Sarah E. Daly, CORNELL UNIVERSITY, sed84@cornell.edu
Patrick A. Gibney, CORNELL UNIVERSITY, pag235@cornell.edu
Abigail B. Snyder, CORNELL UNIVERSITY, abs276@cornell.edu

A Pilot Study for Building Student Metacognitive Skills and Self-Perception in a Food Microbiology Lecture Course

ABSTRACT

Metacognition, or the monitoring of one's own learning, is an underutilized tool in STEM education. Previous research suggests instructional strategies that attempt to improve student metacognitive skills could increase student resilience and retention in STEM classes. This pilot initiative aimed to improve student metacognitive skills and self-perception. To do so, metacognitive-based instructional strategies were added to the curriculum of a food microbiology lecture course. These instructional strategies encouraged students to build their metacognitive skills within a supportive classroom community. Student metacognitive skills, self-perception, and learning strategies were assessed throughout the semester. By the end of the semester, over a third of students reported using at least three higher-order learning strategies. Additionally, there were some significant changes in students' sense of belonging and self-efficacy, with an overall positive improvement compared to their previous science lectures. This study found that metacognitive-based instructional strategies can be an important tool for improving students' experiences in a food microbiology class.

KEYWORDS

metacognition, STEM education, belonging, self-efficacy, learning strategies, curriculum development

INTRODUCTION

Introductory foundational STEM courses, sometimes known as "gateway" courses, have been identified as an important predictor of undergraduate retention in STEM fields (Flanders 2017). Typically, these courses are required for graduation, contain a lecture component, and serve a large number of students. A large volume of material presented at a fast pace is a common attribute of these courses (Weston et al. 2019). Grading tends to be relatively stringent and relies heavily on high-stakes exams (Tomkin and West 2022). Foundational courses have not only been cited as a reason for low numbers of women and underrepresented minorities in many STEM fields (Hatfield, Brown, and Topaz 2022; Mervis 2011), but have also been attributed to stifling students' intellectual curiosity and creativity (Holland 2019). Students have reported dissatisfaction with minimal instructor-student interaction in lectures, insufficient support from instructional staff, disengaged or condescending faculty, disorganized teaching, and inappropriate and inadequate content delivery (Harper, Weston, and Seymour 2019). Furthermore, students are rarely taught strategies to succeed in these courses, such as study skills, which may be a more effective approach for promoting accessibility within traditional STEM lecture courses.

Intentional instruction aimed toward the development of metacognitive skills is a relatively unexplored strategy for promoting student success in STEM education (Watkins and Mazur 2013). Metacognition is knowledge of one's own cognitive processes, namely being able to monitor and adjust one's own learning strategies (Flavell 1979; Wang, Haertel, and Walberg 1990). Strong metacognitive skills have been associated with improved school achievement in adolescents and young adults (Bakracevic Vukman and Licardo 2010). Those with strong metacognitive skills can accurately estimate their knowledge of a subject; know how to monitor, control, and plan their own learning; and can transfer skills to other contexts. Examples of metacognitive skills include summarizing and connecting new information to prior knowledge, constructing mental images, predicting, comprehension monitoring, and questioning (Hartman 2001). Metacognitive skills can be cultivated through instructional activities which facilitate students' understanding of their own learning processes (Lin 2001). Examples of instructional strategies which can foster metacognitive skills include concept maps (Novak 1990), self-assessment (Stanton et al. 2015), and reciprocal teaching (Palinscar and Brown 1984). It has been suggested that metacognitive skills can promote student achievement in foundational courses (Bessy and Knouse 2020), but few undergraduate students start college with strong metacognitive skills (Everson and Tobias 1998; Rickey and Stacy 2000; Sandi-Urena, Cooper, and Stevens 2011). Students who persist in STEM fields often demonstrate creative ways of navigating coursework and degree requirements and possess the ability to adjust and improve learning habits, academic identities, and behaviors (Thiry 2019), all skills associated with strong metacognitive skills. Therefore, improved metacognitive skills could be a useful tool for increasing student persistence in STEM fields.

While the inclusion of metacognitive-based instruction in a STEM classroom may better equip students to succeed in their degree, few studies have actually connected self-efficacy and sense of belonging to metacognitive-based instruction. In general, students who have high self-efficacy, or confidence in themselves to achieve an outcome are more likely to succeed in STEM fields (Thiry 2019). Additionally, students who feel connected to their peers, instructors, and their STEM discipline (i.e., sense of belonging), typically demonstrate greater commitment to persist (Holland 2019). When metacognitive-based instructional strategies are deployed in an environment to promote community, students can obtain more first-hand experience with metacognitive strategies and better absorb these skills through peer interaction and observation, all while gaining confidence as a learner (Lin 2001). For example, shared note-taking can aid students with building metacognitive skills (i.e., knowledge construction), and it can also provide support and community for students (Kalir et al. 2020; Morales et al. 2022). Therefore, metacognitive-based instructional strategies that focus on community building could also improve self-efficacy and sense of belonging in STEM students.

The purpose of this SoTL study was to evaluate how metacognitive-based instructional strategies affected student metacognitive skills and self-perception in a food microbiology lecture course. Two instructional strategies, shared notes and discussion days, were deployed in a pilot initiative in order to foster student metacognitive skills, sense of belonging, and self-efficacy. These changes were introduced into the course curriculum, which remained otherwise unchanged from previous iterations of the course. Two of the authors (Snyder, Gibney) were the instructors of the course used in this study. Therefore, this investigation should be considered as "action research" in which the practitioners intentionally work to create meaningful and authentic change in the classroom (Vaughan, Boerum, and Whitehead 2019). Overall, this SoTL study better elucidates relationships between interventions from promoting metacognition, self-efficacy, and sense of belonging in a STEM lecture course.

MATERIALS AND METHODS

To support inclusive learning environments at the university, a pilot initiative in collaboration with the university's Center for Teaching Innovation was deployed to assess students' metacognitive skills and self-perception in STEM lecture classes. Instructional strategies were introduced in the curriculum of Food Science 3940 with the intention to build student metacognitive skills and foster community. This initiative was conducted during one semester. Students were asked to complete surveys that evaluated their perceptions of the class, themselves, and knowledge gained in the class. The insights gained from this study will be used to guide future STEM lecture course designs. At the end of the pilot initiative, two of the coauthors (Daly, Snyder) presented the results at a conference and on a video platform hosted by the university's Center for Teaching Innovation.

