HOW WE TEACH | Generalizable Education Research

Examining the effects of different teaching strategies on metacognition and academic performance

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INTRODUCTION

Metacognition has become a popular topic among those wanting to better understand how students learn. John H. Flavell (12), originator of the term metacognition, described it as “the act of thinking about thinking.” In other words, it is our ability to know what we know and what we do not know, how we think, and what helps us learn. A review study by Wang et al. (41) revealed metacognition to be the second most powerful predictor of learning, along with classroom management (no. 1), cognitive processes (no. 3), home environment/parental support (no. 4), and student and teacher social interactions (no. 5). Furthermore, in How People Learn (3), the National Academy of Science argues for the effects of the metacognitive approach to instruction, and Hattie (14), in the Visible Learning research, ranks metacognitive strategies among the factors that have the greatest influence on student achievement (46th out of 195 different factors).

From this perspective, numerous studies on metacognition have been conducted in various content areas. Within this literature, there is a lack of focus on physiology education. It is important to consider physiology education when discussing metacognition, as faculty and students alike indicate that anatomy and/or physiology is difficult (26, 33). A systematic study by Michael (26) among 64 faculty at various postsecondary institutions indicated that faculty agree on a three-factor model in making physiology difficult: discipline, teaching, and student factors. Of these factors, discipline-related factors, such as the ability to reason causally, think about dynamic systems, and understand different levels of organization simultaneously, were identified as the primary factors. In a similar study, Sturges and Maurer (35) surveyed 276 undergraduate Human Anatomy and Physiology (HAP) students, who agreed with faculty and placed discipline-specific factors ahead of teaching and students factors in both quantitative and qualitative data. Both groups placed 5 discipline-specific factors in the top 10 factors, although there were few discrepancies on the order of factors ranked. The question, “A&P, like other life sciences, seems to encourage thinking about things in terms of their purpose,” ranked 1st for students and 14th for faculty (out of 18 questions) in making this subject difficult. The question, “Much of our understanding of physiological mechanism is communicated graphically or in other mathematical ways,” was ranked 16th by students and 4th by faculty. These difficulties in learning demand instructional solutions that address specifically how to learn the material. Metacognition addresses some of this need via instruction on not just what to study, but how to study as well.

Perhaps a more important finding in the Sturges and Maurer (35) study was the students’ acknowledgment of their own contributions to making this class difficult, even more so than the responsibility they place on their instructors. Students cited time management, study skills, and effort placed as some student-related factors. There is some additional evidence from interview studies that students emphasize workload elements (e.g., amount of work, number of assignments) over cognitive complexity (10), although Sturges and Maurer (35) presented some evidence that students realize the complexity of the material, but perhaps fail to address it. All of these findings underscore the importance of developing metacognitive skills in students to help them succeed in HAP. Given this information, the present study targeted students enrolled in the first
sequence of a two-semester introductory HAP course taught at a large, public university. Understanding that there are discrepancies in students’ awareness of their own abilities to study and retain information in physiology courses, we focused specifically on metacognition as a way to potentially impact learning within the course.

Researchers define two important aspects of metacognition: knowledge of cognition and regulation of cognition. Metacognitive knowledge refers to acquired knowledge about cognitive processes and knowledge that can be used to control cognitive processes (40). Cognitive knowledge includes the following (40):

- **Declarative**: Knowledge of facts and concepts, e.g., how well a person remembers and organizes information
- **Procedural**: Knowledge of procedures, e.g., awareness of strategies that could prove useful for specific subject areas
- **Conditional**: Knowledge of conditions, e.g., understanding when and why specific strategies will work over others

Metacognitive regulation involves the use of a set of metacognitive strategies (4), which are iterative processes that one uses to control cognitive activities and to ensure that a cognitive goal (e.g., understanding a text) has been met. These include the following (29):

1. **Planning**: planning, goal setting, and allocating resources prior to learning.
2. **Information management**: skills and strategy sequences used on-line to process information more efficiently (e.g., organizing, elaborating, summarizing, selective focusing).
3. **Monitoring**: assessment of one’s learning or strategy use.
4. **Debugging**: strategies to correct comprehension and performance errors.
5. **Evaluation**: analysis of performance and strategy effectiveness after a learning episode.

Research suggests that college-aged students can benefit from the use of specific strategies under the metacognition umbrella, and that metacognitive skills can be taught to students to improve their learning (27, 37). Pintrich (28) advocates that “students who know about the different kinds of strategies for learning, thinking, and problem solving will more likely to use them” and argues for the “need to teach for metacognitive knowledge explicitly.” A similar message is found in more recent literature that presents specific strategies to improve metacognition (23, 25). Some studies have assessed students’ metacognitive level and examined the relationship with student demographic characteristics, such as grade point average (GPA) (9, 30) and academic achievement (43). Higher knowledge and regulation of cognition were reported to correlate with end-of-course grades (43), but awareness of knowledge of cognition was not a determining factor for GPA (30). According to Şendurur and colleagues (30), higher knowledge of cognition was observed among undergraduate students, whereas Young and Fry (43) report that graduate students had higher levels of regulation of cognition than undergraduates, but no differences in knowledge of cognition.

