/CRITIQUE** relative value; determine merit
General examples of biology exam questions	Identify the parts of a eukaryotic cell; identify the correct definition of osmosis	Describe nuclear transport to a lay person; provide an example of a cell signaling pathway	Predict what happens to X if Y increases	Interpret data, graphs, or figures; make a diagnosis or analyze a case study; compare/contrast information	Develop a hypothesis, design an experiment, create a model	Critique an experimental design or a research proposal; appraise data in support of a hypothesis
Type of question						
Labeling	X	X	X			
Fill-in-the-blank	X	X	X	X		
True-false	X	X	X	X		
Multiple-choice	X	X	X	X		X
Short answer	X	X	X	X	X	X
Essay	X	X	X	X	X	X
Characteristics of multiple-choice questions	Question only requires information recall. Possible answers do not include significant distracters[4]	Question requires understanding of concept or terms. Possible answers include significant distracters[4]	Question requires prediction of the most likely outcome given a new situation or perturbation to the system	Question requires interpretation of data and selection of best conclusion	N/A: If provided with choices, students only differentiate between possible answers rather than synthesize a novel response	Question requires assessment of information relative to its support of an argument

[1] The first three levels of Bloom's are usually hierarchal; thus, to complete an analysis-level question, students must also demonstrate knowledge-, comprehension- and application-level skills.

[2] LOCS indicates lower-order cognitive skills.

[3] HOCS indicates higher-order cognitive skills.

[4] Significant distracters are those answers that represent common student misconceptions on that topic.

in diagnosing students' aptitudes and creating new assignments to help students develop critical-thinking skills. Our students used the BBT to create more challenging study questions and self-identify the skill levels that they find the most demanding.

DEVELOPMENT OF THE BLOOMING BIOLOGY TOOL

In developing the BBT, we first established a basic rubric that drew extensively on previous interpretations of Bloom's as it relates to biology (Allen and Tanner, 2002; Ebert-May *et al.*, 2003; Yuretich, 2003; Bissell and Lemons, 2006). Through research and discussion, we agreed that the first two levels of Bloom's (knowledge and comprehension) represent lower orders of cognitive skills (Zoller, 1993). We considered the third level of Bloom's, application, to be a transition between LOCS and HOCS. The three remaining categories (analysis, synthesis, and evaluation) are true HOCS but are not necessarily hierarchical, meaning that a question categorized as evaluation does not always require analytical and synthesis abilities, but may require mastery of the lower three levels (knowledge, comprehension, and application). While ranking questions, we found it helpful to "check-off" each level of Bloom's required to successfully answer the question. For example, a question rated at the analysis level would require knowledge (facts), comprehension (understanding of facts), application (predicting outcomes), and analysis (inference). Each question was ranked at the highest level of Blooms' taxonomy required for its solution.

The level of Bloom's that is assessed by a given type of exam question depends highly on what information is provided to the student and which inferences or connections the student must make on his or her own. It is equally important to consider the level of information previously provided through classroom instruction i.e., if students are explicitly given an answer to an analysis question in class and then given that same question on an exam, then that question only requires recall (Allen and Tanner, 2002). We would argue that labeling of diagrams, figures, etc., cannot assess higher than application-level thinking as this question-type, at most, requires students to apply their knowledge to a new situation. However, fill-in the blank, true-false, and multiple-choice questions can be designed to test analysis-level skills. It is nevertheless challenging to develop fill-in-the-blank questions that require higher than application-level thinking, but we have provided one such example (Supplemental Material A; Virology). Further, whereas multiple-choice questions can be designed to assess evaluation skills if they require students to determine relative value or merit (e.g., which data best support the following hypothesis), multiple-choice questions cannot assess synthesis-level thinking as all the answers are provided, eliminating the need for students to create new models, hypotheses, or experiments on their own. Many resources exist to assist faculty in designing high-quality, multiple-choice questions (Demetrulias *et al.*, 1982; Udovic, 1996; Brady, 2005), and we have provided a list of some of these resources (Supplemental Material B).

To differentiate between Bloom's levels, we found it useful to take one particular topic (e.g., cell biology) and develop a series of increasingly challenging exam questions representing the various levels of Bloom's. In developing these multi-level questions, we considered what a student must know or be able to do in order to answer the question. For example, if the student needed to recall factual information and then be able to describe a process in his/her own words, we considered that question to test comprehension. We have provided examples for three different subdisciplines of biology: cell biology, physiology, and virology, (Supplemental Material A). A similar approach was taken by Nehm *et al.* for the subdisciplines of ecology and evolution (Nehm and Reilly, 2007).

We also found that science questions posed unique challenges to our rubric as they dealt with science-specific skills (e.g., graphing, reading phylogenetic trees, evaluating Punnett squares and pedigrees, and analyzing molecular biology data). To address this, we selected several of these science-specific skills and created examples or descriptions of question-types that would assess mastery at each level (Table 2). Through this process and extensive discussion of our work, we were able to better define and categorize the different types of questions that are typically found on biology exams. To assist us in developing the rubric, we each independently ranked approximately 100 life science exam questions and then extensively discussed our analyses to reach consensus. The BBT reflects the progression of our insights into how to adapt a general assessment method to the discipline-specific skills inherent to biology. We subsequently independently analyzed another 500 questions; statistical analysis of our rankings based on the BBT revealed high interrater reliability (agreement of at least two of the three raters over 91% of the time; [Zheng *et al.*, 2008]).

The BBT is not meant to be an absolute or definitive rubric; rather, the BBT is meant to be used as a general guide to aid both faculty and students in developing and identifying biology-related questions representing the different levels of Bloom's. As with all assessment methods, we expect the BBT to continue to evolve through an iterative process. Continuous feedback from students and faculty using the tool will inform its evolution.

