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| Research Article

Opportunities for guiding development: insights from first-year life science majors' use of metacognition

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ABSTRACT Students with strong metacognitive skills are positioned to learn and achieve more than peers who are still developing their metacognition. Yet, many students come to college without well-developed metacognitive skills. As part of a longitudinal study on metacognitive development, we asked when, why, and how first-year life science majors use metacognitive skills of planning, monitoring, and evaluating. Guided by the metacognition framework, we collected data from 52 undergraduates at three institutions using semi-structured interviews. We found that first-year students seek study recommendations from instructors, peers, and online resources when they plan their study strategies. First-year students struggle to accurately monitor their understanding and benefit when instructors help them confront what they do not yet know. First-year students evaluate the effectiveness of their study plans at two specific points: immediately after taking an exam and/or after receiving their grade on an exam. While first-year students may be particularly open to suggestions on how to learn, they may need help debunking myths about learning. First-year students acknowledge they are still learning to monitor and welcome formative assessments that help them improve the accuracy of their monitoring. First-year students may be primed to receive guidance on their metacognition at the points when they are most likely to evaluate the effectiveness of their study strategies and plans. Based on our results, we offer suggestions for instructors who want to support first-year students to further develop their metacognition.

KEYWORDS metacognition, self-regulated learning, first-year students, biology

Metacognition in undergraduate life science majors

Metacognition is a strong but underused method for supporting student success in undergraduate life science courses. Metacognition is defined as the awareness and control of thinking (1). In a meta-analysis of 179 studies of influences on student learning, metacognition was one of the highest-ranking variables, above cognition, motivation, and affect (2). Metacognition improves student achievement in college (3) and promotes problem-solving ability (4, 5). Given its impact, metacognition should be used to help address the alarming number of students who do not pass introductory biology—as many as 50% at some institutions (6). Students with strong metacognitive skills can identify concepts they do not understand and select appropriate strategies for learning those concepts. They know how to implement selected strategies and carry out their overall study plans. They can evaluate their strategies and adjust their plans based on outcomes.

Metacognitive skills are critical for undergraduates when they learn on their own and in class. While many senior-level life science majors use metacognition when prompted to evaluate their learning (7, 8), introductory life science majors do not always use metacognitive skills in response to prompts (9). We know students need help using metacognition effectively early in their life science majors. Yet, less is known about the

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progression of metacognitive development in college and why metacognition differs among undergraduates (10). To support student success in life science majors, we need a better understanding of how their metacognition develops over time.

This work is grounded in a theoretical framework that outlines two components of metacognition: metacognitive knowledge and metacognitive regulation (11, 12). Metacognitive knowledge includes what you know about your own thinking and what you know about strategies for learning (11–13). Metacognitive knowledge is important for learning, but this awareness will not result in learning if a student does not act on this information. Metacognitive regulation involves the actions you take to learn (14, 15). In this study, we focused primarily on metacognitive regulation skills, while also considering the role of metacognitive knowledge in student learning.

Three key processes comprise metacognitive regulation skills: planning, monitoring, and evaluating (13, 16). Planning involves deciding what strategies to use for a future learning task and when to use them. Monitoring involves assessing your understanding of concepts and the effectiveness of your strategies while learning. Evaluating involves appraising your prior plan after a learning task and adjusting it for the future. These three metacognitive regulation skills are also essential parts of self-regulated learning (17, 18). We aim to uncover developmental milestones of undergraduate life science majors' metacognitive regulation.

Present study

We are conducting a longitudinal study of life science undergraduates' metacognitive development to enhance learning and promote success in science majors. The primary objective of this portion of our longitudinal study is to characterize first-year undergraduate life science majors' use of metacognitive skills for learning. To meet this objective, we asked two research questions: (i) When and why do students use metacognitive skills of planning, monitoring, and evaluating, and (ii) How do students use these metacognitive skills? To help students develop metacognitive skills, we need to better understand their development in college. For example, we need to know when undergraduate life science majors are primed to receive guidance on their metacognition. The knowledge generated from this study will be used to create a curriculum that will accelerate metacognitive growth in first-year students.

