Increasing Student Metacognition and Learning through Classroom-Based Learning Communities and Self-Assessment †

Amy Siegesmund
Department of Biology, Pacific Lutheran University, Tacoma, WA 98447

Student overconfidence challenges success in introductory biology. This study examined the impact of classroom learning communities and self-assessment on student metacognition and subsequent impact on student epistemological beliefs, behaviors, and learning. Students wrote weekly self-assessments reflecting on the process of learning and received individual feedback. Students completed a learning strategies inventory focused on metacognition and study behaviors at the beginning and end of the semester and a Student Assessment of their Learning Gains (SALG) at the end of the semester. Results indicated significant changes in both metacognition and study behaviors over the course of the semester, with a positive impact on learning as determined by broad and singular measures. Self-assessments and SALG data demonstrated a change in student beliefs and behaviors. Taken together, these findings argue that classroom learning communities and self-assessment can increase student metacognition and change student epistemological beliefs and behaviors.

INTRODUCTION

Increasing evidence indicates students enter college unprepared to manage the academic challenges of a college classroom. Recognizing there are a number of proposed explanations for student unpreparedness (4), this study focused on the influence of student epistemological beliefs and associated behaviors on learning. The beliefs students have about their learning (and intelligence) can promote or impede success (8). For example, students frequently believe that memorization equals mastery of the discipline, that learning is compartmentalized and happens quickly, that effort is equivalent to success, and that they are effective multi-taskers (13, 36, 38). Many introductory biology students are millennials, a population often characterized as having breadth without depth of knowledge in several subjects, unrealistic expectations about their lives and the world, and overconfidence in their abilities (29, 42). These characteristics create a classroom situation where student beliefs, behaviors, and overconfidence present barriers to learning. One hypothesis of this study was that student metacognition could be improved with classroom learning communities and reflective self-assessment; the second was that increasing metacognition would lead to changes in student epistemological beliefs and behaviors that positively impact learning.

Tracing their origins to Dewey (16) and Mieklejohn (31), learning communities are a well-documented mechanism for improving student learning (2, 10, 35, 46) and continue to evolve over time. While several different models of learning communities exist (27), they share common characteristics including shared knowledge, knowing, and responsibility (47). In these communities, each student brings particular expertise, and together students work to construct knowledge with a responsibility to each other and the process of moving knowledge forward. While many models of learning communities feature integration across multiple classrooms and outside experiences (21), this study employed classroom-based learning communities (37). In these learning communities (for both whole classroom and smaller groups within the classroom), the emphasis is on students and faculty working cooperatively to move learning forward with an ongoing dialogue that can be helpful as students work toward clarifying their understanding of not only content, but how they learn (32).

Formally defined by Flavell (20), metacognition is more simply defined as thinking about how we think. Metacognition consists of two components: knowledge about cognition and regulation of cognition (39). Knowledge of cognition is reflective, referring to what students know about themselves and the strategies and conditions required for their learning, while regulation of cognition refers to control of cognition and knowledge about planning, implementing, evaluating, and correcting behaviors (39). Metacognition...
is an important component for developing self-regulated learners (1, 34, 41), and a positive relationship exists between increased metacognition and student performance (14, 24, 41, 45, 49, 50).

This study used self-assessment via reflective journaling to target metacognition. Self-assessment involves monitoring and evaluating behavior during learning experiences and identifying strategies to improve understanding and skills (30). Self-assessment empowers students to take responsibility for learning (19, 40), increases self-motivation (30), and is critical for current and lifelong learning (6, 43). Further, formative self-assessment has a positive impact on developing self-regulated learners (7, 9, 32).

This study aimed to answer two questions: 1) whether student metacognitive awareness can be increased through classroom learning communities and self-assessment; and 2) whether increased student metacognition leads to changes in student epistemological beliefs and to behaviors that positively influence student learning. These questions were investigated by implementing whole-classroom and within-classroom (smaller group) learning communities and a reflective journaling project (electronic learning portfolio) targeting metacognitive development via self-assessment.