Course overview

Food Science 3940 is a three-credit hour, lecture-based food microbiology course that meets for 50 minutes three times a week in the fall semester of 2022. It is a required course for the food science majors. In the course section where we employed the pilot initiative, there were 36 students enrolled. The majority of the students surveyed were food science majors in their third year of study. However, several graduate students in food science and senior undergraduate students from related disciplines (biology, microbiology, and public health) were also enrolled. Students were encouraged to attend and participate in in-person lectures, but this was neither required nor graded. Recorded videos of in-person lectures were made available to all students in the course. There were three midterm exams and a final exam, all in-person. Each exam contributed 20% of each students' final grade. An additional 20% came from weekly, low-stakes quizzes.

Metacognitive-based instructional strategy development

The instructional strategies deployed in this study are described as follows:

Shared classroom notes

Students were divided into random groups of three to four people. Each group was assigned to develop classroom notes in a shared document for three lectures throughout the semester. We developed this instructional method using existing pedagogy surrounding social annotation, with an emphasis on building community and metacognitive skills (Novak, Razzouk, and Johnson 2012). The notes were not graded, but could be used during each midterm exam (the final was closed note). The notes were limited to one page with 12-point font and one-inch margins to encourage students to synthesize information, rather than to "cram" it onto a page. A shared Google Doc housed the notes, and students from other groups could provide comments to improve other groups' notes. The notes were printed out by the instructors and brought into the classroom for the exam.

Discussion days

Discussion days were in-class study sessions held in lieu of the lecture before each exam. No new content was presented, but test-taking strategies, practice questions, and review of the shared classroom notes was conducted.

Survey development

In each survey, students were asked a series of questions to evaluate their sense of belonging, self-efficacy, and resource management, defined as participation in course resources (Appendices A, B). The survey administered after the first midterm also included questions that asked students to reflect back on their experiences in previous lecture-based science courses. The questions related to belonging, self-efficacy, and resource management were developed from the Motivated Strategies and learning questionnaire (MSLQ) (Pintrich et al. 1991; Trujillo and Tanner 2014). Responses for questions related to sense of belonging, self-efficacy, and resource management were scored on a 5-point Likert scale (1 = Not at all, 2 = A little, 3 = Somewhat, 4 = Highly, and 5 = Extremely). The Likert scale was used to obtain enough variation in responses in order to obtain clear information on the latent variables (self-efficacy, sense of belonging, and resource management) (Table 1).

Table 1. Likert-scale questions administered to students

Questions related to self-efficacy	Questions related to sense of belonging	Questions related to resource management strategies
• I know how to succeed (earn an A or B) in this course. • I know how to complete the requirements for a food science/STEM degree at this institution. • I know how to obtain a job in food science/STEM someday. • My knowledge of the principles of food microbiology have improved over the semester.	• I can ask a question or make a comment in class. • I feel like I can share a personal opinion in class. • My own social identity/worldview helps me to succeed. • I feel like I belong in a food science/STEM major.	• I know how to change my study habits to do better on future exams/quizzes. • I contribute to the shared notes. • I attend in-person lectures. • I attend discussion days. • I view recorded lectures. • I studied more for this exam than for the first exam. • Shared notes helped me to succeed on exams. • Discussion days helped me to succeed on exams.

The questions assessed self-efficacy, sense of belonging, and resource management strategies.

In every survey, students were also asked to select frequently used learning strategies. Students were prompted to select all the learning strategies that applied to them with the option to input additional unlisted strategies. Learning strategies were selected based on two categories: “higher-order” and “lower-order” learning strategies based on Bloom’s taxonomy (Crowe, Dirks, and Wenderoth 2008; Tabrizi and Rideout 2017). The higher-order learning strategies were associated with higher-order cognitive skills (i.e., application, analysis, synthesis, and evaluation) (Table 2). Lower-order learning strategies were associated with lower order cognitive skills, including memorization and understanding. Additionally, free response questions were included in each survey (Appendices A, B).

Table 2. Learning strategies inventory that was provided to students in every survey

Higher-order learning strategies	Lower-order learning strategies
○ Creating practice questions ○ Creating concept maps/diagrams ○ Studying with a partner or group outside of class ○ Developing acronyms or other memory devices ○ Re-doing missed questions from previous exams/quizzes ○ Connecting concepts in class to personal or "real-world" experiences	○ Reading/viewing materials before class ○ Attending class and taking notes ○ Making flashcards ○ Reviewing notes/readings/slides after class ○ Re-copying notes

Learning strategies were grouped into "higher-order" and "lower-order" learning strategies based on Bloom's taxonomy.

Student grades were not reported. "Student success" was measured by their ability to develop an improved sense of belonging, improved self-efficacy, and developing new learning strategies.

Data collection and analysis

Surveys were administered after the first midterm exam and the final exam, both of which were in-person. Students enrolled in Food Science 3940 were recruited for this study through an email invitation which contained a link to the online survey platform (Qualtrics XM). Responses were completely anonymous. Students could receive one bonus point for completing each survey. Subsequently, 83% of students completed the survey administered after the midterm and 78% of students completed the survey administered after the final exam.

The collected responses were analyzed in R Studio (R Studio Team 2022). Likert scale responses were converted to an interval scale (Harpe 2015). The mode, mean, and standard deviation of Likert responses were calculated for each question within each survey. Significant differences for each question were determined using Wilcox *t*-tests with Benjamini and Hochberg correction. Effect size was calculated using Cohen's *d*. Responses from the learning strategies inventory were counted and converted into percentages of total responses for each survey.

The free responses from the survey administered after the final exam ("What did you do differently to study for this exam compared to how you studied for the first exam?", and "What do you plan to do differently to study for future classes?") were coded using a hierarchical frame (Saldaña 2016). The responses were broken down further into subcategories including: "Made/or plans to make changes to learning strategies" ("yes", "no") and "mentions at least one higher-order learning strategy?" ("yes", "no") (Appendix D, Figure S.1). Responses ("yes", "no") were treated as discrete data points, counted and converted into percentages of total responses from the previous level.

Subjects

For each survey, we obtained informed consent from all the participants in this study (Appendix C). Cornell University's Office of Research Integrity granted this study exemption from review by the Institutional Review Board for Human Participant Research (#IRB0146638).

