

A Course Designed to Improve Students' Critical and Creative Thinking in
the Life Sciences

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Abstract

Students in the life sciences first-year program at NC State University enroll in a course focused on critical and creative thinking. The course is discussion-based with small groups working on problems and case studies associated with the neuroscience of learning, critical and creative thinking, rhetoric in science, diversity in STEM, and experimental design. Groups also work on a semester-long project tying together many of the course topics. Course design and best practices are discussed for adoption and implementation to help grow students' critical thinking and creative thinking skills. Results support that group work all semester helped student learning gains, and that students rank improvement in their understanding of course content as well as skills in the area of argumentative writing and discussions.

A Course Designed to Improve Students' Critical and Creative Thinking in the Life Sciences

Students' ability to engage in critical thinking is consistently listed as a mission for many higher education institutions, as well as being established as a learning objective staple on many syllabi. Additionally, the importance of creative thinking has seen a revitalization as the COVID pandemic brought many societal changes and the resurgence of solving problems in creative ways. In the era of globalization and change, people are not only in need of critical thinking skills but also creative thinking abilities. These are important 21st-century skills (e.g., Pellegrino & Hilton, 2012) as both critical and creative thinking are sources for solving problems in the life sciences as well as all other areas of life.

Critical thinking involves skills such as analyzing arguments, using inductive or deductive reasoning to make inferences, judging information, evaluating content, and making decisions. It is a descriptive term to capture the methods of logic and gathering information that are employed to solve problems. Critical thinking is reflective in nature, focused on decision making through evaluation of the data (Ennis, 2015). Creative thinking, on the other hand, is sometimes defined not in terms of process but in terms of product (Taylor, 1960), with fluency, flexibility of thought, elaboration and originality used to solve problems. Creative thinking is also described as the ability to generate novel ideas, make unique connections and approach challenges in imaginative ways (Good, 2024). Critical and creative thinking are complimentary and useful in approaching problems and providing solutions.

Because of the fast-paced changes in our world today, through automation, artificial intelligence, and instant global connection, it is arguable

that critical and creative thinking skills may be even more relevant than in the distant past. Students need to quickly adapt and think in critical and creative ways to be successful in college and their future careers (Al Mamun, 2024). Creative thinking as well as critical thinking is significant not only for problem solving but for innovation, effective communication, decision making adaptability, and global challenges (Al Mamun, 2024).

Students entering college, who are interested in life sciences, often believe they understand the scientific method thoroughly and that they are adept at critical thinking; however, their impressions are usually not realized. For example, in one study, the critical thinking of senior high school students was found to be in the “very low” category ($n = 115$, mean = 49.95, Mifta Fausan et al., 2021). As such, college freshmen often do not have a strong foundation of critical thinking upon which to build. When assessed over their first two years of college, barely more than half of the undergraduates sampled at 24 institutions made gains in critical thinking during that time (Arum & Roksa, 2011). More recently, a study of 70 students found that students taking a Plant Taxonomy course achieved low scores in critical thinking and creativity (Rosba et al., 2021).

College instructors face barriers when trying to teach critical thinking in their courses. Findings suggest underprepared students, instructors’ limited time and effort, and the favoring of content specific material concentration (for prerequisites) required for subsequent courses are some of the reasons critical thinking in STEM courses is not addressed (Evangelisto, 2023). Additionally, the instructors’ characteristics (as assessed by the Cognitive Reflection Test which aligns with an important aspect of critical thinking) can be a barrier in teaching critical thinking in a course. Instructors with open-minded thinking and a disposition towards effortful teaching saw teaching critical thinking as important for their students. An instructor’s attitude can make a difference. If an instructor doesn’t see the relevance of

teaching critical thinking skills, they will not show effective teaching in this area (Janssen et al., 2019).

When an instructor has the focus and effort to improve critical and creative thinking for their students, results can be found over a short time. There is evidence that freshmen who participate in a course focused on critical thinking can improve their critical thinking and experimental design skills over just one semester (Gottesman & Hoskins, 2013). In another interdisciplinary first-year seminar course, students who were involved in design thinking over the semester achieved success with divergent creative thinking and growing their critical thinking skills, such as asking strong and resonant questions (Dorland, 2022). Even in a content-specific course, like an upper-level biology course, a single semester of an aligned course using active learning and multiple opportunities for practice, can improve the critical thinking skills of students (Heft & Scharff, 2017).