Most importantly, previous studies have explored the effects of teaching about metacognition on academic performance and used multiple instruments to evaluate metacognition (e.g., exit surveys, metacognitive awareness inventory, interactive multimedia exercises, and effective learning strategies surveys). These studies targeted different populations of students: first-year science majors (6), chemistry students (44), first-year biology students (15, 32, 34), computer and accountancy students (18), pre-service teachers (39), nursing students (16), and engineering students (7). In addition, previous research has reported different time frames devoted to metacognition and use of different interventions, such as one 50-min presentation on learning strategies (6, 44); two 50-min study-skills lecture (15); nine 70-min sessions on metacognition (18); self-evaluation for exams and exam wrappers (33, 34); classroom learning communities and self-assessment (32); problem-based learning (39), blended project-based learning (17) and blended learning modules (16).

With regards to the benefits seen by these interventions, some studies reported a full letter grade improvement in the final grade and a change in behavior for those who attended one 50-min presentation, but no change in exam performance (6). Others indicated improved exam performance (tests 2 and 3), with participants who received two separate 50-min interventions outperforming their peers (44). Further evidence of the benefits of metacognition include improved metacognitive awareness (15, 17) and changes in study approaches of students (32), including improved time management skills and the ability to read and understand the material better (18). Stanton and colleagues (34) reported that about one-half of the students were able to monitor, evaluate, and plan their learning strategies after completing a metacognitive assignment. However, Hsu and Hsieh (16) examined the effects of a blended learning module on metacognition, which did not yield higher mean scores on metacognition measures in comparison to a control group. Similar results were seen in a community college setting (33). Overall, this mixed evidence suggests that, among college-aged students, the use of metacognitive strategies may help course performance, but may not improve awareness of metacognitive strategies. Further examination of the types of strategies used and how they work may help clear up the discrepancy.

Students may use a number of learning strategies in each of their classes, which can be classified as low, medium, and high utility. Dunlosky et al. (11) noted that many students try to learn using methods with a low utility, such as summarizing, highlighting, and underlining text, and that many teachers do not teach students more effective strategies, such as practice testing or distributed practice, to learn new material. According to the review, Dunlosky et al. indicate that strategies with low utility demonstrated less impact on performance, were difficult to implement, or were not generalizable to multiple contexts. Without guidance from teachers, students must take it upon themselves in many situations to evaluate methods that work well for them in their diverse learning environments, often adhering to the strategies they have used in the past, even when they are not effective. Some learning strategies are more specific to certain environments, and students must be adaptable to learn differently (11).

Understanding the utility of different metacognitive strategies, and that students in previous studies may or may not have benefitted from using such strategies, a discussion on how specific strategies work is warranted. To that end, this study focuses on three different interventions within sections of a single course on students’ knowledge of cognition, regulation
of cognition, exam, and final course grades. Exam wrappers, watching videos, and peer learning through a group quiz were chosen for this study based on the following goals: easy adoption by any instructor without training, appropriate in any class size, and implementation within a 50-min limit of class time, a minimum time frame claiming an improvement in metacognition or grades (6, 15, 44).

Specific to this study, exam wrappers were utilized to test the abilities of self-assessment and reflection (34), as they have been reported to be useful and beneficial by students and improved metacognitive skills and self-monitoring strategies in previous studies (1, 38), although some studies reported no benefits (33). Achacoso (1) first developed the use of posttest analysis tools to help students improve their metacognitive awareness and self-regulation. Lovett (20) then gave these posttest reflections the name “exam wrappers” and provided a guide on how to structure them. The exam wrapper developed in the present study were created based on the framework described by Achacoso and Lovett. The foundation of all exam wrappers is based on three primary reflections. These include a description of student preparation for the exam, type of errors made on the exam, and how the students plan to change their study habits for the next exam (20). Exam wrappers are reported to work by increasing students’ awareness of their own exam preparation strategies and identifying areas of improvement (1). A benefit to the use of exam wrappers is the incorporation of questions targeted toward the planning, monitoring, and evaluation of study strategies that may promote overall metacognition of learning, nonspecific to one course topic or discipline (36). A study done by Gezer-Templeton et al. (13) found that, after exam wrappers were introduced in the classroom, 72% of the students believed that the exam wrappers helped to improve their study habits, 59% reported that they utilized the exam wrappers for other courses after being introduced to it, and 71% agreed that they planned to use the exam wrappers in future classes.