METHODS

Context and limitations

We collected data at three public institutions: University of Georgia (UGA), University of North Georgia (UNG), and Georgia Gwinnett College (GGC). These institutions represent three different academic environments, which is important because context can affect metacognition. The key differences for these institutions are provided in Table 1. The data we analyzed offer an array of perspectives from diverse students in three different institutional contexts, which extends the generalizability of our study. Yet, our results may not be generalizable to contexts that differ from these three public institutions, which is a limitation of the study. Another limitation is that our data are self-reported, which may be subject to recall bias (19) or social desirability bias (20). We tried to limit recall bias by asking students about recent learning events and to limit social desirability bias by having students or postdoctoral researchers conduct the interviews, rather than a faculty member.

Participant recruitment and selection

This project is the first part of a larger longitudinal study to examine life science majors' metacognitive development from the start to the end of their college career. We are collecting qualitative and quantitative data from participants every year from their first

TABLE 1 Data collection sites

	Georgia Gwinnett College	University of Georgia	University of North Georgia
Institution type	Baccalaureate college	Doctoral R1	Master's university
Location	Suburban	City	Suburban
Number of undergraduates	10,949	30,166	18,155
Students from racially minoritized groups[a]	58.1%	14.6%	19.6%
Students who identify as women	58.7%	58.9%	57.8%
Students who identify as first-generation	37%	9%	20.6%
Average high school GPA	3.0	4.1	3.5
Average SAT score	1065	1355	1135

[a]Students from racially marginalized groups included those who self-reported as Black or African American, Hispanic or Latino, American Indian or Alaska Native, and Native Hawaiian or Other Pacific Islander. These possible categories were provided to students by the University System of Georgia.

year in college until their graduation. In this paper, we focus on year 1 data from semi-structured interviews.

During the 2021–2022 academic year, we recruited participants from introductory science courses at each institution, which had all returned to in-person classes. We used the revised Metacognitive Awareness Inventory (21) to select participants with a range of initial metacognitive awareness. We also asked potential participants for self-reported demographic information to try to create cohorts that are representative of the student body at each institution. We recruited a group of 52 first-year undergraduate life science majors (23 from UGA, 21 from UNG, and 8 from GGC). This is a large cohort for a longitudinal study with multiple data streams. Students provided written consent to participate in this study, which was reviewed and granted exempt status by the University of Georgia Institutional Review Board (# STUDY00006457) and the University of North Georgia Institutional Review Board (2021-003).

Data collection*:* semi-structured interviews

We developed semi-structured interview protocols to examine students' use of three major metacognitive skills. The interview questions probe when, why, and how students develop planning, monitoring, and evaluating skills in the context of the science courses students were taking at the time of the interview. Response process validity was tested by analyzing data from 13 preliminary interviews we conducted using our protocol (22). This process allowed us to cut questions that did not produce useful data and add questions related to emerging findings. Interviews were conducted on Zoom, video-recorded, and professionally transcribed.

Data analysis: content and holistic analysis

We used content and holistic analysis to deeply examine the metacognitive regulation skills used by each participant in the context of that student's data. Guided by our theoretical framework, we developed a profile template that prompted us to use content analysis to identify how, when, and why a student used each metacognitive regulation skill. The profile template also prompted us to label data from the transcript (e.g., phrases or sentences) that provided evidence of each skill. A profile approach was essential for summarizing the rich qualitative data for all 52 participants because of the sheer magnitude of the data.

Profile creation involved iterative rounds of initial coding (23), content analysis, profile creation, and group discussion of content analysis and created profiles. We then synthesized the profiles for each participant into one final profile for year 1 of our longitudinal study. Each participant's data were analyzed by two or three members of our research team, and we analyzed to a consensus to ensure rigor (24, 25).

Data analysis: categorical analysis

We used categorical analysis to compare metacognitive regulation skills across all participants in the cohort. This process allowed us to identify commonalities in the data and propose potential themes. We focused on one skill at a time (e.g., monitoring) and compared how, when, and why participants used that skill. In addition to noting commonalities, we also tracked any notable exceptions, which could provide novel insights about metacognition.