RESULTS AND DISCUSSION

Changes in student learning strategies

Students reported participating in and benefitting from discussion days and shared note-taking. When asked about their engagement with different instructional strategies after the final exam, most students "highly" (mode = 4) agreed that they contributed to shared notes (mean = 3.96) and attended discussion days (mean = 4.11) (Table 3). Students most often reported that discussion days "extremely" (mode = 5, mean = 4.36) helped them to succeed and that shared notes "highly" (mode = 4, mean = 4.07) helped them to succeed (Table 3). Based on these responses, students generally perceived metacognitive-based instructional strategies as beneficial, and there was a high rate of engagement. These results should encourage others interested in deploying metacognitive-based instructional strategies in the classroom, particularly when these strategies are focused on building community.

Table 3. Student perception of and participation with different instructional strategies in Food Science 3940

Question	Mean ± SD	Mode
I contribute to the shared notes.	3.96 ± 1.14	4
I attend discussion days.	4.11 ± 0.92	4
I attend in-person lectures.	3.79 ± 1.20	4
I view recorded lectures.	2.68 ± 1.52	1
Discussion days helped me to succeed on exams.	4.36 ± 0.78	5
Shared notes helped me to succeed on exams.	4.07 ± 0.90	4
I studied more for this exam than for the first exam.	3.53 ± 1.40	5

Student responses were scored on a Likert scale (1–5) for the following questions after the final exam (n = 28). The mean ± standard deviation (SD) and mode of student self-reported Likert scores are shown for each question.

Less than half of the respondents reported using at least three higher-order learning strategies both before and during Food Science 3940. "Three" strategies were considered to indicate more substantial engagement with higher-order learning strategies (Table 2). However, between the midterm and after the final exam, the percentage of students who reported using at least 3 higher-order learning strategies increased from 27% to 36% (Table 4). In comparison, only 33% of students reported using at least three higher-order learning strategies in their previous science lectures (Table 4). Notably, over the semester, the reported use of concept maps and self-made practice questions increased from 13% to 32% and from 17% to 29%, respectively (Table 4). Engagement with higher-order learning strategies is a sign that students can monitor their own knowledge (Santangelo, Cadieux, and Zapata 2021). Furthermore, concept maps are particularly associated with strong metacognitive skills in students (Joshi et al. 2022). The increased use of concept maps and self-made practice questions by students could have been a response to techniques learned in discussion days.

Table 4. Percentage of students who reported using different learning strategies

Learning strategies	Previous science lecture	After midterm	After final exam
Reported using at least three higher-order learning strategies	33%	27%	36%
Reported using concept maps	13%	13%	32%
Reported using acronyms or other memory devices	37%	27%	32%
Reported using study group	53%	43%	36%
Reported creating practice questions	10%	17%	29%
Reported connecting knowledge to personal experiences	17%	33%	29%

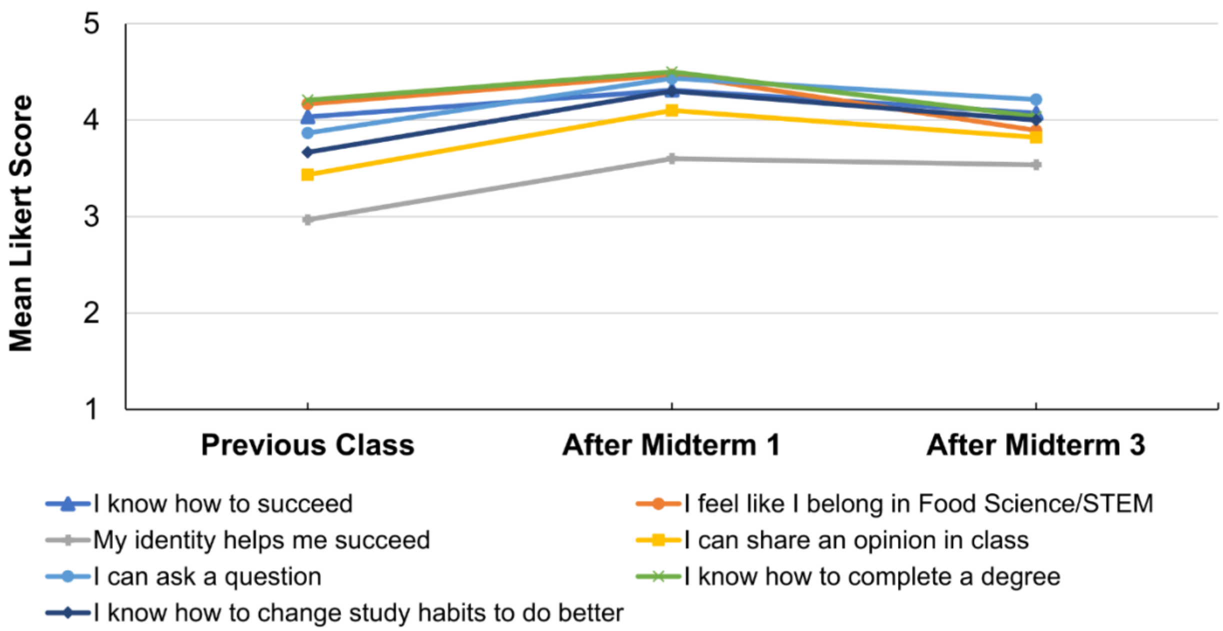
Students were asked to select learning strategies they used for their previous science lectures (n = 30), and then about food science 3940 after the midterm (n = 30) and after the final exam (n = 28).

Free responses from after the final exam revealed that some students had already or planned to change their learning strategies in the future. When responding to the question "what did you do differently to study for this exam compared to how you studied for the first exam?", 68% of respondents indicated that they had changed their study strategies and 42% of those responses included higher-order learning strategies. For the question "what do you plan to do differently to study for future classes?", 68% of student responses indicated that students planned to change their study strategies. However, only 37% of those responses included higher-order learning strategies, such as making practice questions. Overall, students reported using a variety of different learning strategies, many of them associated with higher levels of Bloom's taxonomy. Many students also reported changing their study strategies over the course of the semester. These results indicate that many students were able to monitor their own learning in the course.