In a second type of intervention, a presentation on learning strategies was completed via short videos, which included information on study skills and metacognition. This was chosen because teaching about metacognition, learning strategies, and techniques has been shown, in previous literature, to improve student performance and change study behavior (6, 15, 18, 44). Within these studies, it was argued that teaching new strategies informs students that there are other ways of studying and introduces them to the topic of metacognition. In considering this, there is literature to suggest that this intervention represents a more passive approach, where students are simply given information through an outside source. Still, watching videos represents the least time-consuming and invasive option for instructors. Properly utilized, students in this group would have the potential to develop a systematic approach to studying (42), instead of studying in the exact same way for every class. Weinstein (42) has stated that learning to utilize these new strategies is dependent on systematic instruction and not just introducing them to the concepts. Furthermore, Cao and Nietfeld (5) assert that teaching students about new study techniques does not ensure that they utilize any new study techniques, and many students will not change their study habits in the short term (5). Although there is literature to support the fact that this type of intervention would not be successful, there is an equal number of studies that suggest the opposite. Testing this type of intervention will help to determine whether a quicker and less invasive approach to learning about metacognition will benefit students in HAP courses.

Lastly, collaborative learning followed by a group quiz represented an intervention based in classroom learning communities and problem-based learning (39). This was chosen because the social aspect of metacognition is inherent in collaborative learning (21), which has been reported to improve metacognitive skills (2). Collaborative learning is said to work by engaging students in the process of activation of prior knowledge and elaboration on new knowledge, thereby allowing new connections to be made within the context of a stated problem (11). While applied in different ways, collaborative learning has been shown to improve self-regulation in learning computing skills (24) and domain-specific metacognitive knowledge (19).

It was hypothesized that each intervention would be successful in improving both knowledge and regulation of cognition, in addition to higher exam and final grades in the course. To guide this investigation, the following research questions were examined:

1. What is the effect of different metacognitive strategies (reflection practice, passive knowledge acquisition, and collaborative learning) on students’ knowledge and regulation of cognition?
2. What is the effect of different metacognitive strategies on student academic performance (exam and final course grade)?

MATERIALS AND METHODS

Study context. The Human Anatomy and Physiology (HAP) course covers the cell, histology, integumentary, nervous, muscular, and skeletal systems. There are no prerequisites for the course, and there is an accompanying laboratory component with a separate grade in which students can enroll (simultaneously or off-sequence). Each section enrolls up to 150 students, and the student population consists mostly of freshmen and sophomores in the nursing and exercise science majors, with a minority of students enrolled in nutrition, athletic training, health and physical education, public health, and other majors. Course instruction is primarily traditional lecture that includes occasional role play, small-group discussions, and think-pair-share. Student learning in the course is evaluated through individual performance on summative multiple-choice exams and online quizzes, as well as low-stakes in-class assignments collected using i-clickers.

Participants. For this study, the sample included 129 HAP students (79.8% men, 20.2% women, 69.8% Caucasian, 48.8% sophomores) who were over the age of 18 yr, which was confirmed by the completion of the informed consent document. Overall, most students in the course were in the nursing (28.7%) or exercise science majors (27.1%). Students’ self-reported GPA was most often (38%) at a 3.5–4.0. More information on student demographic characteristics, including overall and by intervention group, is reported in Table 1.

Instrumentation. To assess the effect of these interventions on knowledge and regulation of cognition, a survey was administered during week 2 of the semester (pretest) and during the second class meeting after exam 2 (posttest).

The survey consisted of the following:

- Demographic information: Ten items were included that asked students about sex, ethnicity, race, class standing, if class is required for major, major, likelihood of continuing in the chosen major, self-reported GPA, and status as a first-generation college student. These items were collected to help provide institutional
context, which will assist with future research aims, including replicability or meta-analysis.

The Metacognition Awareness Inventory (MAI) (29): The MAI is a 52-item survey that assesses knowledge and regulation of cognition and requires students to agree or disagree with a statement by answering “true” or “false” on each statement. For example, students were given the prompt, “I try to break studying down into smaller steps,” and indicate their agreement by checking true (score of 1) or false (score of 0). Responses are grouped in specific categories, with a total score calculated by adding the scores for individual questions. All questions on the MAI needed to be answered to compute the score. Categories include knowledge of cognition (declarative, procedural, and conditional knowledge) and regulation of cognition (planning, information management strategies, comprehension monitoring, debugging strategies, and evaluation). Examples of each type of knowledge and regulation of cognition are listed in Table 2. Favorable levels of validity and reliability of this measure were established by Schraw and Dennison (29).

Procedure. After receiving Institutional Review Board approval, the study targeted students enrolled in three sections of HAP I in fall 2016 (~450 students). Sections were randomly assigned to one of three groups, with each group receiving only one of the interventions.

