# Metacognition in Upper-Division Biology Students: Awareness Does Not Always Lead to Control

**Kathryn Morris Dye and Julie Dangremond Stanton***
Department of Cellular Biology, University of Georgia, Athens, GA 30602

## ABSTRACT
**Students with awareness and control of their own thinking can learn more and perform better than students who are not metacognitive. Metacognitive regulation is how you control your thinking in order to learn. It includes the skill of evaluation, which is the ability to appraise your approaches to learning and then modify future plans based on those appraisals. We asked when, why, and how upper-division biology students evaluated their approaches to learning. We used self-evaluation assignments to identify students with potentially high metacognition and conducted semistructured interviews to collect rich qualitative data from them. Through content analysis, we found that students evaluated their approaches to learning when their courses presented novel challenges. Most students evaluated in response to an unsatisfactory grade. While evaluating study strategies, many students considered performance and learning simultaneously. We gained insights on the barriers students face when they try to change their approaches to learning based on their evaluations. A few students continued to use ineffective study strategies even though they were aware of the ineffectiveness of those strategies. A desire to avoid feeling uncomfortable was the primary reason they avoided strategies that they knew were more effective. We examined the behavioral change literature to help interpret these findings.**

## INTRODUCTION
Students with strong metacognitive skills can identify concepts they do not understand and select appropriate approaches to learn those ideas. Metacognitive students know how to implement selected strategies, and they modify their approaches based on experience. These metacognitive skills can have a profound effect on learning (Wang *et al.*, 1990), but many undergraduates have not yet developed these abilities. To enhance student learning through metacognition, we need to understand the important changes that occur as students acquire these skills. One way we can address this need is by examining students with well-developed metacognition to learn when, why, and how they use these abilities. Then we can use insights obtained from highly metacognitive students to help other students improve their metacognition.

Metacognition is a term that has been used so broadly that its meaning can be unclear (Veenman *et al.*, 2006). Metacognition is defined as the awareness and control of thinking (Cross and Paris, 1988), and it is divided into metacognitive knowledge and metacognitive regulation (Brown, 1978; Jacobs and Paris, 1987). Metacognitive knowledge focuses on what we know about our own thinking, whereas metacognitive regulation involves how we control our own thinking for the purpose of learning (Brown, 1978; Jacobs and Paris, 1987; Cross and Paris, 1988). In some studies, metacognitive knowledge has been a poor predictor of learning outcomes, because simply knowing what we do not know does not guarantee that we will do anything about it (Veenman, 2005). What we do in order to learn concepts we do not know involves metacognitive regulation.

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*Address correspondence to: Julie Dangremond Stanton (stantonj@uga.edu).

Metacognitive regulation involves the actions we take in order to learn (Sandi-Urena *et al.*, 2011). Three key metacognitive regulation skills are the abilities to 1) *plan* by selecting strategies and allocating time to meet a learning goal, 2) *monitor* how well strategies are working in real time, and 3) *evaluate* approaches to learning and adjust future plans as needed (Schraw and Moshman, 1995; Ambrose, 2010). These metacognitive regulation skills of planning, monitoring, and evaluating are also part of self-regulated learning (Zimmerman, 1986; Schraw *et al.,* 2006). Planning first develops in young children (Veenman and Spaans, 2005; Whitebread *et al.*, 2009), whereas monitoring and evaluating emerge later in life (Veenman *et al.*, 2004). All three metacognitive regulation skills can improve throughout adulthood (Kuhn, 2000; Veenman and Spaans, 2005).

While we know control of thinking develops over time, we do not understand the key steps in the growth of metacognitive regulation in young adults (Dinsmore *et al.*, 2008; Zohar and Barzilai, 2013). Many students do not need to use metacognition to be successful in high school (McGuire, 2006). Thus, important changes are likely to occur during college, because students are pushed to use metacognition when they perceive learning tasks to be difficult and important (Carr and Taasoobshirazi, 2008). Because there are significant opportunities for metacognition to grow in undergraduates, college biology students are a highly suitable group for studying metacognitive development. Additionally, understanding how metacognition develops in young adults will allow us to better foster metacognitive regulation skills in undergraduate biology students. This is especially important for students who are struggling in college biology, because improved metacognition is expected to enhance learning and performance (Young and Fry, 2008) for all students.

To this end, we previously studied introductory biology students' use of metacognitive regulation skills such as evaluating and planning in the context of exam preparation ($n$ = 245; Stanton *et al.*, 2015). Through analysis of self-evaluation assignments, we found that nearly all of the students in our study were willing to select new learning strategies for future study plans. Yet only half could evaluate the effectiveness of individual strategies. For example, one student reported that reviewing lecture notes and reading over the textbook were effective for her learning, but she could not explain why these strategies were helpful. Less than half of the introductory biology students in our study could use their self-evaluations to adjust their future study plans. For example, one student reported that on the first exam he could narrow down the answers to multiple-choice questions to the two most likely options, but he did not have the depth of knowledge to select the correct one. Yet this student's plan for the second exam centered on reading chapter summaries, an approach that was not likely to give him the level of understanding he needed.

From these data, we proposed a continuum with categories of metacognitive development represented in our sample of introductory biology students (Stanton *et al.*, 2015). We suggested four potential categories: Not Engaging, Struggling, Emerging, and Developing. Only a few students fit in the Not Engaging category. Not Engaging students did not evaluate their study plans, and they were unwilling to change their learning strategies. Most of the students in our sample belonged in the Struggling or Emerging categories. Struggling students were willing to change, but they had trouble evaluating and adjusting for the next exam. These students selected strategies that were not well aligned with issues they reported. Emerging students could evaluate and adjust for the next exam, and they selected appropriate learning strategies. Yet Emerging students did not always follow their plans. Developing students were rare in our sample of introductory biology students. These students evaluated their study plans, adjusted them for the purpose of enhancing their learning, and followed their new plans. Data from this prior work led us to interesting questions for further investigation. For example, aside from a lack of time, why did Emerging students fail to follow their study plans? When, why, and how do Emerging and Developing students use the metacognitive regulation skill of evaluation?

To address these questions, we need to study students who have already developed metacognitive regulation skills or are actively developing them. For this reason, we investigated the metacognitive regulation skill of *evaluation* in senior-level, upper-division biology students. Students evaluate when they consider the effectiveness of their individual approaches to learning (Schraw, 1998). They evaluate when they appraise their overall study plans and use these appraisals to revise their future plans, while taking past success and failure into consideration (Jacobs and Paris, 1987). Using these definitions, we asked the following research questions:

1. When do upper-division biology students evaluate their approaches to learning?
2. What causes them to evaluate their approaches to learning?
3. How do they evaluate the effectiveness of their approaches to learning?
4. What barriers do they face when trying to change their approaches based on their own evaluations?