DEVELOPMENT OF THE BLOOM'S-BASED LEARNING ACTIVITIES FOR STUDENTS

The BBT can also be used by students to help them identify the Bloom's level of exam questions that pose the greatest academic challenge. However, once these challenging areas have been identified, students also need guidance on how to modify their study habits to better prepare themselves to answer those types of questions. We therefore created the Bloom's-based Learning Activities for Students (BLASt; Table 3), a complementary student-directed tool designed to specifically strengthen study skills at each level of Bloom's. We determined which study activities provided students with the type of practice that would lead to success at each Bloom's level. For example, the first two levels of Bloom's rely heavily on memorization skills that can be reinforced by an individual student using flash cards and mnemonics. However, the remaining levels of Bloom's that represent HOCS are more readily achieved through both individual and group activities. The BLASt incorporates a range of study

Table 2. Examples and descriptions of science-specific skills at different levels of Bloom's Taxonomy

	Knowledge[1]	Comprehension[1]	Application[1]	Analysis	Synthesis	Evaluation
	LOCS[2]	LOCS[2]	LOCS[2] HOCS[3]	HOCS[3]	HOCS[3]	HOCS[3]
Calculations	Equation provided and variables identified "plug and chug"	Understand/define components and variables of a given equation	Solve word problems by selecting correct formula and identifying appropriate variables	Solve word problem and infer biological significance or implication	Create an equation that describes the relationship between variables	Evaluate a computational solution to a problem or assess the relative merit(s) of using a specific mathematical tool to solve a particular problem
Concept maps	Structure provided, student fills in the missing linking phrases or concepts that are provided	Structure provided with concepts filled in, student generates linking phrases to describe relationships	Student creates the structure, concepts and linking phrases provided	Student creates structure, concepts are provided, student generates linking phrases to describe relationships and must link two different domains or maps together	Student creates structure and generates concepts and linking terms, map must be sufficiently complex	Student evaluates existing concept maps based on established criteria/rubric
Diagnoses	Identify or list variables found in patient history, vital signs, and/or clinical test results. Know which physiological problem each named disease represents (e.g., Graves' disease, hyperthyroidism)	Define each variable. Define the presenting signs and symptoms of each disease	Given a set of clinical variables, identify the relevant variables and make a diagnosis	Given a set of clinical variables and a diagnosis, determine which other possible diseases (differential diagnoses) need to be ruled out	Given a set of clinical variables and a diagnosis, determine the next clinical test that needs to be performed to confirm the diagnosis	Given a set of clinical variables and a diagnosis, evaluate the evidence supporting the diagnosis and provide the patient with a second opinion
Graphing	Identify the parts of graphs and recognize different types of graphs (e.g., identify the X axis, identify a histogram)	Describe the data represented in a simple graph	Draw a graph based on a given set of data; predict outcomes based on data presented in graph	Read and interpret a complex graph having multiple variables or treatments and explain biological implications of data	Create a graphical representation of a given biological process or concept	Assess the relative effectiveness of different graphical representations of the same data or biological concept
Hardy-Weinberg analyses	Given the Hardy-Weinberg (HW) equation define terms: p^2, q^2, 2pq; If given p+q = 1 and p = 0.7, calculate q	Describe the assumptions of the Hardy-Weinberg equation and its use as a null hypothesis What does 2pq represent in the Hardy-Weinberg equation? (HW equation not given)	Determine the expected number of homozygous recessive individuals in a population if the recessive allele is represented in 30% of that population (HW equation not given)	Determine if the following population is in HW equilibrium: 100 individuals of which 37 are SS, 8 are ss, and 55 are Ss. Defend your answer	Create a new version of the Hardy-Weinberg equation that incorporates 3 alleles	Analyze Chi-square resuts to weigh predicted evolutionary flux

(Continued)

Table 2. (Continued)

	Knowledge[1]	Comprehension[1]	Application[1]	Analysis	Synthesis	Evaluation
Molecular techniques	Identify what is being measured by a molecular technique (e.g., Northern analysis measures relative RNA levels in a given cell or tissue)	Understand what the results of a molecular technique indicate (e.g. the intensity of a band on a Northern blot indicates relative expression of a specific mRNA in the cell type or tissue from which the RNA was obtained)	Draw the expected results you would obtain from a given molecular technique or state which technique could be used to solve a novel problem (e.g., draw the banding pattern you would expect if you analyzed a protein complex containing a 55 kDa protein and a 35 kDa protein by SDS-PAGE)	Interpret the raw data obtained from a molecular technique, including the interpretation of controls and how to normalize data (e.g. interpret the results of a RT-PCR gel analysis by comparing relative expression of experimental genes to a standardized control gene)	Design an experiment using a given molecular technique to test a hypothesis (e.g., design an experiment using Northern analysis to test the hypothesis that transcription factor A regulates expression of gene B)	Assess relative merit of using two different molecular approaches to address a particular hypothesis (e.g., discuss the relative merits of using chromatin immunoprecipitation vs. electrophoretic mobility shift assay to test the hypothesis that a protein binds directly to the promoter of a particular gene
Phylogenetic tree/cladogram	Given a cladogram, circle the root, nodes, or monophyletic groups	Describe the relationship of sister taxa in a cladogram	Given four cladograms, identify which one is different and describe the evolutionary relationships that make it different	Given a set of taxa for which all but one in a pictured tree exhibit a synapomorphy, infer the evolutionary history of one of the taxa. With respect to that same synapomorphy, discuss your conclusions about the most recent common ancestor of the pictured taxa	Given a variety of synapomorphies from different organisms, create a cladogram, identifying where the derived shared characteristics were acquired	Given a case study showing that a group of organisms have different relationships depending on the type of data used to construct the tree, use new information provided to evaluate the collective data and infer the best true relationship of the organisms
Punnett squares and pedigree analyses	Given a Punnett square, identify components (genotypes or phenotypes; parents or offspring) of a given genetic cross	Given parental genotypes, make Punnett square to show or describe offspring's genotypes and phenotypes	Given parental genotypes in a word problem, student identifies variables and makes Punnett square to determine genotypic or phenotypic ratios of offspring. Student is provided with information regarding dominance, sex linkage, crossing-over, etc.	Given parental genotypes, make Punnett square to show or describe offspring's genotypes and phenotypes, and then solves a word problem with the new information. Student must infer relationships regarding dominance, sex linkage, crossing-over, etc.	Use pedigree analysis to develop a hypothesis for how a certain disease is transmitted	Weigh the relative value of different pieces of evidence (pedigree chart, incomplete transmission, linkage analysis, etc.) and determine the probability that an individual will develop a certain disease

[1] The first three levels of Bloom's are usually hierarchal; thus, to complete an analysis-level question, students must also demonstrate knowledge-, comprehension-, and application-level skills.
[2] LOCS indicates lower-order cognitive skills.
[3] HOCS indicates higher-order cognitive skills.
[4] Significant distracters are those answers that represent common student misconceptions on that topic.