### Table 1. Demographic characteristics

| Demographic Characteristics                  | Overall, n (%) | Exam Wrapper, n (%) | Video Training, n (%) | Group/Team Learning, n (%) |
|---------------------------------------------|----------------|--------------------|-----------------------|---------------------------|
| Student distribution by group               |                |                    |                       |                           |
| Major                                       | 129            | 34                 | 84                    | 11                        |
| Nursing                                     | 37 (28.7)      | 11 (32.4)          | 23 (27.4)             | 3 (27.3)                  |
| Exercise Science                            | 35 (27.1)      | 6 (17.6)           | 26 (31.0)             | 3 (27.3)                  |
| Athletic Training                           | 17 (13.2)      | 5 (14.7)           | 10 (11.9)             | 2 (18.2)                  |
| Nutrition and Food Science                  | 4 (3.1)        | 1 (2.9)            | 2 (2.40)              | 1 (9.10)                  |
| Other                                       | 36 (27.9)      | 11 (32.4)          | 23 (27.4)             | 2 (18.2)                  |
| Self-reported GPA                           |                |                    |                       |                           |
| 3.5–4.0                                     | 49 (38)        | 11 (32.4)          | 34 (40.50)            | 4 (36.4)                  |
| 3.0–3.49                                    | 41 (31.8)      | 10 (29.4)          | 28 (33.3)             | 3 (27.3)                  |
| 2.50–2.99                                   | 21 (16.3)      | 6 (17.6)           | 13 (15.5)             | 2 (18.2)                  |
| 2.0–2.49                                    | 10 (7.8)       | 4 (11.8)           | 6 (7.10)              | 0 (0)                     |
| <2.0                                        | 8 (6.2)        | 3 (8.8)            | 3 (3.60)              | 2 (18.2)                  |
| Sex                                         |                |                    |                       |                           |
| Women                                       | 103 (79.8)     | 29 (85.3)          | 67 (79.8)             | 7 (63.6)                  |
| Men                                         | 26 (20.2)      | 5 (14.7)           | 17 (20.2)             | 4 (36.4)                  |
| Race/ethnicity                              |                |                    |                       |                           |
| Non-Hispanic                                | 123 (95.3)     | 34 (100)           | 79 (94.0)             | 10 (90.9)                 |
| Hispanic                                    | 6 (4.7)        | 0 (0)              | 5 (6.00)              | 1 (9.10)                  |
| Caucasian                                   | 90 (69.8)      | 26 (76.5)          | 58 (69.0)             | 6 (54.5)                  |
| African American                            | 33 (25.6)      | 8 (23.5)           | 20 (23.8)             | 5 (45.5)                  |
| Asian                                       | 3 (2.3)        | 0 (0)              | 3 (3.6)               | 0 (0)                     |
| American Indian/Alaskan                     | 1 (0.08)       | 0 (0)              | 1 (1.20)              | 0 (0)                     |
| Native Hawaiian                             | 2 (1.6)        | 0 (0)              | 2 (2.40)              | 0 (0)                     |
| First-generation college student*           |                |                    |                       |                           |
| Yes                                         | 17 (13.2)      | 4 (11.8)           | 12 (14.3)             | 1 (9.10)                  |
| No                                          | 105 (81)       | 28 (82.4)          | 68 (81.0)             | 9 (81.8)                  |
| Not sure                                    | 6 (4.7)        | 2 (5.90)           | 3 (3.6)               | 1 (9.10)                  |
| Class standing                              |                |                    |                       |                           |
| Freshman                                    | 33 (25.6)      | 3 (8.80)           | 24 (28.6)             | 6 (54.5)                  |
| Sophomore                                   | 63 (48.8)      | 23 (67.6)          | 38 (45.2)             | 2 (18.2)                  |
| Junior                                      | 22 (17.1)      | 7 (20.6)           | 14 (16.7)             | 1 (9.10)                  |
| Senior                                      | 10 (7.8)       | 1 (2.90)           | 8 (9.5)               | 1 (9.10)                  |
| Other                                       | 1 (0.80)       | 0 (0)              | 0 (0)                 | 1 (9.10)                  |
| Likely to continue with major               |                |                    |                       |                           |
| Somewhat unlikely                           | 1 (0.80)       | 0 (0)              | 1 (1.20)              | 0 (0)                     |
| Neither unlikely nor likely                 | 2 (1.6)        | 0 (0)              | 1 (1.20)              | 1 (9.10)                  |
| Somewhat likely                             | 16 (12.4)      | 4 (11.8)           | 12 (14.3)             | 0 (0)                     |
| Very likely                                 | 110 (85.3)     | 30 (88.2)          | 70 (83.3)             | 10 (90.9)                 |

Values are n, no. of students (with percentage in parentheses). GPA, grade point average. *n = 128; one student did not answer the question.

### Table 2. Metacognition Awareness Inventory survey components

| Category                  | Subskills (no. of Questions) | Example of Survey True/False Questions |
|---------------------------|------------------------------|---------------------------------------|
| Knowledge of cognition    | Procedural knowledge (4)     | “I am aware of what strategies I use when I study.” |
|                           | Declarative knowledge (8)    | “I know what type of knowledge is the more important to learn.” |
|                           | Conditional knowledge (5)    | “I know when each strategy I use will be most effective.” |
| Metacognitive regulation  | Information management strategies (10) | “I slow down when I encounter important information.” |
|                           | Debugging (5)                | “I ask others for help when I don’t understand something.” |
|                           | Planning (7)                 | “I organize my time to best accomplish my goals.” |
|                           | Comprehensive monitoring (7) | “I considered several alternatives to a problem before I answer.” |
|                           | Evaluation (6)               | “I ask myself if I have considered all options after I solve a problem.” |
To maintain consistency across all sections, interventions were carried out during the second class meeting after exam 1 (22).