## METHODS

### Context and Participants

We collected data at the University of Georgia (UGA), a public, land-grant university with very high research activity. UGA has high enrollment in undergraduate biology courses. Participants were recruited from CBIO3400 Cell Biology, an upper-division biology course. Prerequisites include a semester of 300-level biochemistry and a semester of 300-level genetics. CBIO3400 consists of three interactive lecture periods and one 75-minute breakout session per week. The breakout session focuses on application of course concepts to data from the cell biology literature. Students work in groups of three on problem sets that require them to use higher-order thinking skills. The problem sets are written in the style of process-oriented guided-inquiry learning (POGIL; Moog *et al.*, 2015) and involve questions on methods, experiments, and data from the cell biology literature.

All CBIO3400 students were given the self-evaluation assignments. Only students who were 18 years or older, gave written informed consent, and completed at least one of the assignments were included in this study. To protect our participants' confidentiality, we used randomly assigned identifiers, which allowed us to link their self-evaluation assignments, interview transcripts, and grades. The UGA Institutional Review Board approved this study (#STUDY00001123).

### Self-Evaluation Assignments

We used two self-evaluation assignments that were a part of the regular work in CBIO3400 during the Fall 2015 and Spring 2016 semesters to identify students with potentially high metacognitive regulation skills. These assignments were modified for upper-division students from the exam 1 self-evaluation assignment and exam 2 follow-through assignment from our previous study of introductory biology students (Stanton *et al.*, 2015; see the Supplemental Material).

### Semistructured Interviews

*Purposeful Sampling.* We used purposeful criterion sampling to identify our interview candidates (Quinn, 2002; Suri, 2011). Based on analysis of both self-evaluation assignments (using methods described in Stanton *et al.*, 2015), a subset of students was invited to participate in one-on-one interviews. We contacted students demonstrating metacognitive regulation that fit with the proposed Emerging and Developing categories (see *Introduction*), because their written data suggested they were able to evaluate their approaches to learning.

In Fall 2015, 27 students out of a class of 79 were invited to participate in an interview, and 14 students were interviewed. For Spring 2016, we made a slight modification to the interview invitation to indicate the value of student participation to the research, and we stated the amount of the research compensation. That semester we invited 13 students out of a class of 78, and we interviewed 11 of them. Those choosing to participate were given $20 as research compensation for interviews, which lasted on average 45–60 minutes.

*Semistructured Interview Protocol Development.* We completed two rounds of preliminary testing to create an interview protocol that would answer our research questions. K.M.D. administered a pilot protocol with some questions adapted from our previous study (Neider, Gallegos, Clark, Torres, Lewis, and Stanton, personal communication) to Spring 2015 participants in two focus-group interviews. Student responses were analyzed for their contribution to the research questions and then used to modify the protocol. K.M.D. administered the revised interview protocol to an upper-division biology student, using a one-on-one semistructured cognitive interview format to finalize the wording of the questions (Willis and Artino, 2013). The interview protocol was finalized based on data from this interview.

*Semistructured Interview Protocol.* During semistructured interviews, an established list of questions is asked, but researchers can ask spontaneous follow-up questions based on participant responses. The interview protocol consisted of 27 questions with opportunities for follow-up (see the Supplemental Material). The interview questions encouraged the student to share when, why, and how, over time, they had developed their ability to evaluate individual study strategies and their overall study plans. We also used an activity in which the students were given a series of note cards with all the study strategies they included in their self-evaluation assignments to encourage students to discuss their evaluation of individual study strategies more deeply. They were asked to arrange the strategy cards from most to least effective and to talk through how they made those assessments. During and immediately after each interview was performed, K.M.D. wrote notes with general impressions and comments about the interview (Quinn, 2002). She also listened to each interview to add further notes and to begin to identify any potential patterns across the interviews.

### Qualitative Data Analysis

*First-Cycle Coding.* Audio files of the interviews ($n$ = 25) were transcribed verbatim for qualitative analysis in MAXQDA 11 (VERBI Software, Berlin, Germany). The first goal in our coding process was to label portions of the data that related to our research questions. We began with two rounds of initial coding to first consider all of the data (Saldaña, 2013). Then we used multiple rounds of content analysis to identify meaningful ideas related to students' evaluation of their approaches to learning and barriers to change (Quinn, 2002). In each round of coding, both authors coded the data as individuals, met to share and discuss codes, adjusted the codebook, and recoded the data separately using the revised codebook. We included approximately three to four new transcripts per meeting while also considering previously discussed transcripts. During this iterative process, we used structural coding to label segments of the transcript that addressed our research questions (Saldaña, 2013). These segments ranged from short phrases to complete sentences to long passages. In vivo coding allowed us to capture students' thoughts in their own words, and process coding allowed us to note the actions they described taking during their interviews (Saldaña, 2013). Both authors analyzed all 25 transcripts during first-cycle coding.

*Second-Cycle Coding.* The second goal in our coding process was to identify patterns in the data. Pattern coding allowed us to identify themes that emerged in the data by grouping related codes together (Saldaña, 2013). Focused coding helped us organize our codes into categories and subcategories (Saldaña, 2013). This process included reanalyzing all the segments of data that were given a particular code during the first cycle to confirm codes. These methods are ideal for making comparisons across data as well as within, allowing us to identify characteristics of the individual students and characteristics shared between them (Saldaña, 2013). Both authors analyzed all 25 transcripts during second-cycle coding. Throughout first- and second-cycle coding, we coded to consensus to ensure rigor, rather than calculating interrater reliability. Coding to consensus allowed us to discover nuanced details that could have been overlooked if we had prioritized interrater reliability (Bogdan and Biklen, 2003; Denzin and Lincoln, 2005; Stanton *et al.*, 2015).

Quotes from students were lightly edited for clarity and brevity. For example, we added specific nouns in brackets to indicate what a pronoun was referring to, and we added ellipses to indicate places where we have removed words. Both authors checked all quotes to ensure that any light editing did not alter meaning. All names are pseudonyms.

## RESULTS

### When Do Students Evaluate Their Approaches to Learning?

We were curious to know when students in our study evaluated their approaches to learning in science. We found that most students did not evaluate their approaches to learning during high school, primarily because they performed well without studying. In college, students in our study evaluated their approaches to learning in chemistry courses like Organic Chemistry and in upper-division biology courses like Cell Biology.

*Only a Few Students Evaluated Their Approaches in High School.* We asked participants how they studied for science classes in high school and college, and when they made changes in their study plans. Only a few students described evaluating their approaches to learning in high school, generally in Advanced Placement (AP) science classes or dual-enrollment sciences courses at nearby colleges or universities.