Table 3. Bloom's-based Learning Activities for Students (BLASt)[1]

Bloom's level	Individual activities	Group activities
Knowledge (LOCS)	• Practice labeling diagrams • List characteristics • Identify biological objects or components from flash cards • Quiz yourself with flash cards • Take a self-made quiz on vocabulary • Draw, classify, select, or match items • Write out the textbook definitions	• Check a drawing that another student labeled • Create lists of concepts and processes that your peers can match • Place flash cards in a bag and take turns selecting one for which you must define a term • Do the above activities and have peers check your answers
Comprehension (LOCS)	• Describe a biological process in your own words without copying it from a book or another source • Provide examples of a process • Write a sentence using the word • Give examples of a process	• Discuss content with peers • Take turns quizzing each other about definitions and have your peers check your answer
Application (LOCS/HOCS)	• Review each process you have learned and then ask yourself: What would happen if you increase or decrease a component in the system or what would happen if you alter the activity of a component in the system? • If possible, graph a biological process and create scenarios that change the shape or slope of the graph	• Practice writing out answers to old exam questions on the board and have your peers check to make sure you don't have too much or too little information in your answer • Take turns teaching your peers a biological process while the group critiques the content
Analysis (HOCS)	• Analyze and interpret data in primary literature or a textbook without reading the author's interpretation and then compare the authors' interpretation with your own • Analyze a situation and then identify the assumptions and principles of the argument • Compare and contrast two ideas or concepts • Create a map of the main concepts by defining the relationships of the concepts using one- or two-way arrows	• Work together to analyze and interpret data in primary literature or a textbook without reading the author's interpretation and defend your analysis to your peers • Work together to identify all of the concepts in a paper or textbook chapter, create individual maps linking the concepts together with arrows and words that relate the concepts, and then grade each other's concept maps
Synthesis (HOCS)	• Generate a hypothesis or design an experiment based on information you are studying • Create a model based on a given data set • Create summary sheets that show how facts and concepts relate to each other • Create questions at each level of Bloom's Taxonomy as a practice test and then take the test	• Each student puts forward a hypothesis about biological process and designs an experiment to test it. Peers critique the hypotheses and experiments • Create a new model/summary sheet/concept map that integrates each group member's ideas.
Evaluation (HOCS)	• Provide a written assessment of the strengths and weaknesses of your peers' work or understanding of a given concept based on previously determined criteria	• Provide a verbal assessment of the strengths and weaknesses of your peers' work or understanding of a given concept based on previously described criteria and have your peers critique your assessment

[1] Students can use the individual and/or group study activities described in this table to practice their ability to think at each level of Bloom's Taxonomy.

methods and can be used by students to refine their study skills to become more efficient and effective learners.

IMPLEMENTATION OF THE BBT IN OUR CLASSROOMS

While developing the BBT, we found that the very process of developing the BBT was strongly influencing our own teaching in the classroom. The BBT was guiding us to ask and write better questions, develop more appropriate learning strategies, and assist our students in the development of their metacognitive skills. This tool provided us with a means to consistently apply the principles of Bloom's to biology concepts and skills, thus allowing us to better assess student-learning outcomes.

The following passages illustrate how we have applied the BBT at either a research-one institution or a liberal arts college in three different classroom contexts: (1) a small inquiry-based laboratory, (2) a large lecture, and (3) a medium-sized workshop setting. Table 4 presents the timelines of implementation of each teaching strategy. To facilitate a comparison of our different implementation

Table 4. Timelines for implementing the BBT in three different environments

Faculty use of the BBT in an undergraduate cell biology laboratory course	
1st Quarter	• Students read primary scientific literature on their topic of interest • Students formulate new hypotheses • Students design and perform pilot study to gather preliminary data • Students write a research proposal and receive written feedback on each draft
Postquarter	• Instructor designs a grading rubric to evaluate student performance on research proposal • Instructor uses BBT to classify Bloom's level needed to achieve success with each criterion in grading rubric • Instructor uses BLASt to develop new activities to help students master areas identified as weaknesses
2nd Quarter	• Students read primary scientific literature on their topic of interest • Students are introduced to grading rubric • Students peer-review previous quarter's research proposals • Students formulate new hypotheses • Students design and perform pilot study to gather preliminary data • Students write a research proposal
Postquarter	• Instructor uses grading rubric to evaluate student performance on research proposal
Faculty and student use of the BBT in an undergraduate physiology course	
Day 1	• Bloom's is introduced • Homework to develop a mnemonic for Bloom's is assigned
Day 2	• Discuss Bloom's mnemonics generated by students • Class is asked to "Bloom" the task of critiquing the mnemonics • Class is asked to "Bloom" the task of creating the mnemonic
Each day	• Students are asked to rank all questions according to Bloom's asked in class prior to answering the question
Prior to exam	• Students are given an old exam and told to Bloom each question and calculate the Bloom's distribution for the exam (i.e., what percent of points were given for questions at the level of knowledge, comprehension, etc.) This helps students realize the cognitive challenge level of the upcoming exam
Exam	• Instructor uses BBT to Bloom the exam questions and produces a Bloom's distribution. This helps the instructor better align the challenge of exam to course objectives
Postexam	• Students are shown the class average at each level of Bloom's • Bloom's rank of each questions is included on the exam key • Students enter scores for each of their exam questions into an on-line survey • Instructor computes each student's Bloom's score, posts the score to grade book • Students check their Bloom's score and view pertinent parts of BLASt
Last day of class	• Students are asked to submit a 1–2 paragraph response to the question " How has using Bloom's to analyze exam performance changed your learning strategies?"
Student use of the BBT in biology workshops at a liberal arts college	
Week 1	• Faculty gave formal lecture on Bloom's Taxonomy • Students practiced using Bloom's by ranking 45 biology and chemistry questions
Week 2	• Students worked in small groups to write questions about assigned primary literature papers; each group wrote 2 questions at each level of Bloom's for each paper (24 total) • Groups exchanged questions, ranked the questions, and answered 2 questions
Week 3	• Faculty generated 10 questions at different levels of Bloom's • Students worked in small groups to rank and answer questions
Weeks 6–10	• Each week a student group wrote 4 questions at each of the first 5 levels of Bloom's and submitted them to the faculty at the beginning of the week • Faculty selected the 10 best questions for workshop • Students worked in small groups to answer and rank questions using the BBT; the authors of the questions acted as peer tutors during the workshop

strategies, we have compiled a chart outlining the strengths and challenges of each approach (Supplemental Material C).