METHODS

Institutional and course background

Pacific Lutheran University (PLU) is a private, primarily undergraduate institution with enrollment of approximately 3,200. BIOL 225 (Molecules, Cells, and Organisms) is the first course in a two semester introductory core sequence required of all biology majors. The majority of the population is first year, first semester students, and the class is a required of all biology majors. The majority of the population is first year, first semester students, and the class is a required course for all biology majors. This cohort of BIOL 225 (n = 47) and BIOL 225-2 (n = 45), taught by the same instructor. Both cohorts utilized learning communities, the electronic learning portfolio (ELP), and the same learning experiences (lectures, homework, class activities). A third cohort of BIOL 225 (n = 45) taught by the same instructor was used for comparison where appropriate. This cohort had learning experiences similar to BIOL 225-1 and 225-2, but did not experience learning communities or the ELP.

Course design

Three major aspects of course design in BIOL 225-1 and BIOL 225-2 differed from other cohorts:

1. Establishing and cultivating learning communities. During the first class meeting, students were randomly grouped using an in-class exercise requiring student communication and movement. These learning groups were the primary working groups during lecture; groups remained constant, and group work was a part of every class meeting. Establishing the larger class community also began the first day; after the groups were formed, students completed the “Expectations Exercise.” Beginning individually, students recorded their expectations of the course, the professor, and themselves. Expectations of course and professor were shared in learning groups, and ultimately, a class discussion generated consensus lists clarifying expectations.

Learning communities were cultivated throughout the semester by using a learner-centered course design (described below) and formative group assessment throughout the semester.

2. Cultivating metacognitive ability. Metacognitive awareness was targeted with the ELP as described below.

3. Learner-centered instructional design. Every class session featured collaborative tasks completed in learning groups followed by large group synthesis/review. Various approaches were employed, including EnGaugements (23), Process Oriented Guided Inquiry Learning (POGIL; pogil.org), problem-based learning (PBL; bie.org), and case-based learning (sciencecasenet.org).

Student surveys

During the first week of the semester, students participated in the “Success in the Natural Sciences” workshop at PLU. Students completed a survey in which they predicted their final grade in the biology core sequence. All BIOL 225 students (n = 145) completed the survey anonymously; data represent students from all three sections of BIOL 225 rather than just students from BIOL 225-1 and BIOL 225-2.

Exam predictions

As the final question on the first exam of the semester, students were asked to predict their exam score. The question had no point value and did not impact exam score. The strength of the relationship between predicted and actual exam scores was assessed using Pearson’s r correlation (GraphPad).

Electronic learning portfolios (ELPs)

After the first exam, students completed a weekly electronic learning portfolio (ELP) entry via Sakai, an online course organizational platform. Each entry consisted of two to three questions (3) targeting metacognitive awareness. Questions focused on learning rather than course content and varied depending on the week’s activities (see Appendix 1). Students were required to complete the ELP entries as part of their course homework. Each entry was worth a total of three points (3% of final course grade). Full points were given for substantive and thoughtful responses, and there were
no “right” or “wrong” answers. Most often, students were given personal instructor feedback; approximately twice per semester, collective feedback was posted to the whole class.

Learning strategies inventory (LSI)

The learning strategies inventory (LSI) was comprised of: 1) the Metacognitive Skills Inventory (39), and 2) a study strategies inventory designed for the purpose of this investigation (see Appendix 2) featuring strategies commonly used by students (e.g., highlighting and flashcards) and approaches typically suggested to (but underutilized by) BIOL 225 students (e.g., visiting tutor). The LSI was administered on the first day and during the final week of class with no impact on course grade. Each question was scored on a five-point Likert scale ranging from 5 (“I always do this”) to 1 (“I never or almost never do this”). Average scores for BIOL 225-1 and BIOL 225-2 for the first day and final week were calculated (as described in (41)) and compared. Statistical analyses were performed (GraphPad) using a paired t-test with a significance level of $\alpha < 0.05$. Metacognitive gains (MGs) were calculated using the following formula: (ending metacognitive score – beginning metacognitive score)/(5 – beginning metacognitive score). As described in (22), this formula measures achievement within the context of what was possible (i.e., a maximum score of 5).