RESULTS

We characterized first-year life science majors' use of metacognitive regulation skills based on an in-depth analysis of semi-structured interview data (n = 52). In particular, we were interested in the ways current first-year students' use of planning, monitoring, and evaluating may have changed in recent years compared to before the pandemic. We used our published results on first-year life science majors' metacognition (8, 9) to make comparisons with the current data. All names are pseudonyms.

Planning: first-year life science majors are open to recommendations when they plan their studying

Planning involves deciding what approaches to use for a learning task and when to enact them. We found that nearly all the students in our study plan for high-stakes summative assessment such as exams, but very few plan for low-stakes formative assessment, such as homework. One participant, Reagan, talked about planning for online homework assignments to manage her time across her work and study schedules as a commuter student.

Similar to prior research on first-year students (8, 9), first-year life science majors in the current study often used study strategies that worked well for them in high school when planning for exams. For example, Ignacio said, "They worked in the past; they worked in high school," when asked why he included certain strategies in his study plan. Some students planned to use their high school strategies even though they acknowledged that those approaches were not working in their current college science course.

In contrast to prior research, many first-year life science majors in our study expressed openness to recommendations from their instructors, peers, and online resources, including social media. Some students, like Viola, admitted that she "does not really know how to study" for college science courses, which contributed to her willingness to learn new strategies. Recognizing they are new to college learning, many students selected study strategies simply because they were recommended by their science instructors. Other students like Tiffani realized that her peers have valuable insights on how to learn. She explained, "I've learned very interesting ways to think about stuff from other (students)." Some students like Renee sought study advice from productivity videos on YouTube and TikTok:

> "Sometimes I do go to TikTok for advice…sometimes there's actually genuine people… talking about active recall, recommending active recall. And I was like, 'Okay. Well I might as well try it, clearly what I'm doing is not working.'"—Renee

Interestingly, some first-year students talked about selecting study strategies based on their preferred learning styles. Although the idea that a student learns best in a visual, auditory, or kinesthetic style has been discredited (26), some participants asserted that they learn best when concepts are taught in their preferred learning style, and they used this belief to guide their planning decisions. For example, Astrid described herself as a visual learner and attributed her past struggles in science to a lack of visual learning opportunities:

> "Whenever I remember something, I have to see it in my head…I work very well with visual learning. If we had study guides, I would try to take the study guide and put pictures with everything. I learned over time that I'm a very visual learner…"—Astrid

The belief that a study strategy must align with the learning style misguided some students' plans because some participants would not consider strategies unless they aligned with their preferred learning style.

Monitoring: first-year life science majors are willing to monitor their understanding with guidance from their instructors

Monitoring involves identifying concepts you do and do not know. While studying on their own, first-year life science majors monitored in two main ways: (i) using self-testing and (ii) using self-explanation. While self-testing, students held themselves to a higher standard than self-explanation by making sure they could write or draw something from memory. Sibyll explained,

> "I will go through [the study guide] without using my notes and fill in as much as I can by myself. And then the topics that I couldn't do or that took me an extended period of time to think through and process, those are what I would target."—Sibyll

In contrast to self-testing, participants' self-explanations were often constructed in their minds, sometimes out loud, and very rarely in writing. When monitoring through self-explanation students must be honest with themselves about their understanding, as explained by participant Martina:

> "I'm rather honest with myself. I'm like, 'Okay, do I know this? Do I actually know this? If you were to ask me a question, would I be able to answer it, or would I look at you blankly for two minutes?'"—Martina

Monitoring can be challenging for students to do on their own because it requires them to have enough knowledge to accurately appraise their understanding of concepts. In other words, there is no one to correct them if they think they know something, but they actually do not.