Use of the BBT by a Faculty Member in a Laboratory Course at a Research-One Institution

In a small, upper-division, inquiry-driven cell biology laboratory class (two sections of 11 students each) at a research-one institution, the BBT was used to evaluate student performance and redesign course activities to enhance student learning. The class was taught during consecutive quarters with a new cohort of students each quarter. The primary writing assignment in the course (worth 1/3 of the total grade) was a National Institutes of Health (NIH)-style research proposal. This was a challenging assignment for the students as none had written a research proposal before this course and most (>75%) had no previous research experience. Over the course of the quarter, groups of three or four students read primary scientific literature on their topic of interest, formulated new hypotheses, and designed and performed a pilot study to gather preliminary data in support of their hypotheses (see Table 4 for timeline). Each student then communicated his/her ideas and findings in the form of a written research proposal in which the student posed a hypothesis and described a set of specific aims (i.e., specific research objectives for the proposed study, as defined in NIH grant proposal guidelines) designed to further test this hypothesis. The assignment also required students to provide expected outcomes of their proposed experiments and discuss possible alternate outcomes and limitations inherent in their research design. The assignment was designed to teach students how to synthesize their own data with existing data from the literature and to build a strong argument in support of a new hypothesis. Students turned in one section of the proposal each week (e.g., Background and Significance) and received written feedback. Common difficulties were discussed with the class as a whole; however, neither the grading criteria nor the rubric were made explicit to the students.

To facilitate evaluation of the students' research proposals, a grading rubric was developed (Walvoord and Anderson, 1998; Allen and Tanner, 2006). Students were scored from 1 to 4 for how well they fulfilled each of 12 criteria as well as for overall presentation (Table 5). Student performance was gauged both by looking at the percentage of students who earned full credit on a given criterion (Table 5) and also by determining the average percentage of possible points students earned for each criterion (data not shown). In reviewing these results, it appeared that certain criteria were much more challenging for students than other criteria. For example, whereas 41% of the students provided a well-thought-out and insightful discussion of their study's broader societal and scientific impact, <10% of the students were able to design specific aims that directly tested their hypothesis (Table 5). Others have assessed students' ability to write research proposals and identified similar areas of weakness (Kolikant *et al.*, 2006).

Subsequent to determining student proficiency in each area, the BBT was used to categorize each criterion based on the highest cognitive domain it demanded (Table 5). (Please note that the section entitled "broader societal and scientific significance" was ranked as knowledge/comprehension rather than application/analysis as the instructor had explicitly discussed the significance of this general area of research during lecture and students merely had to recall and focus the information for their specific study rather than apply knowledge to a new situation.) Not surprisingly, students performed best on criteria that required only a knowledge- or comprehension-level of thinking. Those criteria that demanded an ability to synthesize new ideas or critically evaluate a technique or body of knowledge proved to be the most challenging.

After assessing student performance on the research proposal and identifying the criteria that students found the most challenging, the instructor designed new course activities that would provide students with an opportunity to

Table 5. Identification of students' writing weaknesses

Research proposal grading criteria[1]	Percent of students fulfilling criterion[2]	Level of Bloom's[3]
Hypothesis and specific aims		
Context (logical development of hypothesis)	50	App/Anal
Hypothesis	33	Synth/Eval
Specific aims designed to test hypothesis	9	Synth/Eval
Background & significance		
Logical introduction of background relevant to topic	50	Know/Comp
Review of literature identifying gaps in knowledge	27	Synth/Eval
Broader societal and scientific significance of study	41	Know/Comp
Preliminary data		
Presentation of pilot study results	28	App/Anal
Interpretation and relevance of pilot study	28	App/Anal
Research design		
Overall design (appropriate methods, controls)	32	App/Anal
Alternate outcomes for proposed study	23	App/Anal
Limitations of proposed approach	9	Synth/Eval
Methods	32	Know/Comp
Presentation		
Overall organization, grammar, style, figures	14	None[4]

[1] Students' research proposals were evaluated according to 12 different criteria as well as overall presentation.

[2] The percentage of students fulfilling each criterion was determined by dividing the number of students receiving a perfect score on a particular criterion by the total number of students in the class (n = 22).

[3] The highest level of Bloom's cognitive domain required to successfully complete each criterion. Know/Comp indicates knowledge and comprehension; App/Anal, application and analysis; Synth/Eval, synthesis and evaluation.

[4] Presentation was not assigned a Bloom's level.

practice skills needed to complete this complex research assignment (i.e., better scaffold the assignment). Two major changes were implemented when the course was taught the subsequent quarter. First, the assessment methods were made more transparent by introducing students to the grading rubric at the beginning of the quarter. Students were also provided with numerical feedback, in addition to written feedback, on each of their drafts indicating how well they had fulfilled each of the grading criteria (e.g., on their hypothesis and specific aims section they might receive 3 out of 4 for developing a clear testable hypothesis, but only 2 out of 4 for designing specific research objectives that tested this hypothesis). Second, as suggested by the BLASt, students evaluated their peers' research proposals from the previous quarter. This activity served three purposes: (1) to further familiarize students with the grading criteria that would be used to assess their own proposals, (2) to build students' confidence by placing them in the position of evaluator, and (3) to provide students with student-created models of research proposals that they could use to guide development of their own proposals.

To assist students in applying the grading rubric to their peers' proposals, all students were asked to evaluate the same proposal from the previous quarter, and then a "norming session" was held in which the students received the instructor's ratings with further explanation as to why a particular numerical value had been assigned. Interestingly, students on average were harsher critics of their peers than the instructor in areas where they felt most confident (e.g., presentation style), whereas they awarded higher scores than the instructor in areas where they were less knowledgeable (e.g., research design). Students were then assigned a new set of three proposals that they evaluated individually. After reviewing the proposals, students convened in groups of four to act as a "review panel" to discuss the relative strengths and weaknesses of the three proposals and come to consensus on a rank order. These activities took a significant amount of class time, but ensured that students understood each of the criteria on which their own proposals would be scored at the end of the quarter.