Student Assessment of Learning Gains (SALG)

The Student Assessment of Learning Gains (SALG) (www.salgsite.org) assessed student-perceived learning gains in the following areas: class content, skills, attitudes, integrated learning, the course overall, class activities, graded activities and tests, class resources, information given, and support for the individual learner. Students ($n = 73$) voluntarily completed the SALG during the final two weeks with no impact on course grade. Questions were scored on a five-point scale ranging from 1 (“no gain”) to 5 (“great gain”). All students completing the SALG provided responses to open-ended questions in each of the above areas.

Human subjects

Informed consent was obtained from all participants in this study. All instruments and procedures were approved by the PLU Human Participants Review Board (approval HPRBS10-55).

RESULTS

Student overconfidence

Student overconfidence was revealed by estimation of final core grades (Fig. 1, dark bars). The majority (61%) predicted an A, while 36% predicted a B. In stark contrast, only 2% predicted a C, while no students predicted a D or E (PLU uses E rather than F for failing). For comparison, the actual final course grades for BIOL 225-1 are shown (Fig. 1, light bars). The majority earned either a B (31%) or C (32%), 11% earned an A, and 14% earned a D or E. When asked to predict their grade on an exam, students with scores above 75% predicted their scores more accurately than those below (Fig. 2). The greatest discrepancy was in scores of students scoring in the <75% range. For example, one student predicted 75% and earned 23%, while another predicted 70% and earned 46% (Fig. 2, boxed diamonds).
The same trends were observed in BIOL 225-2; collectively, these data characterized a population of students overconfident in their skills and lacking in metacognitive awareness.

**Developing a classroom-based learning community**

Student expectations of the course and professor were remarkably consistent between BIOL 225-1 and BIOL 225-2; expectations in Table 1 were listed by all groups in both cohorts. While students recognized that the core sequence prepares them for upper level courses, expectations focused on rote memorization and regurgitation of facts. A parallel lack of understanding was revealed by expectations of the professor; students place responsibility for learning on the professor rather than acknowledging their own responsibility. Discussion around the lists (including instructor expectations) clarified expectations and set the tone for an interactive, collaborative classroom, which continued for the rest of the semester. Every day, students were expected to engage with their learning group and the larger class and come to class with readings completed; they were allowed to use only their reading or class notes (no textbooks) and the collective group expertise to complete tasks.

At the end of the semester, student attitudes about their learning and learning community were assessed using a SALG (Fig. 3). The majority indicated that doing classroom activities, participating in group work, coming to class with reading done, and working effectively with others contributed moderate or great gains to their learning. An unanticipated result was that 72% indicated that listening to class discussions resulted in moderate or great gains; these are most likely students for whom the auditory component of learning is strong. This value also likely reflects the impact of increased frequency and quality of class discussions in BIOL 225 with learning communities. The finding that 63% understood how their approach to college differs from high school was important, as it suggested students were changing long-held beliefs and behaviors about how they learn. The qualitative SALG responses were also positive and informative (Table 2). Students commented that class activities made them think about material differently and/or apply it to other concepts. While the majority found they had to change high school study habits, some did not change anything about how they studied (e.g., “I’m still terrible at studying”). Students gained a variety of skills, from working better with others to achieve goals, to prioritizing, to writing with precision and reading more effectively. Collectively, these data suggest that building within-classroom and whole-classroom learning communities had a positive impact on skills and behaviors.