While some first-year life science majors in our study monitored on their own, most participants monitored in response to in-class formative assessments provided by their instructors. For example, participants described being confronted with gaps in their knowledge when their instructors and peers revealed correct answers to clicker-style questions while in class. This result contrasts with prior research in which senior-level life science majors rarely mentioned formative assessment as being important for their monitoring (7). Kathleen explained the value of in-class formative assessment:

> "We do [clicker] questions in class…usually we have like five to six of those every class and they usually cover everything we learned that day. And so if I get the question wrong or I didn't understand why the answer was correct, that's how I [know] maybe I needed some more practice studying this than I did on one I got right and understood why."—Kathleen

Some students in our study also used out-of-class formative assessments to monitor their understanding. Shiloh described online quizzes as a way to "get a reality check" so that you know "you have to work on this topic." Thus, instructor-provided formative assessments continued to help students monitor outside of the classroom.

Evaluating: first-year life science majors evaluate primarily based on grades and feelings of confidence

Evaluating involves appraising the effectiveness of learning strategies and study plans after a learning task is completed (15). First-year life science majors described two major time points when they tend to evaluate: (i) after taking an exam and (ii) after receiving their grade on an exam. When participants evaluated after taking an exam, they primarily used their feelings to appraise their overall plan for studying. Students described using feelings of confidence, fluency, and comfort to predict how well they performed. For example, Paige explained that she knew her study plan was effective because “when I took the exam, I was really comfortable with everything that was being asked.”

When participants evaluated after receiving their grade on an exam, they would characterize their approaches to learning as effective if they were satisfied with their grade and ineffective if they were not satisfied with their grade. Nearly every student in our study used grades to evaluate their individual approaches to learning and their overall study plans. Some participants realized that their evaluations at these two time points did not align. Morgan described the mismatch between her recognition of the material and the surprise of earning a lower grade than she predicted:

> “While I was taking the exam everything seemed familiar to me, I didn't feel completely clueless about it, so I just expected a higher grade because the content just looked easy…and when I got the exam back, I was like, ‘Wow.’”—Morgan

When using grades to evaluate, some participants focused on comparing themselves to their peers. When asked to evaluate the effectiveness of his study plan for an exam, Erwin responded, “I got like a 75, which was compared to the class average…that was like right in the middle.” Comparisons like this may be especially relevant when a class uses a curve for grading. Only a few participants were prompted by an instructor to evaluate, and they used grades as the basis for their evaluations. Tabitha explained that her introductory biology instructor asks the class to determine the effectiveness of their study strategies after exams, which allows her to evaluate “all the factors that went into studying for that exam.” Beyond using grades to evaluate, some students considered whether their strategies helped them remember concepts. Philip explained how interleaving his study of biology, math, and English was more effective than spending hours on biology alone because it allowed him to recall the material.

DISCUSSION

Planning: first-year life science majors are more open to recommendations when they plan their studying

Our data suggest that current first-year life science majors may be particularly open to advice on how to study compared to first-year students studied in the past (8, 9). We hypothesize that because the majority of our participants experienced online high school classes when the pandemic started, they may be aware that different studying methods are needed for their in-person college courses. Additionally, current college students are accustomed to seeking online advice on how to do a variety of things in their everyday lives, from gaming to cooking, which may make it easier for them to seek help on how to study (27). Instructors can capitalize on this openness by providing students with instruction and practice on effective learning approaches. It is important that instructors explain when and why a learning approach is useful to help students develop a type of metacognition called conditional knowledge (15). For example, a concept map can be helpful for understanding the connections between ideas, but it is not as useful for memorizing terminology. Seeing an instructor or a peer model new learning approaches while thinking out loud can be especially beneficial for students (16).

To help first-year life science majors plan their studying, instructors may also need to debunk myths about learning such as preferred learning styles. A belief in learning styles can be discouraging to students when their preferred style does not match the instruction in their classes (28). In this study, participants used their learning style as a reason to discard possible study strategies without trying them, which we did not find in our past studies (8, 9). Instructors may need to explicitly explain that learning styles are just preferences (26). While the opportunity to learn in a preferred method may increase a student's motivation (29), a student who prefers visuals may benefit from understanding that they can still learn from resources that are not visual.