Comparison of research proposal scores between the second and first quarter revealed some interesting trends. Criteria requiring the most complex thinking skills showed the most dramatic improvement (Figure 1). For example, the second quarters' students earned an average of 80% of the total possible points for discussing inherent limitations to their research design compared with only 61% in the previous quarter. Likewise, we observed a strong increase in student ability to interpret their data and design their own hypotheses, skills that require analysis and synthesis levels of Bloom's, respectively. As these data were derived from two different populations of students (fall and winter quarter), the students' scores were analyzed according to their rank order using a nonparametric Kruskal-Wallis test, which does not assume that the two data sets possess a normal distribution. Based on this analysis, all three of the most dramatic increases were found to be statistically significant (Figure 1).

Students' scores on criteria requiring LOCS did not show statistically significant differences between the two quarters, indicating that the two groups of students were equivalently matched in terms of their basal knowledge of cell biology. This lack of increase in areas of knowledge and comprehension also suggests that the newly incorporated activities primarily impacted students' HOCS. Students in the second quarter were less successful in describing experimental methods than their peers from the previous quarter; however, this is most likely attributed to the fact that students in the second quarter were asked to include methods that they were proposing to use (but had not used in the laboratory) whereas students in the first quarter were only required to include methods they had used to obtain their preliminary data (and were therefore very familiar with).

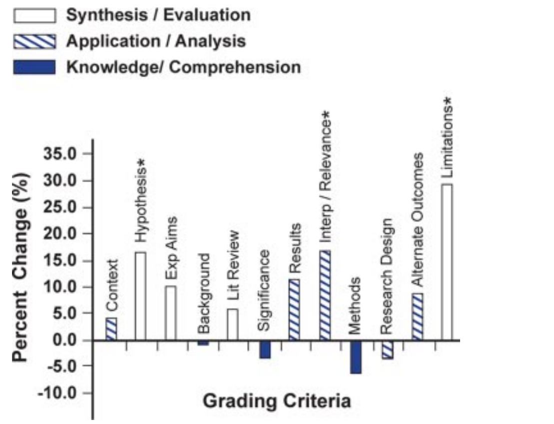

Figure 1. Increased student performance after implementation of grading rubric and peer-review panel. Student research proposals were evaluated based on 12 different criteria (1st quarter, n = 22; 2nd quarter, n = 24). The percentage increase in student performance (average % in 2nd quarter − average % in 1st quarter)/(average % in 1st quarter) × 100). A negative number indicates a decrease in the average percentage students earned in the second quarter relative to the first quarter. Asterisks indicate statistically significant differences based on a nonparametric Kruskal-Wallis test. The average score earned on the research proposal increased from 76% to 82% in the second quarter.

The large increases in student performance on some of the most challenging aspects of the assignment occurred after implementation of class activities designed to enhance HOCS. However, the gains in student achievement could also be attributable to unrelated factors including quarter-to-quarter variation in student motivation or differences in faculty performance. Future research will focus on distinguishing between these different possibilities.

As instructors, it is important that we recognize the complexity of the tasks that we are assigning students and prepare students appropriately for difficult tasks that require higher levels of thinking. As illustrated in this example, different sections of a research proposal require different cognitive skills. By recognizing which parts of an assignment are the most challenging, we can design specific activities or tools to help students succeed in those areas. Here, the faculty was able to use the BBT to identify areas in which students struggle and focus on improving the learning in these areas. The grading criteria were explicitly discussed and students were provided with structured opportunities to act as evaluators of other students' work. By sharing other students' work, it was possible to more clearly illustrate what "success" with a given criterion would or would not look like. These types of activities, based loosely on the cognitive apprenticeship model (Collins *et al.*, 1991), may help prepare students for challenging assignments (Felzien and Cooper, 2005; Kolikant *et al.*, 2006).

Faculty and Student Use of the BBT in an Undergraduate Physiology Course

Bloom's Taxonomy of cognitive domains was introduced during the second class period of a large (120 students) upper-division undergraduate physiology course at a research-one university. Introduction of Bloom's took only 15 minutes and focused on helping students learn the taxonomy and realize the potential it offered for enhancing their learning. To reinforce the concept, students were assigned the homework task of developing their own mnemonic for the levels of Bloom's (see Table 4 for timeline). For the first 10 minutes of the next class, a representative sample of mnemonics was presented, and students were asked to identify the strengths and weaknesses of each mnemonic. Before soliciting responses, the students were queried as to which level of Bloom's was required to complete these two tasks (i.e., creating a mnemonic and identifying the strengths and weaknesses of a mnemonic). In future classes, this activity would be referred to as "Blooming" the question.

Throughout the quarter, three to four questions on course content and concepts were asked during each class period, and the students were always asked to "Bloom" each question before answering it. "Blooming" in-class questions not only affords the students practice in using Bloom's with immediate feedback from the instructor but also allows the students to gain insight into which level of question they are having the most difficulty answering. This type of exercise strengthens student metacognition as it helps them monitor their mastery of the course concepts. Enhancing student metacognition has been found to be critical to student learning (Schraw, 1998; Bransford *et al.*, 2000; Pintrich, 2002; D'Avanzo, 2003; Coutinho, 2007).

Physiology is a challenging subject for students as it is based on a mechanistic and analytical rather than descriptive understanding of organismal processes (Modell, 2007). As such, the discipline requires students to work predominantly at the higher levels of Bloom's Taxonomy. Few students enter the course prepared to use the HOCS required to succeed on exams; therefore, it is necessary to raise awareness of the challenge level of the exam before the exam is given. To this end, students were given a homework assignment of first categorizing each question on the previous year's exam according to Bloom's and then calculating the number of points on the exam associated with each Bloom's level. This exercise helped students gain an appreciation for the Bloom's distribution of the exam questions and allowed them to adjust their studying accordingly.

During the quarter the instructor used the BBT to categorize the Bloom's level of all exam questions. This allowed the instructor to compute a Bloom's distribution for each exam (i.e., 16% points at the knowledge level, 38% at the comprehension level, and 46% at the application level), which in turn indicated the cognitive challenge of the exam. Calculating the Bloom's distribution allowed the instructor to determine whether indeed the exam questions were aligned with the course content and learning goals. Postexam, in addition to the routine analysis of test performance (range, means, SD) the instructor also showed how the class performed at each Bloom's level. It was not surprising to find that on the first exam students earned 80% of the knowledge points, 70% of the comprehension points, and only 55% of the application-level points.