Shifts in student self-perception

The responses indicated that students had relatively high self-perception. The means of the Likert scale responses were above 4 ("highly") for most questions relating to self-perception at most time points in the semester (Table 5). However, there were significant changes in student self-perception. Notably, the scores were lowest for the question "my own social identity/worldview helps me succeed" (mean = 2.97 for previous science lecture; mean = 3.62 after midterm) but the scores after the midterm were significantly higher than reported for the previous science lecture (P = .040, Cohen's d = 0.48). For the question "I know how to change study habits to do better on exams" the scores were significantly higher after the midterm than for the previous science lecture (P = .027, Cohen's d = 0.61). Additionally, for the questions "I know how to ask a question in class," and "I can share an opinion in class" the scores were significantly higher after the midterm than for the previous science lecture (P = .040, Cohen's d = 0.44; P = .039, Cohen's d = 0.49). These effect sizes were considered to be small-to-medium (Sullivan and Feinn 2012). Overall, scores from self-perception questions were all higher after the midterm than what students reported for their previous science lectures. However, these average self-perception scores all declined between the midterm and the end of the semester, though not significantly (Table 5). Notably for belonging, the average score after the final exam (mean = 3.89) was below that of the previous science lecture (mean = 4.17). For responses regarding completing a degree in food science/STEM, the mean fell to 4.04 compared to 4.20 (previous science lecture) (Table 5). However, the increases and declines in student self-perception over the semester were fairly consistent among respondents (Figure 1).

Figure 1. Student self-perception



The mean of student Likert scale responses (1–5) for several questions are shown. Students were asked these questions about their previous science lectures (*n* = 30), about Food Science 3940 after the midterm (*n* = 30), and after the final exam (*n* = 28).

Table 5. Student self-perception

Question	Previous science lecture	After midterm	After final exam
I feel like I belong in food science/STEM.	4.17 ± 0.91	4.47 ± 0.78 P = .27 Cohen's d = 0.23	3.89 ± 0.88 P = .058 Cohen's d = 0.70
My own social identity/worldview helps me to succeed.	2.97 ± 1.38	3.60 ± 1.50 P = .040* Cohen's d = 0.48	3.54 ± 1.23 P = .73 Cohen's d = 0.05
I can share an opinion in class.	3.43 ± 1.45	4.10 ± 1.13 P = .039* Cohen's d = 0.49	3.82 ± 0.98 P = .36 Cohen's d = 0.26
I know how to succeed (earn an A or B) in class.	4.03 ± 1.00	4.31 ± 0.89 P = .12 Cohen's d = 0.29	4.10 ± 0.81 P = .36 Cohen's d = 0.24

I can ask a question in class.	3.87 ± 1.14	4.43 ± 0.63 P = .040* Cohen's d = 0.44	4.21 ± 0.79 P = .37 Cohen's d = 0.31
I know how to complete a degree in food science/STEM.	4.21 ± 0.82	4.50 ± 0.68 P = .12 Cohen's d = 0.33	4.04 ± 0.74 P = .098 Cohen's d = 0.59
I know how to change study habits to do better on exams.	3.67 ± 1.21	4.30 ± 0.99 P = .027* Cohen's d = 0.61	4.00 ± 1.02 P = .36 Cohen's d = 0.30

The mean ± standard deviation of student Likert scale responses (1–5) for several questions are shown. These questions asked students about their previous science lectures (*n* = 30), and then about food science 3940 after the midterm (*n* = 30) and after the final exam (*n* = 28). The Benjamini and Hochberg-corrected *P* values for the Wilcox test and Cohen's *d* are shown (previous science lecture v. after midterm) and (after midterm v. after final exam). * $P < .05$.

There could be several factors that contributed to these changes in self-perception. In most cases, students had stronger self-perception during this course than they reported for previous science lectures. The change in instructor midway through the semester could have affected some students' responses. Not being allowed to use notes on the final exam could have also negatively affected students' self-confidence. Furthermore, undergraduate students taking introductory STEM classes can display over-confidence in their academic abilities at the beginning of semester (Testa, Galano, and Tarallo 2023). Much of this may be due to their success in comparable classes in high school because they had strong memorization skills. Metacognitive-based instruction can help guide students toward more effective study strategies and compensate for this over-confidence (Siegesmund 2016). Giving students strategies to monitor their own knowledge can help prevent disillusionment in students over the semester. Even though there was a dip in self-perception, the results indicate that students still maintained relatively positive self-perception throughout the semester.

Evidence of improved metacognitive skills and self-perception

One aspect of this study considered whether metacognitive-based instruction would improve student metacognitive skills. Generally, students responded positively to shared notes and discussion days with, on average, more students reporting that they attended discussion days and contributed to shared notes than attending in-person lectures (Table 3). There was a clear willingness for students to engage in these instructional strategies. This aligns with other SoTL research that suggests students respond positively to active and collaborative learning strategies and perceive these tools as beneficial (Achen and Lumpkin 2015; Mohamed 2008). Over the semester, the percentage of students using at least three higher-order learning strategies increased. Furthermore, students reported using study strategies that are associated with strong metacognitive skills (i.e., creating practice questions, concept maps) (Table 4). Therefore, there is evidence for some improvements in students' metacognitive skills. While we were unable to track individual student academic outcomes and experiences, the results indicate that students were thinking about their own learning strategies and changed, or were planning to change, their study strategies.

Another aspect of this study considered the effect of metacognitive-based instructional strategies on student self-perception. After the first midterm, there were improvements in students' sense of belonging and self-efficacy compared to the previous science lecture. However, the means of the Likert scale responses were lower for all questions compared to after the midterm. Notably, for the questions "I feel like I belong in food science/STEM" and "I know how to complete a degree in food science/STEM," the means fell below the corresponding means from the previous science lecture (Table 5). The question "I know how to change study habits to do better on exams" was a particularly relevant indicator of student metacognitive skills. Such a decline could indicate a loss of self-confidence in students' ability to select suitable learning strategies for a given context.