**Electronic learning portfolio (ELP)**

The ELP focused on developing metacognitive ability through self-assessment. ELP prompts were provided on Wednesday, students uploaded responses via Sakai by Friday afternoon, and feedback was provided before class on Monday. This schedule was implemented for two reasons: 1) it gave the instructor a weekly update on what was working for students; and 2) it gave students a consistent system of feedback they could incorporate immediately. Entries and feedback were available via Sakai for the entire semester. ELP prompts asked students to identify behaviors and connect

---

**TABLE 1.** Class consensus lists from expectations exercise.

| Student expectations of course | • Learn the basics of biology  |
| • Memorize a lot                |
| • Work really hard             |
| • Prepare us for upper level biology |
|                              |

| Student expectations of professor | • Teach the subject well        |
| • Grade accurately and fairly     |
| • Prepare us for exams           |
| • Cover everything               |
| • Be able to answer our questions|
| • Be able to explain the subject |

| Professor expectations of students | • Be an active participant in your learning |
| • Ask for help when you need it   |
| • Utilize the resources available to you |
| • Push yourself outside of your academic comfort zone |
| • Be responsible for your learning |
| • Give me feedback along the way |

---

**FIGURE 3.** Impact of classroom community on student learning. At the end of the semester, students completed the Student Assessment of Learning Gains (SALG) online survey. Data shown are selected responses reporting gains in understanding class content and skills and how the class activities impacted learning and attitudes. Questions were scored on a 5-point scale ranging from 1 (no gain) to 5 (great gain). Data shown are the combined percentages of BIOL 225-1 and BIOL 225-2 students (n = 73).
them to outcome (Table 3). Student responses were frank, revealing what they had done and how they were feeling (e.g., confused); instructor feedback (to each student for each prompt) generally was brief and focused on reinforcing the connections between behavior and outcome. After each exam, students analyzed specific exam responses. Here, feedback focused on synthesizing student thoughts (e.g., “divide and conquer”) and emphasizing positive habits (e.g., “trust yourself”) with the goal of having students employ these strategies in future applications.

Some students clearly completed the ELP just to earn points. This lack of participation negatively impacted their ELP scores and academic progress. Consider the examples given in Table 4. Student 1 provided thoughtful, thorough responses, with clear reflection on practices and changes that occurred during the previous month. In contrast, student 2 provided brief answers and offered no reflection on previous behaviors and experiences. When asked “what you learned about yourself over the last month,” student 2 replied “nothing really” and referred to the previous year (even though this was a first year student). This student also commented on learning “how and when to study”; this indicates a lack of connection for this student between behavior and outcome as the student earned a D in the course. In contrast, student 1 earned an A in the course. While just two students have been used for illustration, the positive relationship between ELP effort, thought, and course progress was observed in both BIOL 225-1 and BIOL 225-2.

**Changes in student beliefs, behaviors, and course performance**

Metacognitive awareness and study skills were measured using the learning strategies inventory (LSI; Appendix 2).
**TABLE 3.** Sample ELP responses and feedback.

**ELP prompt:** What contributions did you make to your group this week? How did your out-of-class preparation/study impact your role in the group?

**Student response:** This week in my group I tried to add as much knowledge as I knew when applicable. In preparation for this I did all my learning objective questions, and am almost done with next week’s—I have two questions left. But, I am going to continue to try and add more and more each week to my group during class because I feel I listen mostly, probably because I am always a bit confused, and my group members don’t seem to be. But, I will continue to add what I know, and ask questions when I don’t know, or just need clarification.

**Instructor feedback:** Just because your group members don’t seem to be confused doesn’t mean that they aren’t! It’s important to do as much as you can to contribute so that you don’t get led astray by group member’s misconceptions.

**Student response:** Because I was prepared for class this week, with my notes, reading and studying, I was able to contribute to my part of the group discussion and provide my group with well-written notes to help with our projects.

**Instructor feedback:** Exactly! Coming to class prepared makes a huge difference. You’ll see that this makes an impact for the exam—because you’re coming prepared, you’re able to participate more and get more out of class. This helps so much as you prepare for the exam!

**ELP prompt:** Give one example of a successful response on your exam. Try to explain what you did to make this response successful (it may be helpful to compare to a less successful response).

**Student response:** In response to the question about the Red Queen Hypothesis, I divided the two-part question into two bullet points. First I defined the Hypothesis, then I connected it to sexual reproduction and evolution. In this way, I clearly answered all of the parts of the question, unlike in question 12, where I didn’t address all of the parts of the question.