As the quarter progressed, the instructor recognized that it was important to provide students with their individual Bloom's scores. This was necessary as students frequently did not consider the class average to reflect their own performance, and though the Bloom's ranking of each exam question was included on the exam key, few students actually calculated their own Bloom's test score. Therefore, after the second exam was returned to the students, the students were instructed to enter their score for each exam question into an online data-collection tool. This data were then used to generate a Bloom's analysis of each student's test performance. The Bloom's test score is the percentage of points an individual student earns at each level of Bloom's (e.g., if they earned 10 of the 20 points assigned to application-level questions they earn a 50% application score). Students accessed their Bloom's test score through the grade-reporting portion of the course website. By this point in the quarter, the BLASt had been completed and made available to all students. However, students who earned <75% of the points at any Bloom's level were specifically directed to appropriate learning activities of the BLASt and strongly encouraged to incorporate those activities into their study and learning strategies. As individual Bloom's scores were not reported and the BLASt was not available until midway through the second half of the class, significant improvement in student performance on the second midterm was not anticipated.

Research on human learning has found that developing student's ability to monitor their own learning (i.e., metacognition) is crucial to successful learning (Schraw, 1998; Bransford *et al.*, 2000; Pintrich, 2002; D'Avanzo, 2003; Coutinho, 2007). By "Blooming" in-class questions, students are provided with daily formative assessment of their learning while the Bloom's analysis of test performance provides the student with a more focused assessment of the type of question with which they struggle. The technique of providing students with a Bloom's test score in combination with recommendations for alternative learning methods from the BLASt gives students a simple and straightforward means to monitor and change their learning strategies in biology. Unfortunately, by the time the students received their personalized Bloom's analysis of their second test performance, only two weeks remained in the 10-week quarter, and there was not enough time for students to make meaningful changes to their existing study habits. As a result, it was not possible to show significant changes to student learning over the course of the quarter. In future quarters, the personalized Bloom's analysis of test performance will be introduced at the start of the quarter, and greater emphasis will be placed on devising methods to help students learn how to implement study skills appropriate for the academic challenge of the course.

After the quarter ended, students were asked what they thought about adding Bloom's to the course content. Below are two representative student responses:

> I think Bloom gives students an increased insight into the different types of learning and application of knowledge that students do for a class, it makes explicit something that is maybe only understood at a subconscious level. I think it gives students more tools and increases the control they have when they are studying.

> I remember initially thinking, "Why are we wasting valuable class time on Bloom's taxonomy?" I felt that Bloom's taxonomy was a burden, but I now use Bloom's taxonomy unconsciously to attack many problems. It is a method used to help organize my thoughts before I act.

Student Use of the BBT in Biology Workshops at a Liberal Arts College

Bloom's was used to promote pedagogical transparency and enhance students' abilities to design and answer questions in an upper-division interdisciplinary science program. Throughout the year-long program, students participated in weekly lectures, laboratories, seminars, and workshops co-taught by three different faculty who integrated topics in organic chemistry, biochemistry, cell biology, virology, and immunology. Workshops typically provided students with an opportunity to practice their problem-solving skills by answering faculty-generated questions in small groups.

The BBT was implemented in the immunology workshops. Thirty-six students received formal training in using the BBT, and then worked collaboratively in the subsequent 10 wk of the quarter to develop questions representing all different levels of Bloom's for a variety of assigned readings (Table 4). Students were first formally introduced to Bloom's in a half-hour lecture during which the faculty used biology sample questions to exemplify the different levels. After the lecture, small groups used the BBT to rank 45 biology and 20 organic chemistry questions from GRE subject tests and faculty exams. The faculty provided assistance throughout the activity, and students were required to submit their ranked questions for credit. This process allowed students to practice using the BBT for evaluating the different levels at which questions can be written and helped them to engage in discussion about the type of questions presented.

One wk after their initial training, students used the BBT to create questions from the content presented in eight primary literature papers that the students had previously read. Small groups of students were each assigned two papers for which they created two questions at each of the first five levels of Bloom's. The groups exchanged papers and associated questions, critiqued the level and design of the questions, and attempted to answer them. With faculty facilitation, each group presented their critique of and answer to one question to the entire class. The class then engaged in an open discussion about the material presented. These activities provided students with hands-on training for designing questions at different levels of Bloom's and set the stage for the remaining 8 wk of immunology workshops.

During week three, the faculty generated 10 questions at each level of Bloom's covering assigned reading in an immunology textbook. In their scheduled workshop time, students met in small groups to discuss and answer the questions. For homework students were required to individually answer and rank the questions according to Bloom's. Students received credit for both their answers to the questions and their completion of Bloom's rankings.

During the last 5 wk of the program, students were responsible for generating and answering their own questions based on assigned reading. Groups of five to seven students were responsible for writing a total of 20 weekly questions corresponding to the chapter that was being presented in lecture. Each week, a group generated four questions at each of the five levels of Bloom's. The night before the workshop, the questions were sent to the faculty and the best questions were selected and arranged in random order with respect to Bloom's ranking; the designated rankings were excluded from the final handout. In the workshop, authors of the questions served as peer teaching assistants while the other students worked to answer and rank questions. The authors were instructed to withhold the Bloom's ranking from the other students and to assist them only with finding the appropriate textbook material for answering the questions. Students were required to individually type up their answers and rank the questions according to Bloom's. These weekly assignments were turned into the faculty for grading, but students were only graded for their responses to the assigned questions and for completing the Bloom's ranking. Although exams and homework assignments given at The Evergreen State College are graded and scored, the college does not give cumulative numerical grades but rather narrative evaluations of a student's course work. This pedagogical philosophy enhances learning communities and provides an environment for effective group work. Students were held responsible for their participation in workshops by grading their individual responses to the questions.

The goals of the course activities were to teach students about Bloom's and let them practice using the BBT to rank and write good questions at different levels so that they could independently assess the level of their understanding of biology content in the future. Based on a show of hands in class, only one student had heard of Bloom's but did not feel as though they understood it enough to use it. While students were first practicing ranking questions, the instructor formatively assessed their knowledge of Bloom's and confirmed that none of the students in the course had any experience using it. However, by the end of the course, the students were very consistent in their independent ranking of the questions according to Bloom's. For 31 of the 51 questions, greater than 80% of the students agreed on the Bloom's ranking (Figure 2). This indicates that students who are trained to use the BBT are capable of writing and identifying questions at different levels of Bloom's. Students can apply this knowledge to their studying practices, evaluating the levels at which they understand concepts and adjusting their study skills to reach higher levels of Bloom's. These findings were highlighted by students in their final written evaluations of the program; some indicated that these exercises also helped them develop better questions about material they were learning in other areas of the program. The following are evaluation responses related to the use of Bloom's in the program:

> Designing challenging questions proved to be often more difficult than answering them. Studying via question design is a skill that I will apply to new material in the future.