One reason for these declines could have been that students were not allowed to use their shared notes on the final exam. Many students agreed that shared notes helped them succeed on the midterm exam (mean = 4.07), though not as much as discussion days (mean = 4.36) (Table 3), which were designed to assist students in exam preparation. The use of the shared notes on the midterm exam, however, may have played a key role in students' exam preparation. The presence of notes for an exam can shift student preparation from merely memorizing course content to applying, analyzing, synthesizing, and evaluating it (Johanns, Dinkens, and Moore 2017). The use of notes during exams may also improve student self-efficacy (Myyry and Joutsenvirta 2015). Furthermore, this course took the "open-note" concept further and made it a collaborative effort among students, which most likely increased students' sense of belonging. Ultimately, many students "extremely" (mode = 5) agreed with the statement that they studied more for the final exam than for the first exam (Table 3). Indeed, 26% of respondents for the question "what did you do differently to study for this exam compared to how you studied for the first exam?" reported changing their study habits. Several respondents noted that they spent more time on memorization for the final exam. Moreover, final exam periods are a typically stressful time for students. Even though timing has not been found to substantially impact student course and instructor evaluations, this particular time period may have negatively impacted student self-perception (Frey 1976; Pegden and Tucker 2012). Furthermore, the knowledge that the students were participating in a research study could have influenced their behavior, i.e., the Hawthorne effect (McCambridge, Witton, and Elbourne 2014). The survey data were anonymized and had no effect on students' grades, so students were encouraged to reply honestly. Insights from this pilot initiative could be expanded by introducing these instructional strategies into other STEM lecture courses and comparing changes in student metacognitive skills over the semester. The responses from a "control" class, in which no metacognitive skills are introduced, could be compared to these responses to determine whether there were any participation effects. Future studies could also deploy other activities for building metacognitive skills in the classroom.

Overall, the results indicate that metacognitive-based instruction, particularly ones that focus on community-building, could be a useful method to improve student self-perception. Though this study focused on one class, these findings may be relevant to other STEM courses. Student success in STEM lecture courses is necessary for student retention and degree completion. This study also demonstrated that instructional strategies that encourage metacognitive skills and community can positively affect student perception of the course. Food Science 3940, with its high-stakes exams and large volume of content presented, was a fairly typical STEM foundational course. The strategies introduced in the course were not overly time-intensive and did not change the fundamental structure of the course, with the exception of setting aside a discussion day before each exam. Hence, these changes could be used in other classroom settings. Even small, thoughtful changes to a course design could have a sizable benefit for students. Thus, the relationship between metacognitive skills, self-efficacy, and sense of belonging should continue to be examined.

CONCLUSION

Metacognitive-based instruction was received positively by students. Overall, student engagement with higher-order learning strategies increased over the semester, indicating some changes in metacognitive skills. Further, there was an overall increase in student self-perception over the semester. The results from this pilot initiative indicate that metacognitive-based instructional strategies have the potential to positively influence student engagement in an undergraduate food science lecture. Meaningful interactions among peers and active self-reflection of one's own learning processes can build community and equip students with the skills to succeed in their chosen path of study. The results from this pilot initiative can be used to guide future course design aimed at improving student metacognitive skills in the STEM lecture classroom. Further exploration of the relationship between metacognition, self-efficacy, and sense of belonging in undergraduate foundational courses should be conducted.

ACKNOWLEDGMENTS

The authors would like to thank Stephen Parry (Cornell Statistical Consulting Unit) for statistical consulting, the Cornell Center for Teaching Innovation, and Christina Schmidt (director of CALS Office of Curriculum Development and Instructional Support) for guidance on project implementation. This study was supported by an internal grant from Cornell University's Center for Teaching Innovation awarded to Abigail B. Snyder.

AUTHOR BIOGRAPHIES

Sarah E. Daly (USA) is a postdoctoral research associate in the Department of Food Science at Cornell University.

Patrick A. Gibney (USA) is an associate professor in the Department of Food Science at Cornell University.

Abigail B. Snyder (USA) is an associate professor in the Department of Food Science at Cornell University.

DISCLOSURES

The authors report no conflicts of interest.

ETHICS

Cornell University's Office of Research Integrity granted this study exemption from review by the Institutional Review Board for Human Participant Research (#IRB0146638).

REFERENCES

Achen, Rebecca M., and Angela Lumpkin. 2015. "Evaluating Classroom Time Through Systematic Analysis and Student Feedback." *International Journal for the Scholarship of Teaching and Learning* 9 (2). https://doi.org/10.20429/ijsotl.2015.090204.

Bakracevic Vukman, Karin, and Marta Licardo. 2010. "How Cognitive, Metacognitive, Motivational and Emotional Self-Regulation Influence School Performance in Adolescence and Early Adulthood." *Educational Studies* 36 (3): 259–68. https://doi.org/10.1080/03055690903180376.

Bessy, Marianne, and Stephanie Knouse. 2020. "Metacognition, Metalinguistic Awareness, and Relevance in Language Learning: A Report on an Intervention Module Project." *International Journal for the Scholarship of Teaching and Learning* 14 (2). https://doi.org/10.20429/ijsotl.2020.140209.

Crowe, Alison, Clarissa Dirks, and Mary P. Wenderoth. 2008. "Biology in Bloom: Implementing Bloom's Taxonomy to Enhance Student Learning in Biology." *CBE Life Sciences Education* 7 (4): 368–81. https://doi.org/10.1187/cbe.08-05-0024.

Everson, Howard T., and Sigmund Tobias. 1998. "The Ability to Estimate Knowledge and Performance in College: A Metacognitive Analysis." *Instructional Science* 26 (1–2): 65–79. https://doi.org/10.1023/a:1003040130125.

Flanders, Gordon R. 2017. "The Effect of Gateway Course Completion on Freshman College Student Retention." *Journal of College Student Retention: Research, Theory and Practice* 19 (1): 2–24. https://doi.org/10.1177/1521025115611396.

Flavell, John H. 1979. "Metacognition and Cognitive Monitoring: A New Area of Cognitive-Developmental Inquiry." *American Psychologist* 34 (10): 906–11. https://doi.org/10.1037/0003-066X.34.10.906.

Frey, Peter W. 1976. "Validity of Student Instructional Ratings: Does Timing Matter?" *The Journal of Higher Education* 47 (3): 327. https://doi.org/10.2307/1981425.

Harpe, Spencer E. 2015. "How to Analyze Likert and Other Rating Scale Data." *Currents in Pharmacy Teaching and Learning* 7 (6): 836–50. https://doi.org/10.1016/j.cptl.2015.08.001.

Harper, Raquel P., Timothy J. Weston, and Elaine Seymour. 2019. "Student Responses to Problematic STEM Teaching Methods." In *Talking about Leaving Revisited: Persistence, Relocation, and Loss in Undergraduate STEM Education*, edited by Elaine Seymour and Anne-Barrie Hunter, 149–95. Springer. https://doi.org/10.1007/978-3-030-25304-2.