> "[My AP Chemistry class] was a lot harder and I definitely had to study differently for that. That's when I really started using flash cards and outlining lectures. In the introductory classes I more just did the homework and before the test I would rework some of the homework and read back over the notes, but I never really had to do a whole lot of memorization."—Gia

*Reasons Why Students Did Not Evaluate Their Approaches in High School.* Most students in our study did not evaluate their approaches to learning in high school. The main reason was because their performance was satisfactory to them, so they did not consider changing their study strategies. This idea is exemplified by the following data:

> "In high school, I honestly really didn't study. I would review things the night before…I got through high school pretty well doing that."—Tabitha

Many students realized that they did not have to assess their study strategies because their teachers guided them through homework. By completing the required assignments, they were studying the material.

> "In high school especially, you always had homework to be doing, so they kept you up on your studies. In college, you really are left to your own, which is really different as well."—Hannah

In addition to having homework assignments that forced them to keep up with the material, some students noted that they did not study in high school because their science classes were not challenging for them.

> "The science courses at my high school were not rigorous. In fact, we were almost spoon fed the information, so…coming to college, [I was] feeling very underprepared."—Stella

Some students pointed out that, compared with high school, college required a change in their approach to learning because the amount of information in college science courses required new strategies.

> "[In high school] it was easier to remember just by taking notes in class and just looking over the day before the test, but in college, since there is so much information and it goes into way more depth than you realize…high school was more just study the day before with notes that you took, whereas in college you [have to use a variety of strategies]."—Tyler

*Most Students Started Evaluating Their Approaches in College Science Courses.* When asked about their science courses in college, most students in our study mentioned General Chemistry, Organic Chemistry, and in some cases Biochemistry as courses that first caused them to evaluate their approaches to learning. Several students noted that studying for chemistry is fundamentally different from studying for biology. They explained that the opportunity to learn by problem solving influenced the way they studied for chemistry courses (Cartrette and Bodner, 2010), as illustrated by the following data:

> "It almost felt like I was learning a different language with Organic Chemistry. Just memorizing facts didn't do any good. It was all about practice, and I had not really experienced that in a science class…I had to try to [study] a little differently, for example, not making note cards and really just doing more practice problems."—Hailey

Another student in our study contrasted the need to do practice problems in chemistry as opposed to gaining a conceptual understanding in biology.

> "In both the Gen Chem and Organic Chemistry, it's just a constant everyday having to work problems and figure out the method behind it, because you're never going to see the same problem over again. In biology, it's more conceptual rather than having to figure out the method behind how to solve a different problem."—Gia

When students earned unsatisfactory grades in chemistry courses, they evaluated their approaches to learning. For some students, this marked the first time they ever earned unsatisfactory grades in their lives.

> "Boy, that was a rough awakening going into chemistry for the first time. I had never failed anything before so, for the next I'd say three years, I struggled to learn how to study."—Courtney

Students who did not have to use a variety of approaches to learning in high school were uncertain how to study in college when they performed poorly. For example, one student described how not passing Organic Chemistry led him to seek help from his instructor to obtain new study strategies:

> "The first time [I took Organic Chemistry] I dropped it because I was not prepared at all. The second time, I turned it around immediately. At the very beginning I went to talk to the professor and told him, hey, I failed your class last time and I don't want to have to take this again."—Simon

### What Causes Students to Evaluate Their Approaches to Learning?

We were interested to know what causes students in our study to evaluate their approaches to learning. We learned that most students evaluate their approaches to learning only due to an external indicator (an unsatisfactory grade) telling them that they have not learned the material. A few students use an internal indicator (monitoring their own understanding through a practice exam) to determine this, and only one student in the study said she does not evaluate her approach to learning.

*Most Students Evaluate in Response to an External Indicator.* While exploring what causes students to evaluate their approaches to learning, we found that most students evaluate in response to an external indicator, with the most common one being an unsatisfactory grade on an exam.

> "Since my performance was not where I wanted it to be on the first test, I really did evaluate myself [after the first exam], and then I took the instructor's suggestions with my own evaluation…I used that to help me figure out what I needed to do for the next test."—George

A few students said that an unsatisfactory grade was the *only* thing that would cause them to examine their study strategies. Simply put, one student explained,

> "I know I won't change unless I'm not doing well."—Brandon

With unsatisfactory grades as the primary reason to evaluate, some students reported that they use the first exam in a science course as a litmus test for their studying.

> "At the beginning of the semester, I kind of stick with this method and just see how the first test goes, because with each teacher it's different. Typically, after the first test, I'll make adjustments if I don't like where my grade is."—Jasmine

Further support for the importance of external indicators came from students who have always done well academically. These students were evaluating their approaches for the first time because of grades with which they were not satisfied.

> "I've never really had to evaluate how I do things though because up until now I've done really well in [my courses]."—Rachel

While a poor exam grade signaled to most students that changes were needed, a few students explained that they were more concerned about what a low score indicated about their understanding of the material than the grade itself.

> "I didn't do as well on [the first exam in Organic Chemistry]. I wasn't so upset with my grade. That wasn't it, because I knew it was O Chem and it was going to be hard. I was more frustrated that I didn't understand the material even though I thought I did."—Stella

*Only a Few Students Evaluate in Response to an Internal Indicator.* Most students in our study only evaluate their approaches to learning due to an external indicator (an unsatisfactory grade) telling them that they have not learned the material. A few students talked about evaluating their approaches to learning due to an internal indicator. Specifically, they used instructor-provided practice exams as a way to monitor their understanding of the material and make decisions about how to study further.

> "I realized as I was studying that I needed to change my study methods because looking at the old test that was provided, I realized I didn't have enough in my head to answer it, so I figured it out before the first exam happened that I needed to employ [additional] methods."—Wendy

We knew that students in our study experienced a variety of formative assessment in their science courses, because we asked them about their past science courses toward the start of the interview. Although they took classes that included extensive formative assessment (e.g., clicker questions, online homework, or weekly quizzes), students in our study did not mention using these tools when asked what causes them to evaluate their approaches to learning.

*Most Students Evaluate Based on Course Characteristics.* We wondered whether students evaluated in response to course characteristics and, if so, what characteristics caused them to appraise their approaches to learning. All students interviewed reported that they had to adjust their study strategies in Cell Biology, the senior-level course in which data collection took place (see *Methods*). Through our analysis, we identified four characteristics of the course that prompted students to self-evaluate: 1) the course included a novel challenge, 2) the exams were 100% constructed response, 3) the course emphasized higher-order thinking, and 4) the material was inherently detailed.