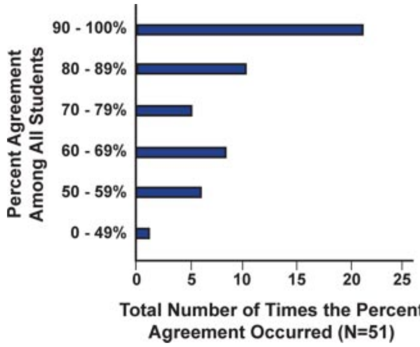

Figure 2. Instruction on Bloom's assists students to agree on rankings. Thirty-four students ranked five sets of immunology questions written by their peers in the class; there were a total of 51 questions. For each question, the percentage of students who agreed on a particular ranking was determined. The total number of times that a percent agreement occurred is reported here. For all but one of the questions, >50% of the students agreed on the same ranking.

> A huge part of this course was learning how to use Bloom's Taxonomy which is a ranking system for formal questions. Throughout the quarter groups were required to write questions as well as answer questions based on this ranking system. Learning Bloom's Taxonomy showed me how much effort goes into designing an exam or a homework assignment. I find myself wanting more.
>
> All year long I engaged my peers in workshop and problem set collaboration, and while I always learn a significant amount in that setting, I was not comfortable with being led through a quarter's worth of assignments by students that knew less than me. However, I must add that [the faculty's] desire to instruct students in the art of thinking like a teacher and asking questions on many different levels of understanding was beneficial.
>
> Learning the different levels of questions really helped me to take tests better and increased my capacity of grasping concepts.

Collectively, this suggests that formal training of students to use the BBT in ranking science questions, followed by substantive practice at writing and ranking questions at different levels of Bloom's Taxonomy, enhances their study skills and metacognitive development.

IMPLICATIONS FOR UNDERGRADUATE BIOLOGY EDUCATION

Assessment is the process of evaluating evidence of student learning with respect to specific learning goals. Assessment methods have been shown to greatly influence students' study habits (Entwistle and Entwistle, 1992). We agree with other educators who have argued that in the process of constructing a course, assessment is second only to establishing course learning goals for guiding course design (Wiggins and McTighe, 1998; Palomba and Banta, 1999; Pellegrino *et al*., 2001; Fink, 2003). Though many faculty establish learning goals for their courses, they often struggle with how to evaluate whether their formative and summative assessment methods truly gauge student success in achieving those goals.

Most faculty would agree that we should teach and test students for higher-cognitive skills. However, when faculty are given training in how to use Bloom's and practice ranking their own exam questions, they often realize that the majority of their test questions are at the lower levels of Bloom's. For example, at a national meeting for undergraduate biology education, 97% of the faculty who attended (n = 37) and received a formal lecture on using Bloom's to rank exam questions agreed that only 25% of their exam questions tested for higher-order cognitive skills (unpublished data). Therefore, most of the time we may not be testing or providing students with enough practice at using content and science process skills at higher cognitive levels, even though our goals are that they master the material at all levels. One explanation for this discrepancy may be that biology faculty have not been given the tools and guidelines that would help them to better align their teaching with assessments of student learning. To further emphasize this point, an analysis of exam questions from courses in medical school that should be aimed at developing HOCS (Whitcomb, 2006) are instead predominantly testing at lower cognitive levels (Zheng *et al*., 2008).

Developing strong assessment methods is a challenging task, and limited resources have been allocated to support faculty in this endeavor. Further, because of the current trend of increasing class size and decreasing teaching assistant support, multiple-choice exams are becoming the most practical assessment method. It is therefore increasingly important for faculty to invest the time necessary to create multiple-choice exam questions that test at the higher levels of Bloom's (Brady, 2005), as well as to develop integrative testing approaches such as requiring students to justify their answers of a small subset of multiple-choice questions (Udovic, 1996; Montepare, 2005). However, in order to accurately gauge student performance, we strongly encourage faculty to include short essay answer questions or other types of questions that test HOCS on their exams. This shift in assessment practice may require additional teaching support from departments and administrations, but we believe this is very important to the cognitive development of our students.

Our aim in developing the BBT was to make an assessment tool for use by biology faculty and students alike. To further facilitate this process, we have created a diverse array of biology-focused examples, inclusive of both specific skills (e.g., graphing) and subdiscipline content (e.g., physiology) that biology students typically encounter. These examples, in conjunction with the BBT, are designed to aid biologists in characterizing questions according to their relative cognitive challenge and, therefore, develop assessment methods that are more closely aligned with an instructor's learning goals. The BBT can also be used in conjunction with BLASt to help students self-diagnose their learning challenges and develop new strategies to strengthen their critical-thinking skills.

Our implementation of the BBT enhanced teaching and learning in a wide variety of instructional environments. Using the BBT, we were able to identify the cognitive levels of learning activities with which students struggle the most and adjust our teaching practices accordingly. The BBT also helped us to create pedagogical transparency and enhance student metacognition. As always, there is a trade-off when class time is used to develop metacognitive skills as opposed to focusing exclusively on course content. However, in our student-based implementation strategies of the BBT, Bloom's Taxonomy was fully integrated into the course subject matter (e.g., designing exam questions at different levels of Bloom's); anecdotal evidence from our students suggests that they continue to use Bloom's to guide their learning strategies in future classes. Given our experience and the well-documented importance of metacognition in student learning in all disciplines, including science (Schraw, 1998; Bransford *et al*., 2000; Pintrich, 2002; D'Avanzo, 2003; Coutinho, 2007), we consider the potential benefits students may gain from learning Bloom's to far outweigh any consequences of minimally decreasing course content.

We envision that the BBT could help faculty create biology questions at appropriate cognitive levels and in this way provide faculty with a means to (1) assess students' mastery of both biological content and skills and (2) better align their assessments and learning objectives. We believe that use of the BBT by both faculty and students will help students achieve a deeper understanding of the concepts and skills that are required to become successful biologists. On a broader scale, the BBT could aid in development of biology assessment tools that could then be used to examine levels of academic challenge between different types of standardized exams in the life sciences and to facilitate departmental and interinstitutional comparisons of college biology courses.