1. Reflection practice group (one class meeting of 50 min): During this intervention, each student was provided with an exam wrapper sheet that consisted of a series of reflection questions. These questions addressed how the students prepared for the exam, types of exam errors, potential patterns in exam errors, and how exam preparation could be improved. Students were asked to record their answers, and, at the end of the class period, exam wrappers were collected by the instructor. Students were not graded on their answers, and exam wrapper analysis was not part of this study.

2. Passive knowledge acquisition group (one class meeting of 50 min): During this intervention, students were instructed to watch and listen to five videos presented on the projector. Videos were part of a series entitled, “How to get the most out of studying” available at https://www.samford.edu/departments/academic-success-center/how-to-study and included the following topics: Beliefs That Make You Fail... Or Succeed; What Students Should Understand About How People Learn; Cognitive Principles for Optimizing Learning; Putting the Principles for Optimizing Learning into Practice; and I Blew the Exam, Now What? This intervention was passive in nature, and its purpose was to inform students about metacognition. No quiz or other reflective assignment was given to students during this intervention.

3. Collaborative learning group (one class meeting of 50 min): For this intervention, students were divided into groups of three to four and assigned an activity on the integumentary system (each group was asked to compare and contrast the layers of the skin). After the completion of the activity, one student in each group was randomly chosen to take a low-stakes quiz over the material learned, with the grade counting for all group members. Attendance was taken during the class period when each intervention was conducted. Exam grades (one before and one after intervention) and final course grades were collected at the end of the semester, whereas the surveys were given before the interventions and during the second class meeting after the second exam. Exams 1 and 2 were two different exams, assessing different content material, a practice used in the design of previous studies in chemistry and engineering classes (6, 44).

Data analysis. Only data from students who fully completed their respective intervention (verified by attendance on day of intervention), along with both surveys (pretest and posttest) were included in the analysis. Since completion of every question on the MAI is necessary for data analysis, students who fulfilled the above requirements, but did not fully fill out the MAI, were eliminated from the study. All collected data from the 129 participants were checked for normality and for the survey measures, Cronbach’s α was calculated to ensure reliability in the current sample. To determine potential associations with knowledge of cognition, regulation of cognition, and course performance, Pearson correlations were carried out, using an α-level of 0.05 to determine significance. To determine potential differences in knowledge of cognition, regulation of cognition, and exam grades by intervention and time, a two-way (group × time) ANOVA was carried out, using an α-level of 0.05 to determine significance. Where appropriate, follow-up pairwise comparisons were made for groups using a Tukey post hoc test. Differences in final course grades were calculated via χ² analysis. A post hoc power analysis indicated that the sample size of the study was robust enough to draw proper conclusions. In addition, measures of effect size are included within the results for each comparison.

RESULTS

Relationships between knowledge of cognition, regulation of cognition, and course performance. Correlations were run across all intervention groups, revealing significant correlations between knowledge of cognition at time 2 and test 2 (r = 0.28, P = 0.01). No other correlations were significant. Within each intervention group, significant correlations were found in the regulation of cognition at time 2 and test 2 within the reflection practice group, and no significant relationships between variables in the passive acquisition of knowledge and the collaborative learning group.

Knowledge and regulation of cognition. For knowledge of cognition, analyses revealed a significant interaction between time and group for the students [Wilks’ λ = 0.92, F(2,126) = 5.17, P = 0.007, η² = 0.076]. Students in the reflection practice group increased in their knowledge of cognition [pretest mean (Mpre) = 13.85, SD = 2.46; posttest mean (Mpost) = 14.21, SD = 2.76], the passive acquisition of knowledge group decreased in their knowledge of cognition (Mpre = 14.58, SD = 2.31; Mpost = 13.61, SD = 2.95), and the collaborative learning group saw no change in knowledge of cognition (Mpre = 13.45, SD = 1.69; Mpost = 13.45, SD = 1.81). Table 3 details the individual means for procedural, declarative, and conditional knowledge across groups and time. On examining mean values of the types of knowledge, procedural knowledge was highest among students in the reflection practice group, followed by the passive acquisition of knowledge group, and then collaborative learning group. Interestingly, the values of procedural knowledge fell from pretest to posttest for the passive acquisition of knowledge group. For declarative knowledge, similar patterns were seen, with an increase in this type of knowledge among the reflection practice group and collaborative learning group. Finally, for conditional knowledge, the reflection practice group saw an increase in score, whereas video training and collaborative learning groups saw a decrease.