Cell Biology students evaluated their approaches to learning because the course provided a novel challenge they had not previously encountered. Students were asked to learn experimental methods, analyze cell biology data, design new experiments, and predict their outcomes. One student explained that the focus on understanding cell biology research was a new emphasis with which he had little experience:

> "In a few other of my courses in the past we've kind of looked at experiments and seen how scientists in the past have come to realize this…but we've never really had to do anything about designing your own experiment or really interpreting data in other classes."—Max

Students also evaluated their approaches to learning in Cell Biology because of the exam format. Exams consisted of all constructed-response questions of the short-essay type. Most students reported that they primarily had multiple-choice exams in their previous science courses. They explained that constructed-response questions required a more detailed understanding of the material.

> "In science, other than Organic Chemistry, all of my exams have usually been a mixture of multiple choice and [some] short answer. [In Cell Biology] I am getting used to knowing the level of detail that a full short answer test requires. That made a much bigger impact than I had originally accounted for but I definitely had to get into the mindset of really knowing the details of things."—Hailey

Students also recognized that, in addition to adjusting to the exam format, success on Cell Biology exams also required higher-order thinking skills. This idea was exemplified by the following data:

"With other classes, all they are testing is comprehension, so I can wait until three days before to try to comprehend it because I know I can do it, whereas in Cell Biology, that's [only] the basic level and you have to master it, so I have to try to comprehend it as the unit goes on."—Wendy

Specifically, students commented on the need to apply the concepts on Cell Biology exams. One student described how the knowledge from lecture had to be integrated with the applications in breakout sessions:

"This class is different [because] it's a lot of application-based questions on exams and that's where breakout comes in handy, because everything you're learning…you can actually use it, whereas in my other biology classes it was more of just memorize. To apply what you know from breakout, you have to know all the information that was covered and then that's how it all makes sense."—Tyler

Another characteristic of Cell Biology that caused students to self-evaluate was the amount of detailed material covered. This idea was summarized as follows:

"Cell Bio has been the most challenging class I've ever taken and I think it's just because of the influx of information."—Stella

### How Do Upper-Division Biology Students Evaluate Their Approaches to Learning?

We wanted to understand how students evaluate their approaches to learning. We asked our participants about this throughout their interviews. To help students explore this topic further, we gave them cards with each of the study strategies they reported using on their self-evaluation assignments written on a separate card. We asked them to rank the strategies from most effective to least effective. Students sorted their cards based on what each strategy helped them accomplish. Students also considered the efficiency of their approaches to learning while ranking their strategies.

*Students Evaluate Strategies Based on the Ability to Obtain and Recall Information.* Some students gave high rankings to strategies that allowed them to obtain and recall course information. For example, Gia explained that strategies for acquiring the necessary information (recording lectures, using Quizlet, making flash cards) were most effective during her card sort (Figure 1). Some considered whether a particular resource included *all* the material they needed to learn. While explaining why recording and listening to lectures was most effective for her, Gia discussed her goal of not missing anything.

"I feel like if I didn't record the lectures, the notes I took in class [would be missing something]. If I'm writing something and the instructor is talking about something that's not on the PowerPoint, I'm missing that and that could be a key part of the lecture that could help me make the connection."—Gia

Many students said they evaluate their study strategies based on their ability to recall course information after using the strategy. For example, in response to why she knew answering study questions was the most effective method, one student explained,

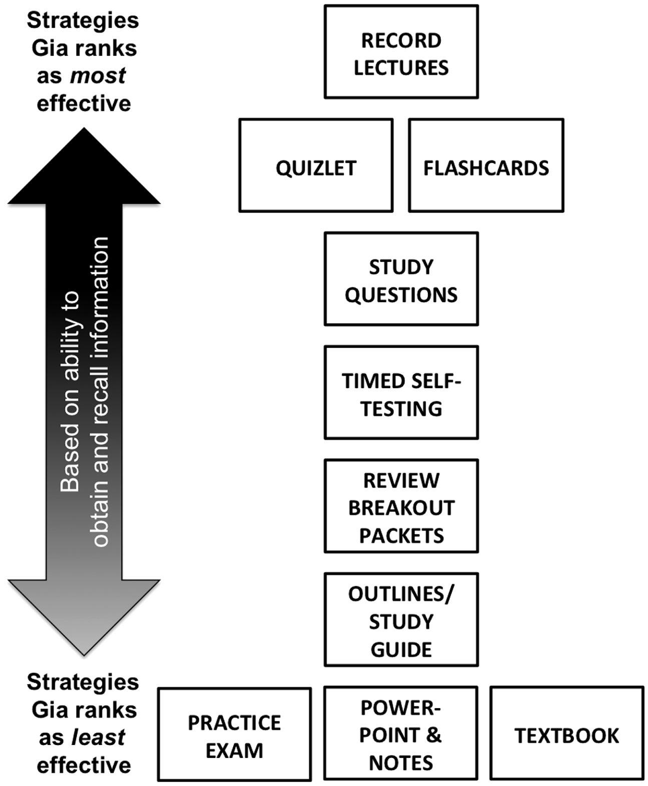


**FIGURE 1. Evaluating study strategy effectiveness based on ability to obtain and recall information. During her interview, Gia ranked the study strategies she used in Cell Biology from most to least effective. She viewed strategies for obtaining and recalling course material, such as recording lectures and using flash cards as most effective. In contrast, she viewed strategies for using material, such as taking the practice exam, as least effective. This is a graphical representation of Gia's card-sort exercise data.**

"I think I would say it's working well if I can come back to it later and I still understand what I thought I understood when I was going through. So if I answered these study questions a week before and then when I look back at them and it comes back to me quickly or I understand it without having to rethink through all of the steps and understand why, I think I would say it was effective because I'm remembering it well."—Jasmine

While many students aimed to be able to use the information to apply, connect, and create, some students noted that if you do not know the information you cannot use it.

"You have to really know the material to really be able to apply it. You have to be able to connect it and be able to do it on your own."—Rose

This explained why some students ranked study strategies that helped them obtain or recall information as more effective than strategies that required them to use the information.

*Students Evaluate Strategies Based on the Ability to Monitor Their Understanding.* A few students evaluated strategy effectiveness based on whether or not the strategy allowed them to monitor their understanding of concepts. Monitoring understanding involves determining what you know and what you do not know. One student described this outcome as follows:

> "Being able to check my understanding involves being able to pull those files out of my mind and understand a pathway completely and being able to draw it thoroughly, fully and completely on a board without referencing anything and then maybe being able to check it and say, okay, if this enzyme wasn't there [what would happen]?"—Max

Similarly, Karen explained that taking a practice test is an effective strategy, because it forces her to confront what she does not know when she has to skip a question because she cannot write the answer for it. Related to monitoring understanding, one student talked about the value of a strategy that mimics the exam experience. This type of approach is also known as a rehearsal strategy (Nist and Holschuh, 2000).

> "The practice tests, those are really helpful because you're actually simulating the situation. You sit down and you actually are writing…and that's the most effective preparation [because it is] actually simulating the circumstance."—Michael

Michael went on to explain how this strategy made the actual test less intimidating, because he had practiced for it.