Monitoring: first-year life science majors are more willing to monitor their understanding with guidance from their instructors

In this study, first-year life science majors explained the value of formative assessment for identifying concepts they do and do not understand when asked how they monitor. This is in contrast to our past research on metacognition, where students rarely reported using formative assessment for monitoring (7). Based on this result, we encourage instructors to continue discussing the value of formative assessment for monitoring with their students. Providing this "activity messaging" is important for student buy-in and should be done well beyond the first day of class (30).

First-year life science majors in our study realized that their monitoring was not always accurate. Developing monitoring skills such as calibration, or the ability to align predicted exam scores with actual exam scores, is challenging for learners (31). Students who overestimate their knowledge tend to perform lower on exams, and students who underestimate their knowledge tend to perform higher on exams (32). Monitoring through in-class formative assessment may be especially effective for first-year students because it will allow them to increase their monitoring accuracy in the moment despite their nascent monitoring skills. For example, answering a clicker question and then having the correct answer revealed in class helped first-year life science majors confront what they did not yet know instead of thinking they knew the correct answer when they were actually wrong. We encourage instructors to continue explaining the correct answers to in-class formative assessments so that students can benefit from their expert thinking and continue to improve their monitoring skills (33). In addition, instructors can promote metacognition by asking students to answer in-class monitoring questions such as "What are you realizing about your knowledge as you answer these clicker questions?" (34).

Evaluating: first-year life science majors evaluate primarily based on grades and feelings of confidence

Our data suggest that first-year life science majors may be primed to evaluate the effectiveness of their approaches to learning at two time points: (i) after taking an exam and (ii) when they receive a grade on an exam. Instructors could focus their guidance on these time points to better help students develop their evaluation skills. For example, instructors can invite students to complete written reflections on the effectiveness of their study strategies immediately after completing an exam and seeing the grade they earned on the exam (7, 35).

Similar to our prior work on student metacognition, first-year life science majors in this study relied on their performance to evaluate their individual study strategies and overall study plans for an exam (8, 9). If participants were satisfied with the grade they earned, they deemed their studying as effective. When exam grades were not available, participants used their feelings of confidence, fluency, or comfort during the exam to assess their approaches to learning. Yet, researchers caution against the "fluency fallacy," which happens when learners experience ease in remembering a concept so they believe they understand the concept (36). Instead of using feelings, which can be misleading, instructors can encourage students to consider whether their exam preparation allowed them to do specific things. For example, instructors can ask students

TABLE 2 Implications for instructors for supporting student metacognition

Metacognitive skill	Key findings	Possible implications for instructors
Planning	First-year life science majors seek suggestions from others when they plan their studying.[a] Some students use "learning styles" as a reason not to use a strategy or resource.[a]	Current first-year life science majors may be particularly open to advice on how to study. Instructors can capitalize on this openness by providing students with step-by-step instruction and practice on effective learning approaches. For more information, see the instructor checklist from this free student metacognition guide: https://lse.ascb.org/evidence-based-teaching-guides/student-metacognition/. Instructors may need to debunk myths such as learning styles to help first-year students make better planning decisions.
Monitoring	In class, first-year life science majors monitor their understanding through formative assessment.[a] Out of class, students monitor by explaining concepts to themselves.	Current first-year students understand the benefit of formative assessment for monitoring. Instructors should continue to provide opportunities for students to answer questions in class. Instructors should continue to explain the answers to in-class questions because current first-year students need help developing their monitoring accuracy. When instructors provide out of class questions, sharing an answer key can help students assess their knowledge more accurately.
Evaluating	First-year life science majors evaluate their study plans based on the grades they earn. Before receiving a grade, students use their feelings to evaluate.	Current first-year students may need help to evaluate their study plans in a way that is not based on grades. Instructors can provide other mechanisms of evaluation, such as asking students to consider how well a study plan prepared them to gain an in-depth understanding, apply their knowledge, or make connections between concepts.

[a]Indicates findings that differ from our published results on student metacognition before the pandemic (8, 9).

to consider whether their study plans allowed them to make connections between concepts or apply concepts to new situations.

Conclusion

By understanding how, when, and why first-year students use metacognition, we have gained insights into what can support them to be more metacognitive. We have summarized specific suggestions for instructors in Table 2. We hope these recommendations will help foster student metacognition in the life sciences.

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