Table 3. Means and SDs for types of knowledge and regulation of cognition

| Knowledge of Cognition | Intervention Type        | Pretest | Posttest |
|------------------------|--------------------------|---------|----------|
|                        |                          | Mean    | SD       | Mean    | SD       |
| Procedural knowledge (total score = 4) | Exam wrapper          | 3.47    | 0.79     | 3.56    | 0.70     |
|                        | Video training           | 3.45    | 0.84     | 3.23    | 1.02     |
|                        | Group/team learning      | 2.91    | 0.70     | 3.09    | 0.83     |
| Declarative knowledge (total score = 8) | Exam wrapper          | 6.38    | 1.54     | 6.47    | 1.67     |
|                        | Video training           | 6.82    | 1.26     | 6.21    | 1.69     |
|                        | Group/team learning      | 6.09    | 1.14     | 6.36    | 1.69     |
| Conditional knowledge (total score = 5)  | Exam wrappers          | 4.00    | 0.85     | 4.18    | 0.97     |
|                        | Video training           | 4.31    | 0.85     | 4.17    | 0.94     |
|                        | Group/team learning      | 4.45    | 0.69     | 4.00    | 0.89     |
Comparisons of regulation of cognition indicated no main effects \[
\text{Wilks' } \lambda = 0.99, F(1,126) = 0.197, P = 0.658, \eta^2 = 0.002\]
or significant interactions \[
\text{Wilks' } \lambda = 0.959, F(1,126) = 2.67, P = 0.073, \eta^2 = 0.041\]
for time or intervention type. Means and SDs for regulation of cognition were similar across the groups and time (reflection practice group: \(M_{\text{pre}} = 26.21, \ SD = 4.98\) and \(M_{\text{post}} = 27.65, \ SD = 4.67\); passive acquisition of knowledge group: \(M_{\text{pre}} = 27.65, \ SD = 5.40\) and \(M_{\text{post}} = 27.17, \ SD = 5.45\); and collaborative learning group: \(M_{\text{pre}} = 26.18, \ SD = 5.00\) and \(M_{\text{post}} = 24.45, \ SD = 6.44\), respectively). Table 4 details the individual means and SDs for planning, information management strategies, comprehension monitoring, debugging strategies, and evaluation across groups. Regardless of time or group, students tended to report using debugging strategies most often, followed by information management strategies, comprehension monitoring, planning, and evaluation. Mean levels for planning and evaluation were below the midline for this sample.

**Exam grades and final course grades.** Comparison of exam grades over time show no significant main effects \[
\text{Wilks' } \lambda = 0.96, F(2,124) = 2.75, P = 0.068\]
or significant interactions \[
\text{Wilks' } \lambda = 0.97, F(1,124) = 2.76, P = 0.099\]. The final course grade distribution among the students showed that C’s occurred the most frequently (44 students), followed by B’s (18 students), A’s (14 students), and D’s (13 students), respectively. When comparing grades between groups, \(\chi^2(8) = 15.16, P = 0.056\). Table 5 illustrates the means and SDs for exam scores by group.

**DISCUSSION**

The purpose of this study was to determine the effects of three separate interventions on students’ knowledge and regulation of cognition, as well as academic performance, as measured by exam and final course grades. From a more mechanistic perspective (31), the results of the study will be discussed in terms of what we found and why these interventions may not have been successful. With the exception of an increase in knowledge of cognition for one intervention type (reflection practice group), the hypotheses were not supported. In some cases, some of the interventions decreased knowledge of cognition. Overall, there was very little association between regulation of cognition and exam scores. However, posttest knowledge of cognition had a weak correlation with test 2 performance. It is important to consider these results within the context of our sample, in that the majority of our sample was nursing and exercise science majors with high self-reported GPAs. Examining the mean values of the individual categories within knowledge and regulation of cognition, students indicated high levels of procedural, declarative, and conditional knowledge, which could explain why their scores did not rise after the intervention. However, mean levels of regulation of cognition, including planning, information management strategies, comprehension monitoring, debugging, and evaluation, were average.

With regards to metacognitive measures, the fact that exam wrappers significantly increased knowledge of cognition was promising. Of the three interventions, this provided the most concrete feedback to students about specific exam performance, while also engaging students in metacognitive processes. Previous research has indicated that exam wrappers may be mostly beneficial for students who are not high achievers (13). Given this information, the results of the present study support the fact that exam wrappers benefited the students who used them and contradict the results of Soicher and Gurung (33). More specifically, the exercise of identifying what types of study skills students used and what potential patterns they found in their mistakes was helpful in increasing procedural, declarative, and conditional knowledge. In other words, this intervention somewhat worked as intended, as reflective practices allowed students to think about how they prepared for the exam, identified of the types of errors made, and helped students to devise a plan to improve on the next exam. It would be expected that this intervention would also improve regulation of cognition, but the results do not support this notion.