*Students Evaluate Strategies Based on Their Ability to Use Information.* Other students ranked the study strategies that allowed them to use information as the most effective. For example, Leo highly appraised strategies that allowed him to *create* something new with course information (writing his own questions) or apply course information (taking a practice test and redoing breakout problem sets; Figure 2). He explained why writing and answering his own study questions was most effective for his learning.

> "I think creation is the highest form of [learning] because when you start creating your own things, it's because you have a grasp of what's going on."—Leo

Other students discussed their appreciation of strategies that required them to apply the material to new situations.

> "I think the study questions are most effective for me, because they get me thinking about the material outside of just knowing this is the protein that does this. I have to apply it to something else."—Jasmine

Similarly, another student explained that going over problem sets from breakout sessions was an effective study strategy, because it helped him to apply the concepts to experiments. He also noted the alignment between the problem set questions and the types of questions asked on exams.

> "[Breakout sessions] show you how you apply the information you're learning, which is basically what their test is…it is almost like a test being in a breakout because it's not just recalling the information, but you've got this information, now apply it to these different sets of data, so it's definitely useful."—Simon

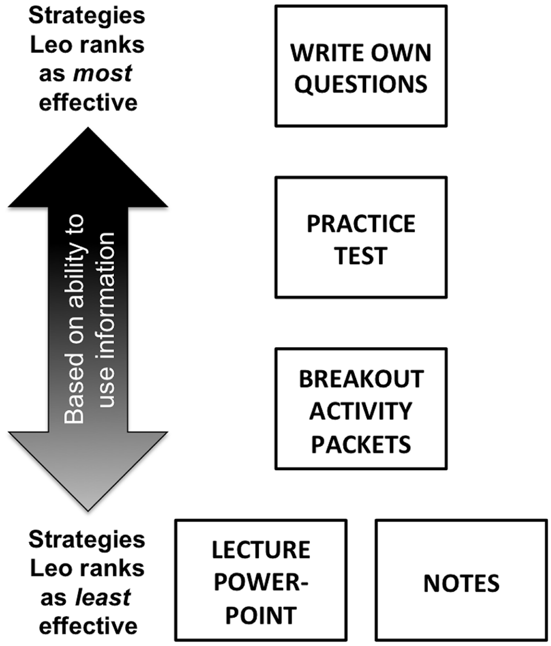


**FIGURE 2. Evaluating study strategy effectiveness based on ability to use information. In a card-sort exercise, Leo evaluated the effectiveness of his approaches to learning in Cell Biology. He gave high rankings to strategies that allowed him to apply course material (writing his own questions and taking a practice test) compared with strategies for finding and memorizing information (lecture slides and class notes). This is a graphical representation of Leo's data.**

In addition to study strategies that helped them apply the information, students valued strategies that allowed them to make connections between concepts. For example, a student explained his ranking of approaches that allowed him to connect information.

> "Making flow charts and talking through major processes [are more effective than] just rewriting notes because they make you engage with the information a little bit more, and trying to understand how things connect."—Brian

Many of the students who evaluated strategies based on their ability to use information talked about wanting to learn while at the same time wanting to perform well. For example, during her card-sort exercise, Wendy explained that her two goals for studying are to earn high exam grades and to understand the material.

> "My goal is to perform well on the test primarily, but I actually really do like cell biology. I do like to understand…how things actually work so [another goal] is just to learn."—Wendy

Thus, students who evaluated based on the ability to use information were concerned about both learning and performance.

*Students Consider Strategy Efficiency When Evaluating.* While ranking their approaches to learning from most to least effective, some students explained that they also considered the efficiency of their strategies. Nearly all the students in this study were seniors who were taking full course loads, and many were involved in professional and graduate school application processes. It makes sense that they would try to use strategies that are not only effective but also not very time-consuming. For example, one student explained his ranking of study strategies as follows:

> "That's how I rank their effectiveness, especially based on the time that it takes to do that [rewriting notes while reviewing lecture slides]. So that takes a lot of time whereas just going over some questions and answering them [is faster]."—Brian

Similarly another student talked about triaging more time-consuming strategies, such as taking a practice exam, as needed.

> "If I had a choice between I can do the practice test or look at the PowerPoints, I would definitely choose the PowerPoints…I want to make sure I'm comfortable with all of this stuff and then, if I get to the practice test then good, but if not, then I'm like it's not the end of the world. I'll still probably do fine."—Simon

For students who considered strategy efficiency, a lack of time was a barrier they faced in using more beneficial strategies. In addition to lack of time, our interview data allowed us to explore other barriers students encountered in changing their approaches to learning, which we describe below.

### What Barriers Do Upper-Division Biology Students Face When Changing Their Approaches to Learning?

Most of the students in our study were able to adjust their study strategies based on experience. This is not surprising; we purposely selected students whose written data suggested they might have highly developed metacognitive skills. Yet our interview data revealed that a few students in our study may have less well-developed metacognitive skills. These students provided valuable insights into the reasons they struggled to change their approaches to learning. They avoided effective strategies, because these approaches made them uncomfortable. In one case, a student (Abbie) was not aware of the value of the strategies she avoided. Interestingly, two other students (Hailey and Bridget) understood the value of the strategies they avoided and realized that the approaches they used instead were not likely to bring them success.

*"This stresses me out": A Desire to Avoid Discomfort and a Lack of Awareness of Strategy Value.* Three students in our sample talked about shunning approaches that caused them stress. One of these students, Abbie, did not display an awareness of the usefulness of the study strategies she avoided.

> "Study groups often stress me out more than they help me. Same with practice exams. I actually haven't done a practice exam at all this semester…I'll do that if I have extra time and I feel like I understand the material and need to do something else, but a lot of times study groups and practice exams just make me a lot more anxious and more stressed than I need to be and I feel like they hurt me in the end."—Abbie

She went on to explain that these strategies cause her stress because they reveal areas of confusion.

> "I feel like a lot of times in study groups I question what I already know, someone will say something and that doesn't line up with what I thought and sometimes the discussion just makes me doubt my own knowledge of the material [rather than] understanding it better."—Abbie

In her interview, Abbie did not seem to realize that identifying points of confusion could be valuable to her learning.

*"This is my comfort food": A Desire to Avoid Discomfort Despite Awareness of Strategy Value.* Two students in our sample, Hailey and Bridget, explained that they use passive strategies as a coping mechanism when the demands of a course become too stressful. Hailey described how she kept reading the textbook, even though she knew she could benefit from strategies that would allow her to monitor her understanding instead.