Therefore, it is possible to design a semester-long college course to help improve both the critical and creative thinking skills of students. Both these skills reinforce each other and help students in a variety of ways. Students who engage in creative thinking were more likely to see success with tasks that focused on critical thinking skills (Kim, 2011). Memory consolidation and student learning (with subjects such as math and science) can be improved through creative thinking development (Tzachrista et al, 2023). Critical thinking on its own has a correlation with higher order thinking skills such as synthesizing and evaluating (Prince & Felder, 2013), and there is a significant correlation between critical thinking skills and creative thinking skills with cognitive learning (Siburian et al., 2019). Both critical and creative thinking should be cultivated in students and can be done so in a discipline-specific course like Biology. In such a course, critical and creative thinking skills can be developed in familiar contexts and then applied to less familiar and unobservable contexts (Lawson, 2001). In general, critical and

creative thinking can be developed in content specific courses as well as more interdisciplinary courses and seminar courses.

The current study describes a general interdisciplinary course that was developed to better equip life sciences students for scientific thinking. These skills are needed in today's learners, and these critical and creative thinking skills can be developed over a semester. The current study focuses on a course for first-semester freshmen entitled *Critical and Creative Thinking in the Life Sciences*. This course is discussion-based, using case studies and problem-solving sessions throughout the semester, with students working in groups of four. Case studies help students learn how to evaluate data, think through a scenario, and plan and reason by studying the actions of scientists (Hachtmann, 2016). Students also work on reflection papers throughout the semester where they connect what they are learning in the classroom to their own lives. This is considered an essential part of the student learning process as students consider content, analyze material and form reasoned judgements as part of the critical thinking process (Quinton & Smallbone, 2010).

Throughout the semester, students work on divergent thinking activities, create a product together, and engage in discussions, and their critical thinking as well as their creative thinking improves. This study describes the overall course structure as well as courses activities that can be adapted and implemented into any course.