It was interesting to see that the passive acquisition of knowledge group significantly decreased knowledge of cognition over time. Although evidence showing the utility of this type of intervention is conflicted, our results indicate that a quick and less invasive approach may not work well with students. The decrease in knowledge of cognition could have occurred because of the way the videos were presented during the intervention. All five videos were viewed in succession, with no discussion in between about how they might impact

| Table 4. Regulation of cognition |
|----------------------------------|
| **Group**                      | **Pretest** | **Posttest** |
| **Mean** | **SD** | **Mean** | **SD** |
| Information management strategies (total score = 10) | | |
| Exam wrapper | 7.79 | 1.43 | 7.97 | 1.31 |
| Video training | 8.11 | 1.66 | 8.04 | 1.65 |
| Group/team learning | 8.36 | 1.22 | 7.45 | 1.92 |
| Debugging (total score = 5) | | |
| Exam wrapper | 4.59 | 0.74 | 4.57 | 0.75 |
| Video training | 4.62 | 0.77 | 4.46 | 0.80 |
| Group/team learning | 4.18 | 0.75 | 4.27 | 1.19 |
| Planning (total score = 7) | | |
| Exam wrapper | 4.76 | 1.54 | 5.09 | 1.50 |
| Video training | 5.23 | 1.81 | 5.02 | 1.63 |
| Group/team learning | 4.82 | 1.66 | 4.73 | 1.35 |
| Comprehension (total score = 7) | | |
| Exam wrapper | 5.15 | 1.62 | 5.62 | 1.37 |
| Video training | 5.63 | 1.42 | 5.38 | 1.65 |
| Group/team learning | 5.27 | 1.10 | 4.55 | 1.81 |
| Evaluation (total score = 6) | | |
| Exam wrapper | 3.91 | 1.56 | 4.41 | 1.35 |
| Video training | 4.07 | 1.57 | 4.26 | 1.44 |
| Group/team learning | 3.55 | 1.75 | 3.45 | 1.81 |
students. Upon visual inspection, levels of procedural, declarative, and conditional knowledge decreased in this group, which further illustrates that it may not be a properly aligned intervention for these students. It is possible that lower scores are also due to the passive nature of the video training intervention. Students were not asked any questions at the end, nor did they have to actively reflect on the presented content. Ultimately, students could have been better served by completing some sort of activity to apply or work with the new knowledge they obtained from the videos. In essence, a passive type of intervention with this population was not successful in improving metacognitive processes because students did not have to actively interact with the learned information.

Regulation of cognition remained unchanged among students in all three groups. This was an unexpected result, as Stanton and colleagues (34) indicated that students did experience a change in planning, monitoring, and evaluation. The three interventions did little to change students’ planning, which, according to mean levels pre- and postintervention, were lower than expected. The interventions were equally ineffective at raising moderate levels of information management and comprehension monitoring as well. Students in this study did have moderately high levels of debugging strategies and evaluation according to mean levels pre- and postintervention. This course tends to be a difficult one for students, so, while this information is promising, higher levels of these two strategies would be beneficial for students. With the exam wrapper specifically, students are asked questions to determine what mistakes they may have made on the exam and how they planned to address these mistakes. The fact that changes were not seen in that group suggests that the regulation of cognition may need to be explicitly explained to students. In addition, it may be that each intervention was not long enough to adequately address the explanation of the regulation of cognition. This is an introductory class with an increasingly higher population of freshmen in recent years. It is possible that students are learning about metacognition for the first time in their lives and a one-time intervention is not sufficient to address both components. There is also some evidence that metacognition regulation development is a continuum, and students need help with metacognitive knowledge before they can execute learning strategies of their choice (34). Given these results, it appears that more time would need to be dedicated to teaching metacognition in courses of this type.

The hypotheses were also not supported with regards to the interventions’ effects on exam and final course grades. When examined by the intervention group, exam grades remained stable from pretest to posttest. Looking at the reflection practice group specifically, exam grades increased slightly, which could be supported by the significant difference seen in the knowledge of cognition found. This would support some of the previous research results (6), but the other two groups showed decreases in exam grades over time. Final course grades, although analyzed differently, showed no significant relationships with the type of intervention. In essence, the interventions did not have an influence on this measure of performance either. Explanations for this result are similar to the lack of significant change in exam score. Overall scores on the exams were stable, and the most commonly awarded grade in the course was a B for the exam wrapper and group/team learning intervention groups, and a C for the passive acquisition of knowledge group, which mimicked scores on the two exams used for analysis. Evaluation of grades should consider the fact that exams assessed different content. Exam 1 assessed knowledge of introduction into HAP, chemistry principles, cytology, and epithelial tissues, whereas exam 2 covered connective tissue including osseous tissue, major bones of the skeleton, and the integumentary system. However, previously published studies evaluated changes in grades for tests with different content as well (6, 44). In engaging in the explanation of how these interventions might have impacted grades, it is possible that there are other intermediary mechanisms that work to connect knowledge and regulation of cognition to course performance. There is merit in investigating how students actually apply the metacognitive strategies they might learn, as the interventions represented here only address the awareness of metacognition and not actual metacognitive strategy use.