> "I got so overwhelmed by the amount of material that I fell into a passive learning rut. I just wanted to keep reading and reading the details and I wasn't really spending time seeing what do I actually know and understand."—Hailey

As a second-semester senior, Hailey explained that she was concerned not only about the possibility of not passing the class, but also of not graduating. She said that her response to this stress was to panic. The panic led her to try to go over as many details as possible, without assessing how well she was learning.

> "I didn't really spend much time processing the information or seeing how much of the details I could remember, I was just trying to absorb as much as I could…it was a panic reflex. If you don't do well, you won't graduate so you just get obsessed with the amount of material and it's easy to forget to see how much you actually know."—Hailey

In the same way, Bridget was aware that her response to stress led her to use strategies that were not effective. She described this during the card-sort exercise of her interview when she explained why she favored working with her class notes over more effective strategies, such as making her own chart of the cell biology techniques (Figure 3).

> Bridget: "This is like my comfort food of studying."
>
> Interviewer: "Condensing and revising notes?"
>
> Bridget: "Yeah, because it's super passive."
>
> Interviewer: "Okay, take me through it."
>
> Bridget: "It's just stuff that I kind of cling to when I'm feeling really uncomfortable with [the material]."

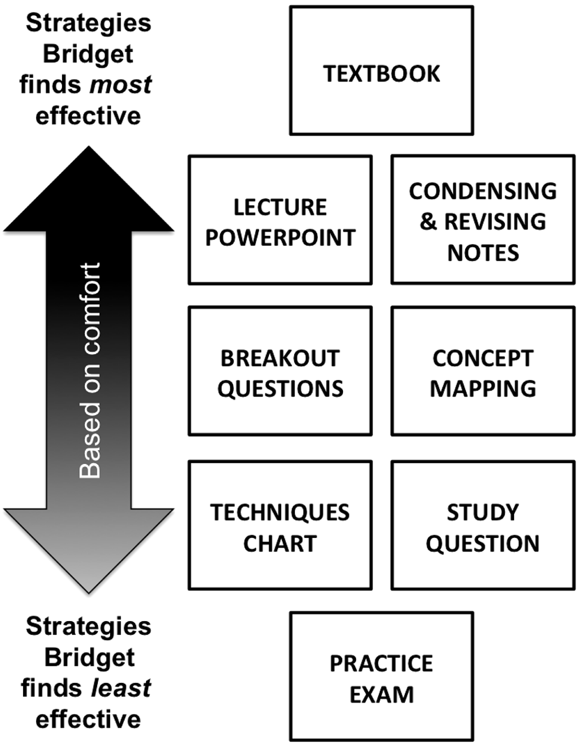


FIGURE 3. Evaluating study strategy effectiveness based on comfort. Bridget ranked the study strategies she used in Cell Biology from most to least effective during a card-sort exercise. She gave high rankings to strategies that brought her success in the past and described condensing and revising her notes as her "comfort food of studying." Despite ranking the practice exam as least effective, she explained in her interview why using this tool would be beneficial for learning. This is a graphical representation of Bridget's data.

Notably, Bridget knew that working with her class notes is not the best choice, and she could clearly articulate why this approach is not effective. She described how she goes back to strategies that worked well for her in the past as a way of making herself more comfortable. For example, Bridget explained that she was previously successful in science courses when she read the textbook. Then she described how she often returns to the textbook, because using this previously effective strategy brings her comfort, even though it is no longer productive.

> "[The textbook is] something I still come back to when I'm feeling pretty desperate. Especially on the days closer to exams, if I'm feeling like I'm not super comfortable. It's more of an old comfort thing to be able to look at the textbook even if it doesn't help me at all. It's just something that I kind of fall back on, but I know it's not as productive as my other methods, so I try not to do it, but especially for Cell Bio, that is something that I've ended up doing a lot, and it has not been super successful."—Bridget

Similarly, another student described having to force herself not to continually use a favorite strategy, making flash cards. She described having to ask herself when flash cards are appropriate.

> "I love flash cards, and for a while there I would make flash cards about everything, and I was so busy making flash cards that I wasn't spending any time going over the flash cards. I can make a million flash cards for all the different factors we're learning in Cell Bio right now, but if I do that so much that I never have the chance to review them, it's kind of useless."—Gretchen

Beyond comfort, we were curious to understand why students would use approaches they knew were not effective. Bridget provided some insight when explaining that reading the textbook allows her to continue studying, even though it is not an active strategy.

> "I just know [reading the textbook] is not a good use of my time because it's not like active recall. It's just something that I do when I'm feeling really nervous and especially when I'm feeling tired of studying and tired of doing active recall. I'll just go back to [the textbook] because I'm still looking at the material but it's not mentally taxing and I know all the information is in there."—Bridget

Thus, she felt that she was still learning by continuing to study, even though she was not using strategies she knew were most effective.

*"Getting out of your comfort zone": Recognizing the Value of Discomfort for Learning.* In contrast to the three examples described above, we found that many students in our study recognized that some discomfort is a valuable part of learning.

> "I think the way you learn the best is by getting out of your comfort zone and stretching yourself by doing things that you aren't used to doing."—Max

For example, students found value in study groups and practice exams, precisely because of the opportunity to identify areas of confusion.

> "[My study group] was really helpful for me because I could explain things to people, if I'm explaining it wrong, then somebody else is probably going to correct me and if I wasn't explaining it [to somebody else] then I wouldn't know [it was wrong]. That double checking was really good and also just being able to say it again for me was helpful."—Hannah

In contrast to Abbie, Hannah appreciated the opportunity to be corrected by members of her study group, because it allowed her to identify points of confusion. Another student felt similarly about practice exams.

> "The practice exam I really use more for confidence boosting, so I take it the night before to make sure that I feel good, I can do the time thing, I can write it, I have all the knowledge. Sometimes it will point out holes or show me things that they think are important."—Wendy

Another student who, like Abbie, experienced stress when using a practice exam, modified her approach to taking a practice exam so she would not be uncomfortable. Instead of taking the practice exam by herself, she discussed possible answers to each question with a small group of peers. She explained why this approach was helpful to her.

> "Practice exams, seeing questions that the professor has made and how I might have to apply all of this information and being able to talk about that with my study group and not just freaking out if it's not so obvious to me at first necessarily."—Alice

Similarly, another student welcomed the chance to identify areas for improvement by comparing his progress with his peers' progress.

> "[Breakout sessions] help expose my weaknesses…when I'm with my partners and there are some things from week to week that they know the answer to this really quickly or they are able to really move through these questions quickly whereas I'm struggling. [I think], okay, these guys have been doing something I haven't been doing, so where are my weaknesses there?"—Max

## DISCUSSION

Using rich qualitative data obtained from semistructured interviews, we examined when, why, and how senior-level, upper-division biology students evaluate their approaches to learning. In this section, we explore implications for research, including hypotheses generated from our data. These ideas are not conclusions from our study but hypotheses derived from our results that could be tested with larger sample populations in future studies (Andrews and Lemons, 2015). We also share implications for teaching based on our results, including specific suggestions for instructors.