**Instructor feedback:** Good to draw comparison to a question you didn’t do as well on. Also good to recognize how the “divide and conquer” approach can be effective in a multi-level question.

**ELP prompt:** Give one example (if relevant) of a less successful response. Can you explain what you did wrong/failed to do in this example?

**Student response:** I did remember I got the hypotonic question wrong and it was because I changed my response. I read the statement that said, “do cells really want glucose” or something of that nature and it through [sic] me off. I need to remember to stick to my answers!

**Instructor feedback:** It’s amazing how many times your first instinct about a response is correct. Trust yourself!

**ELP =** electronic learning portfolio.

---

**TABLE 4.** Comparison of student ELP responses.

**ELP prompt:** What have you learned about yourself as a learner over the course of the last month? What changes have you made to your learning strategies during that time?

**Student 1 response:** Looking over the past responses I think that I have been adjusting more strategies to take biology to a whole new level, trying to keep the detail, but taking the time to take a step back & look at the bigger effects & how the cycles interact with each other. I feel that learning this way is much more applicable to the actual field of biology, which is not in a classroom, but the real world where systems change the way they operate & we have to understand what is happening or leading to this change in the organism.

**Student 2 response:** I have been putting more time into all my classes and now that football is over I got like 5 hours extra a day I can put into studying.

**ELP prompt:** What have you learned about yourself as a learner over the course of the last month? What changes have you made to your learning strategies during that time?

**Student 1 response:** I have learned that it is easy to get stuck on the same learning as in high school science classes, memorize everything, spit it out for the test, and then forget. I found myself doing this for the first test, and that grade reflects that this is not how to study for biology in the real world or at the college level. After that I found that I can filter information out a lot better than I thought. I have learned that I learn by going through the material and understanding the general vocabulary as in high school, but then applying this by thinking about how changes in certain steps might affect the whole system.

**Student 2 response:** Nothing really. I made every mistake possible last year so I learned a lot from that year. How and when to study.

---

Scores in both BIOL 225-1 (p = 0.01, t = 2.5, df = 36) and BIOL 225-2 (p = 0.02, t = 2.2, df = 37) increased significantly, indicating gains in student metacognition (Fig. 4). Study skills scores (Fig. 5) decreased significantly in both BIOL 225-1 (p < 0.0001, t = 5.16, df = 36) and BIOL 225-2 (p < 0.0001, t = 22.06, df = 37). Examination of individual questions

---

**FIGURE 4.** Metacognitive awareness (MA) scores pre- and post-ELP. Students completed electronic learning portfolio (ELP) entries from week 5 through the end of the semester. Metacognitive awareness was assessed as part of the learning strategies inventory (items 1–52) given at the beginning (pre-ELP) and end (post-ELP) of the semester. There were significant increases in MA scores in both BIOL 225-1 (dark bars, p = 0.01) and BIOL 225-2 (light bars, p = 0.02). Error bars depict the standard error of the mean.
suggested that students abandoned strategies they no longer found helpful. For example, 77% of BIOL 225-1 students indicated they “usually” or “almost always” used flashcards at the beginning; this value decreased to 50% at the end of the semester. Taken together, these data indicate an increase in student metacognitive awareness with an associated change in study approaches.

As reported on the SALG, over 70% of students indicated moderate or high gains in “understanding my strengths and weaknesses as a learner” and “identifying skills that result in increases in my learning” (Fig. 6), and 74% reported moderate or high gains in “managing time & tasks effectively.” Students made behavioral changes resulting in moderate or high gains in learning including eliminating ineffective study behaviors (66%) and trying new approaches (65%). Notably, 69% reported moderate or high gains from “writing in my ELP & reading the feedback.” Students felt they developed critical thinking skills, study strategies, determination and willingness to work with a group and share their ideas (Table 5). Students also realized that learning is not compartmentalized, and they connected what they were doing and learning in BIOL 225 to learning outside our classroom. The skills and strategies mentioned by students are not biology-specific; they are transferable across disciplines (Table 5). Collectively, these data support the positive impact of the ELP not only on student learning but on metacognition and behavior.