Hartman, Hope J. 2001. *Metacognition in Learning and Instruction Theory, Research and Practice*. Springer Science + Business Media Dordrecht. https://doi.org/10.1007/978-94-017-2243-8.

Hatfield, Neil, Nathanial Brown, and Chad M. Topaz. 2022. "Do Introductory Courses Disproportionately Drive Minoritized Students out of STEM Pathways?" *SocArXiv:* 1–10. https://doi.org/10.31235/osf.io/3gqps.

Holland, Dana G. 2019. "The Struggle to Belong and Thrive." In *Talking about Leaving Revisited: Persistence, Relocation, and Loss in Undergraduate STEM Education*, edited by Elaine Seymour and Anne-Barrie Hunter, 277–327. Springer. https://doi.org/10.1007/978-3-030-25304-2.

Johanns, Beth, Amber Dinkens, and Jill Moore. 2017. "A Systematic Review Comparing Open-Book and Closed-Book Examinations: Evaluating Effects on Development of Critical Thinking Skills." *Nurse Education in Practice* 27: 89–94. https://doi.org/10.1016/j.nepr.2017.08.018.

Joshi, Rucha, Dustin Hadley, Saivageethi Nuthikattu, Shierly Fok, Leora Goldbloom-Helzner, and Matthew Curtis. 2022. "Concept Mapping as a Metacognition Tool in a Problem-Solving-Based BME Course During In-Person and Online Instruction." *Biomedical Engineering Education* 2 (2): 281–303. https://doi.org/10.1007/s43683-022-00066-3.

Kalir, Jeremiah H., Esteban Morales, Alice Fleerackers, and Juan P. Alperin. 2020. "'When I Saw My Peers Annotating:' Student Perceptions of Social Annotation for Learning in Multiple Courses." *Information and Learning Science* 121 (3–4): 207–30. https://doi.org/10.1108/ILS-12-2019-0128.

Lin, Xiaodong. 2001. "Designing Metacognitive Activities." *Educational Technology Research and Development* 49 (2): 23–40. https://doi.org/10.1007/BF02504926.

McCambridge, Jim, John Witton, and Diana R. Elbourne. 2014. "Systematic Review of the Hawthorne Effect: New Concepts Are Needed to Study Research Participation Effects." *Journal of Clinical Epidemiology* 67 (3): 267–77. https://doi.org/10.1016/j.jclinepi.2013.08.015.

Mervis, Jeffrey. 2011. "Undergraduate Science: Weed-out Courses Hamper Diversity." *Science* 334 (6061): 1333. https://doi.org/10.1126/science.334.6061.1333.

Mohamed, Abdi-Rizak. 2008. "Effects of Active Learning Variants on Student Performance and Learning Perceptions." *International Journal for the Scholarship of Teaching and Learning* 2 (2). https://doi.org/10.20429/ijsotl.2008.020211.

Morales, Esteban, Jeremiah H. Kalir, Alice Fleerackers, and Juan Pablo Alperin. 2022. "Using Social Annotation to Construct Knowledge with Others: A Case Study across Undergraduate Courses." *F1000Research* 11: 1–21. https://doi.org/10.12688/f1000research.109525.2.

Myyry, Liisa, and Taina Joutsenvirta. 2015. "Open-Book, Open-Web Online Examinations: Developing Examination Practices to Support University Students' Learning and Self-Efficacy." *Active Learning in Higher Education* 16 (2): 119–32. https://doi.org/10.1177/1469787415574053.

Novak, Elena, Rim Razzouk, and Tristan E. Johnson. 2012. "The Educational Use of Social Annotation Tools in Higher Education: A Literature Review." *Internet and Higher Education* 15 (1): 39–49. https://doi.org/10.1016/j.iheduc.2011.09.002.

Novak, Joseph D. 1990. "Concept Maps and Vee Diagrams: Two Metacognitive Tools to Facilitate Meaningful Learning." *Instructional Science* 19 (1): 29–52. https://doi.org/10.1007/BF00377984.

Palinscar, Annemaria S., and Ann L. Brown. 1984. "Reciprocal Teaching of Comprehension-Fostering and Comprehension Monitoring Activities." *Cognition and Instruction* 1 (2): 117–75. http://www.jstor.com/stable/3233567.

Pegden, Julie-Ann, and Beatrice Tucker. 2012. "Does the Timing of Evaluations Matter? An Investigation into Online Student Feedback and Whether Timing Has an Impact." *Studies in Learning, Evaluation, Innovation and Development* 9 (1): 55–65.

Pintrich Paul R., David Smith, Teresa Garcia, and Wilbert J. McKeachie. 1991. "Manual for the Use of the Motivated Strategies for Learning Questionnaire (MSLQ)." Ann Arbor, MI: The University of Michigan. https://files.eric.ed.gov/fulltext/ED338122.pdf.

R Studio Team. 2022. "RStudio: Integrated Development Environment for R." http://www.rstudio.com/.

Rickey, Dawn, and Angelica M. Stacy. 2000. "The Role of Metacognition in Learning Chemistry." *Journal of Chemical Education* 77 (7): 915–20. https://doi.org/10.1021/ed077p915.

Saldaña, Johnny. 2016. "An Introduction to Codes and Coding." In *The Coding Manual for Qualitative Researchers*, 3rd ed., 1–31. Sage. https://www.sagepub.com/sites/default/files/upm-binaries/24614_01_Saldana_Ch_01.pdf.

Sandi-Urena, Santiago, Melanie M. Cooper, and Ron H. Stevens. 2011. "Enhancement of Metacognition Use and Awareness by Means of a Collaborative Intervention." *International Journal of Science Education* 33 (3): 323–40. https://doi.org/10.1080/09500690903452922.

Santangelo, Jessica, Marissa Cadieux, and Samantha Zapata. 2021. "Developing Student Metacognitive Skills Using Active Learning with Embedded Metacognition Instruction." *Journal of STEM Education: Innovations and Research* 22 (2): 75–87. https://www.jstem.org/jstem/index.php/JSTEM/article/view/2475.

Siegesmund, Amy. 2016. "Increasing Student Metacognition and Learning Through Classroom-Based Learning Communities and Self-Assessment." *Journal of Microbiology and Biology Education* 17 (2): 204–14. https://doi.org/10.1128/jmbe.v17i2.954.