### Implications for Research

*Hypothesis: Biology Students Use Metacognition When Faced with Novel Challenges.* Students in our study evaluated their approaches to learning when their science courses presented new challenges. For example, many students mentioned Organic Chemistry as the first class that required them to be metacognitive. There were two primary reasons for this. First, Organic Chemistry presented students with a novel situation in which memorization alone did not bring them success. Students noted that Organic Chemistry involved learning through problem solving. Although students were likely familiar with math-based problem solving from General Chemistry, they probably had less experience with the non–math based problem solving prevalent in Organic Chemistry (Cartrette and Bodner, 2010). Second, students said they knew that Organic Chemistry would be demanding, so they were more willing to respond to the expected difficulty by considering what they could do differently to succeed. Our data suggest a valuable role for Organic Chemistry in a life science curriculum, in contrast to the view of Organic Chemistry as a "gatekeeper" course that impedes the progress of students in science, technology, engineering, and mathematics (STEM) majors (Gasiewski *et al.*, 2012). Importantly, students in our study talked about transferring the metacognitive skills they gained in Organic Chemistry to other science courses, such as Biochemistry and Genetics. This worked well until they encountered new challenges, such as those in Cell Biology.

An upper-division cell biology course presented several new challenges that led students in our study to evaluate their approaches to learning. In this course, ~40% of the class time and ~40% of the assessment is focused on working with data from the cell biology literature. Students must learn to analyze data, design experiments, and predict experimental outcomes. Students explained that, to be successful in Cell Biology, they needed to develop skills that were not required to the same extent or at all in their previous courses. For example, students practiced higher-order thinking skills of application, analysis, and synthesis in the course (Bloom *et al.*, 1956). In general, college science courses provide few opportunities for students to develop higher-order thinking skills (Momsen *et al.*, 2010; Ebert-May *et al.*, 2011). Another challenge was posed by the format of Cell Biology exams, which were 100% constructed-response questions. Students explained that these open-ended questions caused them to change their approaches to learning, which fits with previous work indicating that students prepare for exams differently based on their format (Traub and MacRury, 1990; Stanger-Hall, 2012). Additionally, the material in Cell Biology is inherently detailed, which students described as adding to the difficulty. While their instructors attempted to focus on conceptual thinking, mastering some cell biology concepts requires a detailed understanding of underlying mechanisms. From these data we hypothesize that undergraduate students use metacognitive skills when they face novel challenges. Our results align with the finding that K–12 students do not use metacognitive skills unless they view a learning task as both difficult and important (Carr and Taasoobshirazi, 2008).

*Hypothesis: A Life Science Curriculum Drives Metacognitive Development.*
*Alternative Hypothesis: A Life Science Curriculum Selects for Students Who Have Developed Metacognition.* Our data show that a life science curriculum can provide students with opportunities to practice metacognitive skills such as evaluation. We do not know whether the curriculum *drives* the development of these skills or whether it *selects* for students who already posses them. A variation on the second hypothesis is that courses like Organic Chemistry and Cell Biology select for students who have the capacity to develop metacognitive skills when pushed. Yet we know from our data that this is not always the case. For example, Abbie did not provide evidence of strong evaluation skills in her interview, yet she was a high-performing senior who earned a good grade in Cell Biology. To distinguish between these two hypotheses, we would need to conduct a longitudinal study to investigate how individuals develop metacognitive skills over time. Longitudinal studies account for individual differences in areas such as cognitive ability and rates of change (Schaie, 2005).

*Hypothesis: Biology Students Choose Ineffective Strategies Based on Past Success.* A few students in our study could identify effective strategies, including active approaches to learning, yet they did not use them. We explored behavioral change theories and found that social cognitive theory could help us interpret our results (Bandura, 1986, 1997). In this theoretical framework, learning occurs within a social context, involving the interaction of three components: people, their behaviors, and their environments. The behavioral factor that is most often found to be positively correlated with change is *self-efficacy* (Rothman, 2000). Self-efficacy can be defined as the belief that you are capable of making a change. Another important factor is *outcome expectancy* (Schwarzer and Renner, 2000), the likely or predicted consequences of change. Both self-efficacy and outcome expectancy contribute to behavioral change.

Behavioral change can be divided into two phases: initiation of change and maintenance of change (Rothman, 2000; Schwarzer and Renner, 2000; Renner *et al.*, 2012). Initiation of change is based on the perception of a satisfactory outcome, and is positively correlated with *action* self-efficacy (Schwarzer and Renner, 2000). For example, students may expect concept mapping to help them understand connections between course concepts. If they believe they can enact this strategy (action self-efficacy), they are more likely to try it for the first time. Maintenance of change is based on satisfaction with previous outcomes and is positively correlated with *coping* self-efficacy (Schwarzer and Renner, 2000). For example, students who have tried concept mapping will use it again if it brought them success in the past. If they believe they can persist in the face of setbacks (coping self-efficacy), they are more likely to continue using this strategy, even if it is not easy to do. Thus, the reasons students try a study strategy for the first time are different from the factors that cause them to continue using that strategy (Baldwin *et al.*, 2006).

In our study, Bridget knew that taking a practice exam would be an effective study strategy, but she chose a less active strategy because it brought her comfort. As an upper-division biology student, Bridget had initiated a change by trying to use the practice test as a study tool in previous courses. While taking Cell Biology she may have lacked the coping self-efficacy required to maintain this change when she was stressed. Social cognitive theory supports the idea that she chose to use a passive strategy because of its past outcome expectancy. At the same time, Bridget knew that condensing and revising notes was not working in her current course work. In the future, our research group will examine the ways biology students use action self-efficacy and coping self-efficacy to initiate and maintain changes in study behavior.

### Implications for Teaching

*Students May Be Evaluating Approaches to Learning for the First Time in College.* Most students in our study did not evaluate their approaches to learning science in high school because they performed well without studying and viewed their science classes as easy. Some students realized that this was because their teachers scaffolded the learning process for them through homework (Tomanek and Montplaisir, 2004). While teacher scaffolding is valuable to learning (Levy and Wilensky, 2009), these data suggest that some students may need additional help transitioning from teacher-directed studying to self-directed studying. In contrast, two students in our sample attended homeschool cooperatives, and both described how they were encouraged to self-direct their own studying in high school. For example, one student explained how her science teacher showed her how to use "on your own" questions to monitor her understanding while reading the textbook. This approach to learning was important because this student did not meet with her science teacher on a regular basis, so she had to learn how to guide herself through the material. As a result of this type of training, the two homeschooled students said they felt well prepared to direct their own studying in college. Yet because most students in our study did not evaluate their approaches to learning in high school, college was the first time they practiced this metacognitive skill.