Course DFW and DE (failing only) rates support the positive impact of the ELP on learning (Fig. 7). When no
ELP was employed, the DFW (20%) and DE (11%) rates were consistent with the historical average. In BIOL 225-1 the DFW and DE rate were 14%; this DE rate is higher than the no ELP cohort because no students dropped the course. In BIOL 225-2 the DFW rate decreased to 12% and the DE rate dropped to 6% (6 students dropped the course). Student exam scores over the semester provided a link between increased metacognition and learning. BIOL 225 exams are entirely short-answer format focused on higher-order thinking; on average, exams contained 62% higher-order questions as defined in (15). This format aligns with the class learning approach, where students practice methods that encourage deep learning (13, 48), and exams provide students with new scenarios to apply content and skills. Figure 8 uses representative students to illustrate trends observed in metacognitive and learning gains across cohorts. Figure 8a depicts students with increased metacognitive and exam scores (representative of 57% of students). Collectively, there was an average metacognitive gain (MG) of 0.31 (31%) and an average increase of 22% (2 letter grades) on exams. While the majority of students with MGs had improved scores, 29% had consistently high scores (A or B) throughout the semester; a small number of students (14%) had consistently low scores. Students with little MG fell into two main categories, as seen in Figure 8b. Some students were high performers at the beginning and throughout the semester (Fig. 8b, MG = 0.14). In contrast, other students with low MGs had low performance throughout the semester; 67% of these students never earned a passing grade on an exam. Based on both broad (Fig. 7) and singular (Fig. 8) measures of learning, these data indicate a positive relationship between metacognition and learning gains.

**FIGURE 7.** DFW and DE rates pre- and post-ELP. BIOL 225-1 and BIOL 225-2 students (n = 92) completed electronic learning portfolio (ELP) entries from week 5 through the end of the semester. DFW rates represent students who dropped, failed, or withdrew from the course. DE rate represents students who received a failing grade (D or E) in the course. No ELP refers to a cohort of BIOL 225 taught by the same instructor in which the ELP was not employed.

**FIGURE 8.** Metacognitive gains (MG) and exam scores in BIOL 225-1 and BIOL 225-2. Metacognitive gains (MG) were calculated as described in Methods. Exam 1 was taken pre-ELP and exams 2, 3, and 4 were taken post-ELP. A) Positive impact of MG on exam performance. Exam scores are shown for three representative students with increased MG and exam scores over the course of the semester. One student (MG = 0.35) had an exam score above 100% due to an extra credit question. B) Lower MG and relatively unchanged exam performance. Exam scores are shown for three representative students with little change in MG and exam scores over the course of the semester.

**DISCUSSION**

**Student overconfidence in introductory biology**

Student overconfidence and unpreparedness present us with a new perspective on what we must achieve in the classroom. Not only must we facilitate learning the skills and content of our discipline, we must teach the skills necessary for success; by ignoring the latter, we sacrifice the former. Early in the semester, student overconfidence is apparent in student performance predictions. While 97% of students predict either an A or B in the course, only 44% will earn those grades (Fig. 1). This finding is not surprising as these beliefs stem from students’ previous experience (5). Students enter BIOL 225 with a set of skills that led to success in high school science courses; while 39% of students acknowledged they would have to
study more than in high school (Siegesmund, unpublished data), most students believed that high school approaches would continue to be effective. Students’ previous experiences shape their beliefs about how they learn and impact behaviors ranging from class attendance to class participation and how to study (12). Students continued to overestimate their ability early in the semester, with a wide range in student ability to accurately predict exam scores. Consistent with other reports (18,26) the bottom performers overestimated their performance to a greater degree than their higher-performing peers (Fig. 2). These students are particularly concerning in light of data indicating that incompetent individuals are not only incompetent, but they also fail to realize their incompetence (17,26) and that students with lower monitoring abilities are less able to regulate their own learning (41).