Stanton, Julie D., Xyanthe N. Neider, Isaura J. Gallegos, and Nicole C. Clark. 2015. "Differences in Metacognitive Regulation in Introductory Biology Students: When Prompts Are Not Enough." *CBE Life Sciences Education* 14 (2): 1–12. https://doi.org/10.1187/cbe.14-08-0135.

Sullivan, Gail M., and Richard Feinn. 2012. "Using Effect Size—or Why the P Value Is Not Enough." *Journal of Graduate Medical Education* 4 (3): 279–82. https://doi.org/10.4300/jgme-d-12-00156.1.

Tabrizi, Sirous, and Glenn Rideout. 2017. "Active Learning: Using Bloom's Taxonomy to Support Critical Pedagogy." *International Journal for Cross-Disciplinary Subjects in Education* 8 (3): 3202–9. https://doi.org/10.20533/ijcdse.2042.6364.2017.0429.

Testa, Italo, Silvia Galano, and Oreste Tarallo. 2023. "The Relationships Between Freshmen's Accuracy of Self-Evaluation and the Likelihood of Succeeding in Chemistry and Physics Exams in Two STEM Undergraduate Courses." *International Journal of Science Education* 45 (5): 358–82. https://doi.org/10.1080/09500693.2022.2162833.

Thiry, Heather. 2019. "What Enables Persistence?" In *Talking about Leaving Revisited: Persistence, Relocation, and Loss in Undergraduate STEM Education*, edited by Elaine Seymour and Anne-Barrie Hunter, 399–436. Springer. https://doi.org/10.1007/978-3-030-25304-2.

Tomkin, Jonathan H., and Matthew West. 2022. "STEM Courses Are Harder: Evaluating Inter-Course Grading Disparities with a Calibrated GPA Model." *International Journal of STEM Education* 9 (1): 1–17. https://doi.org/10.1186/s40594-022-00343-1.

Trujillo, Gloriana, and Kimberly D. Tanner. 2014. "Considering the Role of Affect in Learning: Monitoring Students' Self-Efficacy, Sense of Belonging, and Science Identity." *CBE Life Sciences Education* 13 (1): 6–15. https://doi.org/10.1187/cbe.13-12-0241.

Vaughan, Michelle, Christopher Boerum, and Linda S. Whitehead. 2019. "Action Research in Doctoral Coursework: Perceptions of Independent Research Experiences." *International Journal for the Scholarship of Teaching and Learning* 13 (1). https://doi.org/10.20429/ijsotl.2019.130106.

Wang, Margaret C., Geneva D. Haertel, and Herbert J. Walberg. 1990. "What Influences Learning? A Content Analysis of Review Literature." *Journal of Educational Research* 84 (1): 30–43. https://doi.org/10.1080/00220671.1990.10885988.

Watkins, Jessica, and Eric Mazur. 2013. "Retaining Students in Science, Technology, Engineering, and Mathematics (STEM) Majors." *Journal of College Science Teaching* 42 (5): 36–41. https://www.jstor.org/stable/43631580.

Weston, Timothy J., Elaine Seymour, Andrew K. Koch, and Brent M. Drake. 2019. "Weed-out Classes and Their Consequences." In *Talking about Leaving Revisited: Persistence, Relocation, and Loss in Undergraduate STEM Education*, edited by Elaine Seymour and Anne-Barrie Hunter, 197–244. Springer. https://doi.org/10.1007/978-3-030-25304-2.

APPENDIX A

Survey administered after first midterm

Question 1 [MULTIPLE CHOICE]
Before taking this class, this is what I felt about previous science lecture courses
Selection Options: *"Not at all", "A little", "Somewhat", "Highly", "Extremely"*

- I started studying for exams the week of the exam.
- I knew how to change my study habits to do better on exams.
- I knew how to succeed (earn an A or B) in the class.
- I had the support I needed to be successful.
- I could ask a question or make a comment in class.
- I could share a personal opinion in class.
- I felt like I belonged in Food Science/STEM.
- I could cope with a lower than expected grade on an exam.
- My social identity/world view helped me to succeed in the class.
- I knew that I could complete a Food Science/STEM degree.
- The course material was useful to my future aspirations.

Question 2 [MULTIPLE CHOICE]
Before taking this class, I used the following study habits in my science lecture courses (Select all that apply)

- o Reading/viewing materials before class
- o Attending class and taking notes
- o Making flashcards
- o Reviewing notes/readings/slides after class
- o Re-copying notes
- o Creating my own practice questions
- o Creating concept maps/diagrams
- o Studying with a partner or group outside of class
- o Develop acronyms or other memory devices
- o Re-doing missed questions from previous exams/quizzes
- o Connecting concepts in class to personal or "real-world" experiences
- o Other: Please specify

Question 3 [MULTIPLE CHOICE]
Please rate how much you agree with the following statements for **this class**
I know how too…
Selection Options: *"Not at all", "A little", "Somewhat", "Highly", "Extremely"*

- Change my study habits to do better on future quizzes/exams
- Succeed (earn an A or B) in this course
- Complete the requirements for a Food Science/STEM degree at this intuition
- Obtain a job in Food Science /STEM someday

Question 4 [MULTIPLE CHOICE]
Please rate how much you agree with the following statements for this class.
Selection Options: *"Not at all", "A little", "Somewhat", "Highly", "Extremely"*

- I have the support I need to be successful.
- I can ask a question or make a comment in class.
- I feel like I can share a personal opinion in class.
- The course material is useful to my future aspirations.
- My own social identity/world view helps me to succeed.
- I feel like I belong in a Food Science/STEM major.

Question 5 [MULTIPLE CHOICE]
For this class, which of these study habits do you use? (Select all that apply)

- Reading/viewing materials before class
- Attending class and taking notes
- Making flashcards
- Reviewing notes/readings/slides after class
- Re-copying notes
- Creating my own practice questions
- Creating concept maps/diagrams
- Studying with a partner or group outside of class
- Develop acronyms or other memory devices
- Re-doing missed questions from previous exams/quizzes
- Connecting concepts in class to personal or “real-world” experiences
- Other: Please specify

Question 6 [RANK]
Please rank the following instructional methods which have been most useful to you for this class (you can drag and drop responses)

Shared classroom notes
Weekly quizzes
Discussion Days
Recorded Lectures
In-person lectures

Question 7 [FREE RESPONSE]
What study habits are you doing now that are most useful for learning Food Science?