*Upper-Division Biology Students Can Self-Evaluate When Prompted.* As biology instructors, we were encouraged to discover that all but one of the upper-division biology students in our study could evaluate their approaches to learning on their own and/or when prompted in interviews. In contrast, only about half of introductory biology students in our previous study could evaluate in response to postexam self-evaluation assignments (Stanton *et al.*, 2015). Our current results suggest that this type of assignment may be sufficient for upper-division students to evaluate their approaches to learning. Although they can evaluate on their own, students in our study reported that they benefited from the opportunity to reflect in a more structured way through self-evaluation assignments. We recommend that biology instructors give self-evaluation assignments as part of their courses. When investigating why students evaluated their approaches to learning, we found that most students only considered altering their study strategies after earning an unsatisfactory grade on an exam. We recommend that instructors aim to give a reasonable yet difficult first exam to encourage students to be metacognitive early in a course. Another option could be to give a challenging "mini-exam," worth half the points of a regular exam, after the first two weeks of a semester.

Only a few students reported evaluating in response to an internal indicator. These students described monitoring their understanding of the material using an instructor-provided practice exam. They evaluated their approaches to learning when they could not answer practice exam questions on their own. Although the students in our study had experience with other tools for monitoring understanding, they did not report changing their study strategies in response to poor performance on formative assessments. One possible explanation is that students did not think that they "studied" for formative assessments. Thus, they did not view poor performance on formative assessments as an indicator to change their study strategies. Our data suggest that exam-like tools can prompt students to be metacognitive. We recommend that instructors explicitly discuss the value of clicker questions, online homework, weekly quizzes, and other formative assessments as tools students can use to gauge the effectiveness of their study strategies. When feasible, students can also benefit from the opportunity to use practice exams for self-evaluation.

*Upper-Division Biology Students Can Focus on Performance and Mastery Simultaneously.* Most students in our study evaluated their approaches to learning using one of two approaches. Some students ranked their study strategies based on whether the approaches allowed them to *obtain and recall* course information (Figure 1), whereas others preferred approaches that allowed them to *use* course information (Figure 2). These evaluation approaches can be compared with the achievement goals framework, which includes mastery and performance approaches to learning (Elliot, 1999; Elliot and McGregor, 2001; Zimmerman, 2000). Students with a performance approach tend to focus on earning grades, whereas students with a mastery approach tend to focus on learning (Ames and Archer, 1988). Empirical evidence suggests that performance and mastery approaches are not necessarily in opposition, and viewing them as dichotomies may be an oversimplification (Pintrich, 2000). Additionally, a focus on earning a grade does not necessarily have a negative impact on learning (Dinsmore *et al.*, 2008).

Our data suggest that a focus on performance is not mutually exclusive with a focus on mastery for upper-division biology students. We found that some of the students in our study who favored study strategies that allowed them to obtain and recall information were performance focused, while some of the students who favored study strategies that allowed them to use information were learning focused. Yet we also found reverse examples and combinations of both approaches. Additionally, some students noted that they have to know course material before they can apply it. Thus, they ranked strategies that allowed them to obtain and recall information as more valuable, because those strategies were a prerequisite to using the information. Overall we found that upper-division biology students in our study were simultaneously invested in earning grades *and* learning the material for reasons beyond grades. Many students had already been accepted to professional or graduate school at the time of their interviews. They spoke of a desire to understand biology not only because they knew they would need it in the future but also because they truly enjoyed the subject.

*Some Students May Avoid Effective Strategies Because Those Strategies Cause Them Discomfort.* Most of the students in our study recognized the value of discomfort for learning, but a few students did not see any value in struggling while learning. "Desirable difficulties" are conditions that create greater challenge for students, but they also enhance their learning (Bjork and Bjork, 2011). Unfortunately, student perceptions of what enhances learning do not always align with what actually helps them learn (Kornell and Bjork, 2008; Kang and Pashler, 2012; Birnbaum *et al.*, 2013). For example, students believed that studying one concept over a long period of time (blocking) was more beneficial than alternating the study of more than one concept (interleaving) (Birnbaum *et al.*, 2013). Yet they performed better on questions that came from interleaved study rather than blocked study (Kornell and Bjork, 2008; Birnbaum *et al.*, 2013).

Students like Abbie may avoid uncomfortable but beneficial strategies because they do not appreciate the positive effect of challenging conditions on learning. This may be because these students have a fixed mindset when it comes to learning (Dweck and Leggett, 1988). They may believe that intelligence does not change and therefore learning comes easily or not at all. This mindset prevents some students from using effective strategies that are more difficult to enact and from using metacognitive regulation in general. To help students like Abbie, instructors should openly discuss "desirable difficulties" with students to help them understand that learning can be hard and strategies that will allow them to apply concepts may not be easy to do. Students can also benefit from explicit instruction on the benefits of using active approaches to learning along with instructor or peer modeling to show them that challenging strategies are possible to enact (Bandura, 1997). Additionally, students may benefit from video-recorded "testimonials" from previous students who talk candidly about how facing the difficulties of active approaches to learning brought them success.

Students like Bridget recognize the benefits of active approaches to learning but choose to use strategies that bring them comfort instead. These students may need help anticipating barriers to using difficult study strategies and developing a plan for how to handle challenges when they arise. This is known as *coping planning* (Renner *et al.*, 2012). For example, another student, Hailey, often favored the textbook for her studying. In her interview she explained that she had to read the textbook in the early days of her exam studying to prevent herself from relying solely on this tool. In later study sessions, she found she had to make her book physically inaccessible so that she was not tempted to read and reread it at times when she needed to focus on using strategies for monitoring her understanding. By identifying other mechanisms of coping planning, we can help students like Bridget engage in active approaches to learning.

## CONCLUSIONS

In conclusion, the senior-level, upper-division biology students in our study evaluated their approaches to learning for the first time in college, making this an opportune time for instructors to help students develop evaluation skills. Students evaluated their study strategies while taking courses like Organic Chemistry and Cell Biology, which presented them with novel challenges, such as constructed-response exams. Most students in our study evaluated their approaches to learning only in response to external indicators such as an unsatisfactory exam performance. Most evaluated their study strategies based on either their ability to obtain and recall course content or based on their ability to use course content. Although students were focused on earning grades, they were simultaneously invested in learning. Thus, our qualitative study provides insights on when, why, and how upper-division biology students evaluate their approaches to learning. Finally, a few of the students understood the benefits of active approaches to learning, but they chose not to implement these approaches in order to avoid discomfort. We will apply this knowledge to help other students develop evaluation skills, which will increase their metacognition and, in turn, their learning and performance.

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