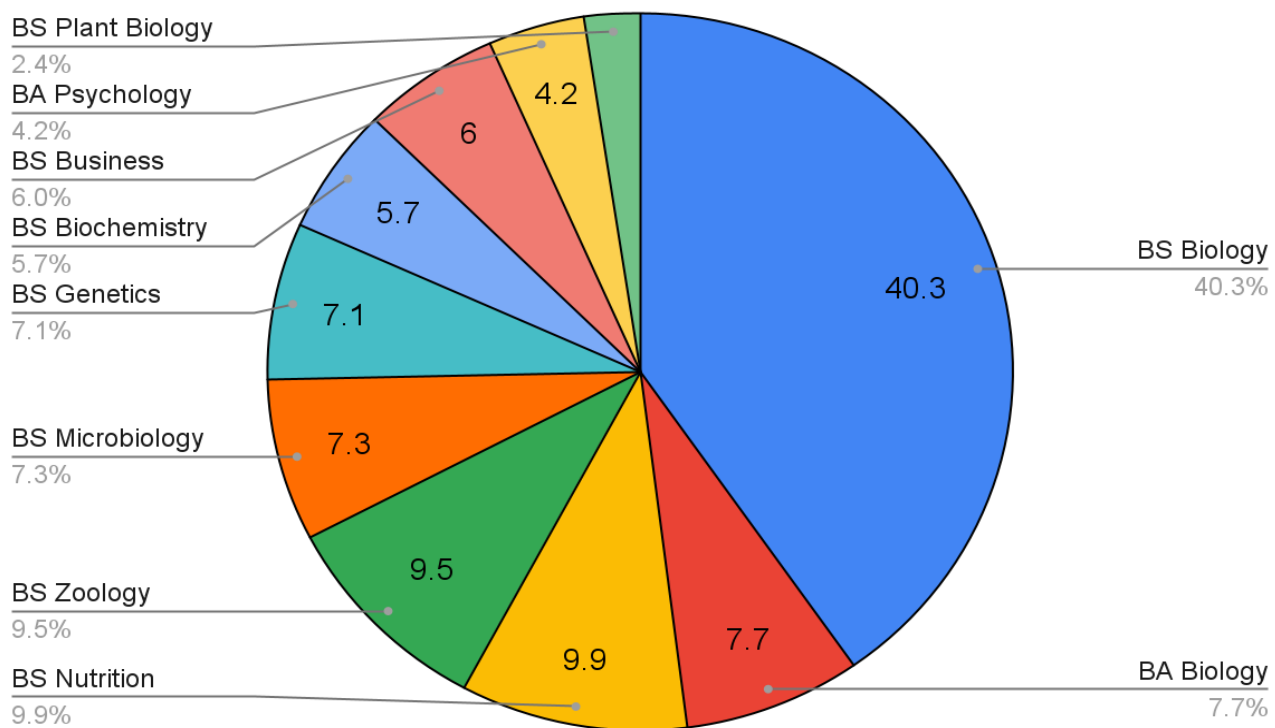
Course Structure & Evolution

Student Population. Since the course has been offered starting in 2015, approximately 5,351 students have completed the course (as of end of Fall 2024). For the students for whom we have data on degrees earned (n=1454), the vast majority primarily continued in the life science disciplines, earning degrees in one of the areas we support, or 71% of this population.

Many others changed to other areas that were science disciplines, such as fisheries and wildlife or animal science. The top ten majors and degrees earned are primarily in the majors supported by the life science first-year program (Fig 1); however, regardless of which degree was earned, any major or college graduate would do well to improve their critical and creative thinking skills.

Figure 1

The top 10 Majors where degrees were earned comprised of students who would have taken the course Critical & Creative Thinking in the Life Sciences during their first semester at NC State University. N= 1,454 students.



Course Objectives. The course was designed and first taught in 2015 and as the Life Sciences First Year program grew, so too did the course offerings as well as its design. The topics have been consistent throughout time, with the exception of an additional learning objective and focus added in 2020 centered on diversity in STEM (see #6 below). The learning objectives for the course include that as a result of completing the course, students will be able to:

1. apply essential elements and intellectual standards of critical and creative thinking
2. critique the practice of science (e.g., designing experiments, writing hypotheses, discussing ethical issues)
3. create arguments using appropriate rhetorical elements (e.g., on the nature and practice of science)
4. analyze samples of work from life scientists and rhetoricians of science
5. implement fundamental principles of the neurobiology of learning to their own strategies for learning
6. evaluate science through the lens of history, socioeconomics, and cultural biases

Course Delivery. The course meets either once a week for two hours or two times a week for one hour each session. Students are assigned to be a member of a group of 4 people. Group arrangements are often sorted by intended major, so a diversity of disciplines might be presented, but other factors may play a role, like gender, race, and hometown (again to maximize diversity).

The main topics covered throughout the semester include the neuroscience of learning, the rhetoric of science, critical and creative thinking (including intellectual standards), science as a process (including social factors), and growth

of scientific method comprehension (e.g., experimental design). In their groups, students typically work on something collectively during class to turn in for credit by the end of each session related to these topics. Examples include answers to problems and questions centered around a case study, ideas generated for a creative thinking exercise, or short reflections on what was learned that day.

Additionally, the groups work on a project that ultimately is presented to the class at the end of the semester. The scope of the group project changes from year to year and with the instructor; however, the nature of the project is always to design a solution to a problem by employing techniques and strategies used throughout the class. This could be an environmental problem (like climate change or plastics in the ocean) or a problem of how to connect three unrelated, random items into one theme which leads to the creation of a product (e.g., toothbrush, DNA, and chocolate being used to create a children's book revolving around a Superhero in order to teach kids about natural selection). Regardless of the subject for the group project, we have learned that dividing up the project into smaller scalable parts throughout the semester is helpful to the students. Additionally, setting aside 20 minutes in a 2-hour class every other week is appreciated by the students and keeps them engaged and on target to finish in a timely manner.

Individual work includes two short reflection papers designed to encourage students to contemplate topics covered and to promote their individual growth. For example, one reflection assignment asks the following: "We have learned about mindsets in class. Which of the two mindsets do you have for chemistry? How do memory and learning play into these? What did you learn from the book and class that you will bring forward from now on into other courses? Why?" Another example of a reflection paper prompt is "Refer to the list of intellectual standards of critical thinking, which of these standards have you developed or improved in this course? Give specific examples to illustrate how you have developed/improved these standards."

Individuals may be given an occasional homework assignment, such as questions to help students work through a reading assignment, so they can come to class prepared for discussion. We have also asked students to do short end-of-class observations and opinions to help with learning. For example, we may ask students to name and describe the two major categories of learning/memory. And then follow up by asking students to use the concept of the two categories of learning/memory to provide a possible neurobiological explanation for the disconnect between student perceptions of learning and their actual learning. In other words, we would ask “Why (neurobiologically speaking) might students think they know the material better than they show on an exam?” For these short reflections, students are allowed to use their notes and books or other material from class to answer the questions.