**Using self-assessment to increase metacognition**

Developing metacognition is one mechanism for helping students become self-directed lifelong learners. As measured by the metacognitive awareness inventory (MAI), there was a significant increase in student metacognition (Fig. 4), supporting the hypothesis that classroom learning communities and self-assessment can increase student metacognition. It is important to establish learning communities and clarify expectations (Table 1) on the first day of class for three reasons: 1) students interact with each other immediately; 2) interaction between instructor and students is established; and 3) the class and instructor have interactively and collaboratively established what the classroom will and will not be. At the end of the semester, students acknowledged that the classroom environment resulted in good to great gains in their learning (Fig. 3). These gains are likely an indirect result of the classroom learning communities. As demonstrated by Rocconi (35), the positive impacts of learning communities are mediated via increased student engagement. A comparison of BIOL 225 student engagement and final course grade (Siegesmund, unpublished data) supported the positive correlation between engagement and performance.

One mechanism by which students monitor their engagement is the use of formative assessments (11), such as the self-assessments done in the ELP (Tables 3 and 4). These self-assessments help students monitor their learning process and its outcomes, identify changes, and evaluate their success. Their ability to do so is related to their metacognitive awareness; the example student ELP responses (Tables 3 and 4) illustrate that students are thinking about their thinking. It is important to acknowledge the role of feedback in this process. Formative external feedback such as that provided by the instructor (Table 3) helps students to self-monitor, which in turn generates more internal feedback (11). Students who incorporate external feedback and generate more internal feedback tend to be more effective at regulating their learning (9).

**Impact of metacognitive awareness on beliefs, behaviors, and learning**

This study analyzed whether increased metacognition influences student beliefs and behaviors with positive impacts on learning. There was a significant change in student study behaviors over the course of the semester (Fig. 5). The decrease in study skills scores is consistent with SALG data (Fig. 6) indicating that 66% of students identified and eliminated study behaviors that were no longer effective. Student SALG responses (Tables 2 and 5) indicated changes in behaviors both in and outside of the classroom. Students identified their own strengths and weaknesses, were willing to try new approaches, and identified skills that increased learning (Fig. 6). The change in student behaviors and beliefs had a positive impact on student learning, as indicated by both broad (Fig. 7) and singular (Fig. 8) measures. Collectively, the data support a model of self-regulated learning; students were evaluating, planning, monitoring, and reflecting on their learning. As student behaviors are a result of their epistemological beliefs (5), it is reasonable to conclude that these data indicate a shift in beliefs as well. This study supports previous findings (25, 33) indicating that by acknowledging and addressing student epistemological beliefs, faculty can help change student beliefs and behaviors to positively influence learning.

While the data presented here focused on introductory biology, they have relevance to both other STEM (science, technology, engineering, and mathematics) and non-STEM disciplines. This work demonstrated that classroom-based learning communities and self-assessment can be used in concert to increase metacognition and positively influence student learning. For some institutions, the development of traditional learning communities is challenging. This study demonstrates that classroom-based learning communities, which are feasible in almost all institutions, positively influence student learning. The author acknowledges that the class sizes in this study were relatively small, and a class with >100 students is not conducive to reflective journaling with weekly individual feedback. A more time-efficient option is using a technology-based platform similar to that described by Mair (28). There are many mechanisms for introducing metacognitive reflection into the classroom that are less time-intensive for the instructor and therefore more amenable for large classes (44). Regardless of the models employed, increasing student metacognition is an effective strategy for training self-directed lifelong learners in any discipline.

**SUPPLEMENTAL MATERIALS**

Appendix 1: Electronic learning portfolio (ELP) prompts
Appendix 2: Learning strategies inventory

**ACKNOWLEDGMENTS**

The author thanks the Biology Scholars Research Residency Program (National Science Foundation Award #0715777) for
its guidance in the design and implementation of this project. The author declares that there are no conflicts of interest.

REFERENCES