Taking each of these analyses into consideration, the length of the intervention may need to be longer than one 50-min class session. Initially, we chose this length of time based on previous literature (6, 44). Although there were examples in the literature of a more extensive intervention (15, 18), a longer session would have forced us to eliminate content from the course and would make the adoption of the intervention by other instructors less likely. It is possible that smaller chunks of time could be utilized to help students improve, which would eventually add up to more time focused on how to study instead of just what to study. On examining the course subjects of previous research, none had a basis in HAP, comprising work in engineering, chemistry, teacher education, computer and accountancy, first-year science, and biology. Many targeted introductory classes similar to HAP, since students enrolled in the course were primarily freshman and sophomores. It is possible that the interventions used may not adequately address the needs of these students as they transition from high school. Course work encountered in the first 2 yr of college tend to be eye-opening to students, where they may realize that they do not have the required skills to study successfully. It is also possible that using each strategy in isolation was not adequate for the population in this study.

As the relative success of interventions in metacognition are well documented, we feel that a combination of the interventions might be useful among this group of students. More specifically, combining the use of exam wrappers and video training may help students connect the utility of metacognition with actual thoughts on how they performed after an exam. This would allow the instructors to teach about knowledge of metacognition (video training), while providing students with active reflection opportunities (exam wrappers). Our experience with students in the collaborative learning group indicates that this induced a certain amount of undue stress on students, since part of their grade depended on a randomly chosen member of the group. Despite the fact that the quiz was a
low-stakes assignment, this intervention would have to be modified or eliminated from future research. Future research should test the idea of using a multi-strategy approach, where different interventions are used in sequence, and how it might affect student metacognition and academic performance.

**Limitations.** There are several limitations of this study. First, the MAI required each person to fill out the survey completely. Although we had a possible participant pool of 450 students, many did not complete the full survey, making the data unusable. A possible solution to this limitation would be administration of the MAI through a modality that would require an answer to each question, before proceeding to the next one. Second, the time of day the courses were offered (two courses on Monday, Wednesday, and Friday and two courses on Tuesday and Thursday) may have had an effect on the results, but we have no way of testing this. Additionally, since this research was conducted in intact classes, we had no way of randomizing students into a course. Care was taken to randomize students into intervention groups, but a larger and more random sample might have given different results.

The lack of process data on individual students was another major limitation. This study did not track the contributions of each student within an intervention or the level of attentiveness of students within an intervention. We only recorded if a student was present for the intervention that was presented to the entire class. For the collaborative learning group specifically, we did not track who actually took the quiz and who was just a member of the group. From a study design perspective, both the data collection methods and the design itself were not situated in a way that addressed actual behaviors of students, but rather a self-reported vision of what their metacognitive behaviors were. With a group this large, assessing behaviors via protocol analysis, observations, or individual interviews could have elicited a more accurate representation of students’ knowledge and regulation of cognition. With the larger sample of students, it would be nearly impossible to conduct such an analysis, although future study looking at smaller groups of students is warranted.

A larger limitation is present in this study, in that content across exams varied, which could have affected the overall results. Furthermore, the tests used for this study were the same that students normally receive in the course, which maintained ecological validity, but also bring about issues of whether learning could actually be assessed, since students were not given the same exam twice over the same material. As this was situated as a practical application and designed to be widely replicated in real classrooms, we do acknowledge that there are flaws in the design that could have contributed to the results we observed. However, testing a real-world application instead of relying solely on previous literature using course work unlike HAP and with less feasible time frames and number of students in the course was paramount.

Considering these limitations, it is important to consider the relationships between knowledge and regulation of cognition and course performance. As mentioned previously, it is clear that there may be some intermediary considerations between these variables that might better explain the results that we found. As each intervention was constructed to be efficiently delivered, there was not an explicit attempt to engage students in understanding knowledge and regulation of cognition. It is possible that students need to be instructed on exactly what knowledge and regulation of cognition is, along with processes that might help them improve their course performance.

**Conclusions.** With these limitations notwithstanding, this study helps to address the application of metacognitive strategies in physiology education from a practical perspective. Although more metacognition studies are needed, this study suggests that more active individualized reflection may be beneficial to improving knowledge of cognition. The addition of complimentary metacognitive strategies to facilitate the improvement in regulation of cognition may be needed when introducing these strategies for the first time and/or when there is an intention to influence academic performance. In addition, we argue that metacognitive strategy use may only be improved when it is more integrated into the course and not just a “one-shot” application. Future interventions should be more reflective in nature, repeated intervention may be necessary, and additional methods of evaluating students other than test grades should be considered.

**DISCLOSURES.**

No conflicts of interest, financial or otherwise, are declared by the authors.

**AUTHOR CONTRIBUTIONS**

J.L., A.J.R., J.M., and M.S. conceived and designed research; J.L., D.T.B., and A.J.R. performed experiments; J.L., M.W., and A.J.R. analyzed data; J.L., D.T.B., A.J.R., J.M., and M.S. interpreted results of experiments; J.L. and M.W. prepared figures; J.L. and D.T.B. drafted manuscript; J.L., D.T.B., M.W., A.J.R., J.M., M.S., and M.C.C. edited and revised manuscript; J.L., D.T.B., A.J.R., J.M., M.S., and M.C.C. approved final version of manuscript.

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