Discussions in the class center on rhetoric, both verbal and text. Time is spent working with a book dedicated to scientific writing (Hofman, 2016). Over the iteration of this course, the use of this book has differed based on the instructor; however, all instructors agree that its use is valuable in future science courses and as a reference as students matriculate through college. Most students decide to keep this book and reference it semester after semester. The intellectual standards for critical thinking (Table 1) are used throughout the course as well but introduced and emphasized at the start of the semester, during this time initially of rhetoric discussion. By returning to, and using the intellectual standards over and over, students gain practice by employing them regularly with the goal of students making them part of their routine as they move through other courses and life.

Table 1

The 9 intellectual standards of critical thinking

Intellectual Standard	Guided Questions
Clarity	Could you give me an example or elaborate further?
Accuracy	How could we check on that?
Precision	Could you be more specific? Could you give me more details?
Relevance	How does that relate to the problem? How does that help us with the issue?
Depth	What are some of the complexities of this question?
Breadth	Do we need to look at this from another perspective?
Logic	Does all this make sense together?
Significance	Is this the central idea to focus on? Is this an important problem to consider?
Fairness	Do I have any vested interest in this issue? Am I sympathetically representing the viewpoints of others?

Other discussions in the class center on the scientific process itself and the neuroscience of learning. For example, there are case studies that are dedicated to the scientific method itself and experimental design. There are others that center on perspectives brought to the scientific table through different disciplines, gender, race, and background. Video clips (such as TED Talks) are used often to help supplement discussions and to provide interest. Published case studies (e.g., see NCCSTS Case Collection) and in-house generated case students are used for problem-solving and data analysis. We also use the book *The New Science of Learning: How to Learn in Harmony with your Brain, 2nd edition* (Doyle &

Zakrajsek, 2018). Students learn strategies to help with memory, we discuss the importance of sleep in long-term potentiation, and other aspects of the neuroscience behind memory.

Creative thinking is fostered by allowing students to practice solving problems and working on strategies building on creativity. For example, exercises in the classroom focused on divergent thinking are useful. Other ideas for growing creative thinking in students include employing SCAMPER to an issue - that is, considering "substitution, combination, addition, modification, putting to another use, elimination, and rearrangement". Additional activities that can be useful in the classroom include attribute listing, design thinking and divergent thinking exercises, 6 thinking hats (for decision-making), and experimental design. The intellectual standards of creative thinking are also introduced and used consistently throughout the semester to promote liberal use with the students both in and out of the classroom (Table 2).

Table 2

The 4 intellectual standards of creative thinking.

Intellectual Standards	Guided Questions
Originality	Did the idea arise from constructive imagination and independent thought?
Flexibility & Adaptability	Did you adjust your thinking to changes in the situation or context?
Appropriateness	Is there a good fit between the constraints of the problem and the properties of the solution?
Contribution to the Domain	Is the new idea of value to the discipline?

Course Project

A major focus of the course centers around students working collaboratively to produce a product to present to the class at the end of the semester. In course evaluations, students often commented that this was the most rewarding aspect of the course. Not only do students learn more about content, but they also grow their creative and critical thinking skills in a fun way. Additionally, students learn more about group interactions and potentially grow their leadership skills.

The project itself has taken on primarily two versions. In the first version, students select two non-science words out of a bag and one science word. They are asked to connect these three words together in some way. Students will often try to use the three words to create a story using these words as the subjects, but this is not the goal. Steering students towards how the words are similar helps spark creativity. For example, a group that chose the words “Captain America”, “ponytail tie” and “black hole” ultimately saw the similarity and connection of “hold-

ing things". They used these words and others (like purses, bowls, pens, bottles, books, and briefcases) to create a children's book on describing objects that hold things. Captain America holds a shield and fights bad guys. A ponytail tie holds hair and a black hole holds light and objects. The message of the book was that their hands could hold lots of things and be effective at creating and doing as a result. The students used graphics and computer software to create a professional-looking and beautiful book that they read to the class during presentation time. Other groups have created podcasts, written poems, created commercials, and designed buildings.

In the second version of the group project, students work on a life science real-world project both individually and in their groups. Each person initially selects a life science problem and writes a problem statement of 200-250 words. The statement provides a broad description and scope of the specific problem and identifies who or what is impacted by this problem. The statement also offers an explanation of the current resources that are available to address the problem and addresses the previous attempts made to solve the problem. Individuals then present their ideas to their group during class and attempt to persuade others to select their specific problem for the team project. After coming to a consensus, the group will identify three existing solutions to the team problem and discuss and write about their strengths and weaknesses. The team will then propose a creative, meaningful, and feasible solution to the group project. Individually, each person writes a 500-word assessment of the team solution and then the group as a whole creates and presents a video presentation on their findings and suggestions to the class.