Question 8 [FREE RESPONSE]
In your opinion, what helps students succeed in lecture-based science courses?

Question 9 [MULTIPLE CHOICE]
Please select the year you are in:

- Graduate student
- Senior
- Junior
- Sophomore
- Freshman

Question 10 [MULTIPLE CHOICE]
Please select your intended major

- Food Science
- Another STEM major
- Other, please specify

APPENDIX B

Survey administered after final exam

Question 1 [MULTIPLE CHOICE]

For this class, which of these study habits do you use? (Select all that apply)

- Reading/viewing materials before class
- Attending class and taking notes
- Making flashcards
- Reviewing notes/readings/slides after class
- Re-copying notes
- Creating my own practice questions
- Creating concept maps/diagrams
- Studying with a partner or group outside of class
- Develop acronyms or other memory devices
- Re-doing missed questions from previous exams/quizzes
- Connecting concepts in class to personal or "real-world" experiences
- Other: Please specify

Question 2 [RANK]

Please rank the following instructional methods which have been most useful to you for this class (you can drag and drop responses)

Shared classroom notes
Weekly quizzes
Discussion Days
Recorded Lectures
In-person lectures

Question 3 [MULTIPLE CHOICE]

Please rate how much you agree with the following statements **for this class**
Selection Options: *"Not at all", "A little", "Somewhat", "Highly", "Extremely"*

- My knowledge of the principles of Food Microbiology have improved over the semester.
- The course content was in-depth enough.
- The quality of the course content was consistent over the semester.

Question 4 [MULTIPLE CHOICE]

Please rate how much you agree with the following statements **for this class**
Selection Options: *"Not at all", "A little", "Somewhat", "Highly", "Extremely"*

- Shared notes helped me to succeed on prelim exams.
- I can ask a question or make a comment in class.
- I feel like I can share a personal opinion in class.
- The course material is useful for my future aspirations.
- My own social identity/world view helps me to succeed.
- I feel like I belong in a Food Science/STEM major.

Question 5 [MULTIPLE CHOICE]
Please rate how much you agree with the following statements for **this class**
I know how too…
Selection Options: *"Not at all", "A little", "Somewhat", "Highly", "Extremely"*

- Change my study habits to do better on future quizzes/exams
- Succeed (earn an A or B) in this course
- Complete the requirements for a Food Science/STEM degree at this intuition
- Obtain a job in Food Science /STEM someday

Question 6 [FREE RESPONSE]
What did you do differently to study for this exam compared to how you studied for the first exam?

Question 7 [FREE RESPONSE]
What key concepts will you take away from the course?

Question 8 [FREE RESPONSE]
What do you plan to do differently to study for future classes?

Question 9 [MULTIPLE CHOICE]
Please select your intended major

- Food Science
- Another STEM major
- Other, please specify

Question 10 [MULTIPLE CHOICE]
Please select the year you are in:

- Graduate student
- Senior
- Junior
- Sophomore
- Freshman

APPENDIX C

INFORMED CONSENT

We want to understand your background and approach to this class. Your responses will help guide any changes we might make in future classes - we are always looking for ways to improve the learning experience! This survey should take about **5 minutes** to complete. Please answer the questions honestly. **Your responses are anonymous** - we have no way of associating you with your answers. You may receive 1 bonus point for completing this survey. Please take a screenshot of the last page of your Qualtrics survey that says "We thank you for your time spent on this survey" and email to your TA. If you do not wish to complete this survey, you may instead write a 1-page summary of an outbreak of foodborne illness and email to your TA. Your input is greatly appreciated! Please contact Sarah Daly at [redacted] if you have any questions. We are asking you to participate in a research study entitled, "Using Metacognition Instruction to Promote Student Success in a Food Science Course". We will describe this study to you and answer any of your questions. This study is being led by Abigail Snyder and Sarah Daly.

What the study is about: The purpose of this research is to collect information about your learning experience in this class to determine the effectiveness of the teaching strategies used in this class. These teaching strategies aim to promote metacognition, self-efficacy, and a sense of belonging using active learning alongside the guidelines established for Universal Design for Learning. Subsequent surveys will be used to measure the effects of these changes. We are focusing on large enrollment courses required for Food Science majors. Future materials and practices will be developed and promoted based on current best practices and feedback from students and instructors.

What we will ask you to do: We will ask you to complete an online survey about your self-assessment of your learning approaches and confidence performing different classroom activities, and about your academic background. This survey will take about 5-10 minutes to complete.

Risks and discomforts: We do not anticipate any risks from participating in this research.

Benefits: There are no direct benefits for participating in this research. Data from this survey will be used to develop course materials and practices that will enhance the learning experience for students in large enrollment courses in Food Science. Data from this study may be published in a peer-reviewed educational journal.

Compensation for participation: Students who complete the survey will receive 1 extra credit point. For alternative credit, students can write a 1 page summary of an outbreak of food borne illness.

Privacy/Confidentiality/Data Security: Data elements will be separated into a coded data set to be used for research purposes. PI will maintain a list of individuals who have access to the data. All electronic devices used by the research team will be password protected, and data will not be saved on researchers' mobile devices. We anticipate that your participation in this survey presents no greater risk than everyday use of the Internet.

Sharing Data Collected in this Research: Data from this study may be shared with the research community at large to Advance science. No one will be able to identify you from the information we share.

Taking part is voluntary: Involvement in this education research is voluntary, so all participants may refuse to participate before the study begins, discontinue at any time, or skip some questions/procedures that may make them feel uncomfortable. Skipping these survey questions will result in no penalty. Skipping these survey questions will result in no penalty. No effect on the compensation earned before withdrawing, or their academic standing, record, or relationship with the university or other organization or service that may be involved with the research. If you have questions, you may contact Sarah Daly. If you have any questions or concerns regarding your rights as a subject in this study, you may contact the Institutional Review Board (IRB) for Human Participants at [redacted] or access their website at [redacted]. You may also report your concerns or complaints anonymously through Ethicspoint online or by calling toll free at [redacted]. Ethicspoint is an independent organization that serves as a liaison between the University and the person bringing the complaint so that anonymity can be ensured.

- I CONSENT to take part in the study. I have read the above information and have received answers to any questions I asked.
- I DO NOT CONSENT to take part in the study. I have read the above information and have received answers to any questions I asked.

APPENDIX D

Figure S.1. Hierarchical frame used to code free responses questions