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REFERENCES

Allen, D., and Tanner, K. (2002). Approaches to cell biology teaching: questions about questions. Cell Biol. Educ. *1*, 63–67.

Allen, D., and Tanner, K. (2006). Rubrics: tools for making learning goals and evaluation criteria explicit for both teachers and learners. CBE Life Sci. Educ. *5*, 197–203.

Allen, D., and Tanner, K. (2007). Putting the horse back in front of the cart: using visions and decisions about high-quality learning experiences to drive course design. CBE Life Sci. Educ. *6*, 85–89.

Anderson, L. W., Krathwohl, D. R., and Bloom, B. S. (2001). A Taxonomy for Learning, Teaching, and Assessing a Revision of Bloom's Taxonomy of Educational Objectives, New York, NY: Longman.

Athanassiou, N., McNett, J. M., and Harvey, C. (2003). Critical thinking in the management classroom: Bloom's taxonomy as a learning tool. J. Manag. Educ. *27*, 533–555.

Bailin, S. (2002). Critical thinking and science education. Sci. Educ. *11*, 361–375.

Ball, A., and Washburn, S. (2001). Teaching students to think: practical applications of Bloom's taxonomy. Agr. Educ. Mag. *74*, 16–17.

Bissell, A. N., and Lemons, P. P. (2006). A new method for assessing critical thinking in the classroom. BioScience *56*, 66–72.

Bloom, B. S., Krathwohl, D. R., and Masia, B. B. (1956). Taxonomy of Educational Objectives: The Classification of Educational Goals, New York, NY: D. McKay.

Brady, A. (2005). Assessment of learning with multiple-choice questions. Nurse Educ. Pract. *5*, 238–242.

Bransford, J., Brown, A. L., and Cocking, R. (2000). How People Learn: Brain, Mind, Experience, and School, Washington, DC: National Academies Press.

Collins, A., Brown, J. S., and Holum, A. (1991). Cognitive apprenticeship: making thinking visible. Amer. Educator, 6–46.

Coutinho, S. A. (2007). The relationship between goals, metacognition, and academic success. Educate *7*, 39–47.

Demetrulias, D. A., and McCubbin, L. E. (1982). Constructing test questions for higher level thinking. Nurse Educator *7*, 13–17.

D'Avanzo, C. (2003). Application of research on learning to college teaching: ecological examples. BioSciences *53*, 1121–1128.

Ebert-May, D., Batzli, J., and Lim, H. (2003). Disciplinary research strategies for assessment of learning. BioScience *53*, 1221–1228.

Entwistle, A., and Entwistle, N. (1992). Experiences of understanding in revising for degree examinations. Learn. Instruct. *2*, 1–22.

Felzien, L., and Cooper, J. (2005). Modeling the research process: alternative approaches to teaching undergraduates. J. College Sci. Teach. *34*, 42–46.

Fink, L. D. (2003). Creating Significant Learning Experiences: An Integrated Approach to Designing College Courses, San Francisco, CA: Jossey-Bass.

Gardiner, L. F. (1994). Redesigning Higher Education: Producing Dramatic Gains in Student Learning, Washington, DC: George Washington University.

Handelsman, J., *et al*. (2004). Scientific teaching. Science *304*, 521–522.

Imrie, B. W. (1995). Assessment for learning: quality and taxonomies. Assess. Eval. Higher Educ. *20*, 175–189.

Kolikant, Y. B.-D., Gatchell, D. W., Hirsch, P. L., and Linsenmeier, R. A. (2006). A cognitive-apprenticeship-inspired instructional approach for teaching scientific reading and writing. J. College Sci. Teach. *36*, 20–25.

Kunen, S., Cohen, R., and Solman, R. (1981). A levels-of-processing analysis of Bloom's Taxonomy. J. Educ. Psych. *73*, 202–211.

Modell, H. I. (2007). Helping students make sense of physiological mechanisms: the "view from the inside." Advan. Physiol. Edu. *31*, 186–192.

Montepare, J. (2005). A self-correcting approach to multiple choice tests. Observer *18*.

Nehm, R., and Reilly, L. (2007). Biology majors' knowledge and misconceptions of natural selection. BioScience *57*, 263–272.

Palomba, C. A., and Banta, T. W. (1999). Assessment Essentials: Planning, Implementing, and Improving Assessment in Higher Education, San Francisco CA: Jossey-Bass.

Pellegrino, J. W., Chudowsky, N., and Glaser, R. (2001). Knowing What Students Know: The Science and Design of Educational Assessment, Washington, DC: National Academies Press.

Pintrich, P. (2002). The role of metacognitive knowledge in learning, teaching, and assessing. Theory into Pract. *41*, 219–226.

Schraw, G. (1998). Promoting general metacognition awareness. Instruc. Sci. *26*, 113–125.

Scouller, K. (1998). The influence of assessment method on students' learning approaches: multiple choice question examination versus assignment essay. Higher Educ. *35*, 453–472.

Sundberg, M. D. (2002). Assessing student learning. Cell Biol. Educ. *1*, 11–15.

Tanner, K., and Allen, D. (2004). Approaches to biology teaching and learning: from assays to assessments. Cell Biol. Educ. *3*, 69–74.

Taylor, D. S., Goles, T., and Chin, W. W. (2002). Measuring student learning. e-Service Journal *1*, 41–51.

Udovic, D., Morris, D., Dickman, A., Postlethwait, J., and Wetherwax, P. (1996). The Workshop Biology Curriculum Handbook, Eugene: University of Oregon.

Walvoord, B.E.F., and Anderson, V. J. (1998). Effective Grading: A Tool for Learning and Assessment, San Francisco, CA: Jossey-Bass.

Whitcomb, M. E. (2006). The teaching of basic sciences in medical schools. Acad. Med. *81*, 413–414.

Wiggins, G. P., and McTighe, J. (1998). Understanding by Design, Alexandria, VA: Association for Supervision and Curriculum Development.

Yuretich, R. F. (2003). Encouraging critical thinking. J. College Sci. Teach. *33*, 40–45.

Zheng, A. Y., Lawhorn, J. K., Lumley, T., and Freeman, S. (2008). Assessment: application of Bloom's Taxonomy debunks the "MCAT Myth." Science *319*, 414–415.

Zoller, U. (1993). Are lecture and learning compatible? Maybe for LOCS: unlikely for HOCS (SYM). J. Chem. Educ. *70.*, 195–197.