Because there is always the possibility that certain members of a group do not carry their fair share of the work outside of class time, we have dedicated some time every session for groups to work together. This has proven to be most effective in monitoring and guiding projects more thoroughly than in the past. For example, the instructor can check in at each table and ask pointed questions. They

can make suggestions or give inspiration to make the project more sophisticated if necessary.

Course Assessment

Over the years, there has been some flux in thought and action as to how to best assess student gains in critical thinking and creative thinking. Initially, there was an in-house generated pre and post-test that aimed to monitor student growth. The analysis of these tests turned out to be overwhelming and cumbersome. We switched to having more of a student-written reflection of growth in paper format; however, this proved not to be as helpful to our understanding of student gains as hoped. We have settled on giving an objective final exam at the end of the semester, coupled with using the instrument called SALG - Student Assessment of Learning Gains (available at <https://www.salgsite.net>). With this instrument, students rank how much they have learned using a Likert scale rating. Examples of the types of overarching questions asked include: (1) How much did the following aspects of the course help you in your learning? and then you can list resources provided - like the case studies used during class; (2) As a result of your work in this class, what gains did you make in your understanding of each of the following? and then you can list aspects of the course learning objectives - like the rhetorical elements of creating arguments (3) As a result of your work in this class, what gains did you make in the following skills?; and then you can list aspects of the course - like developing your creative thinking.

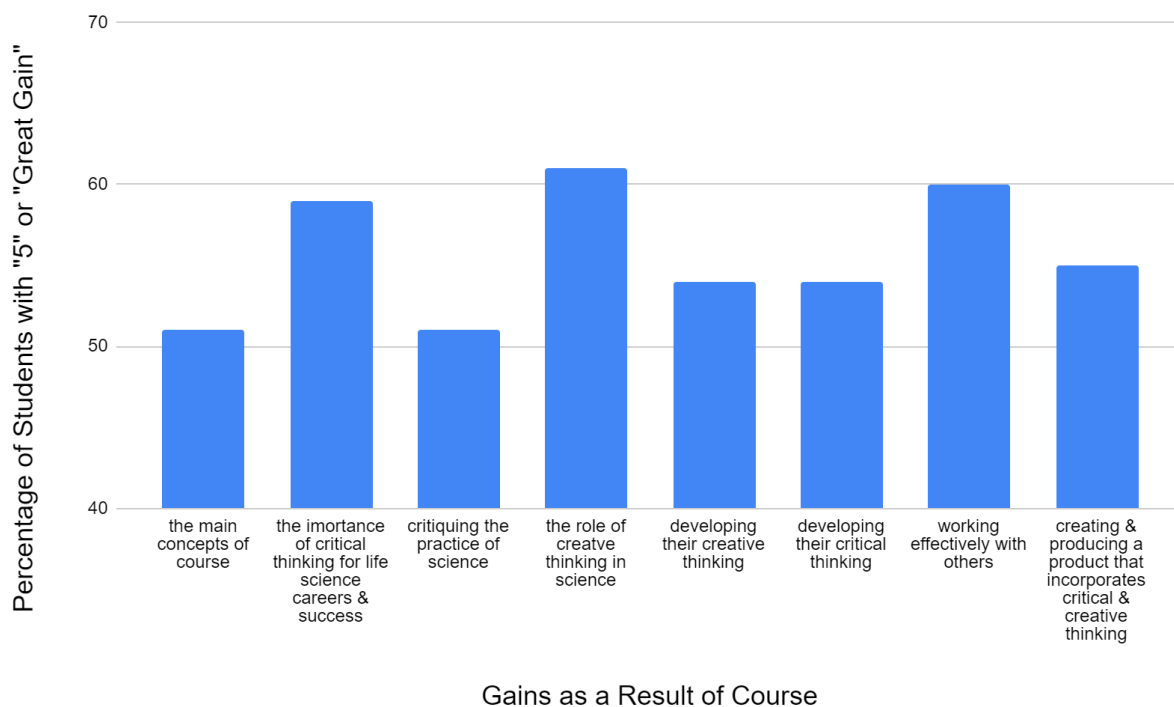
From the most recent data collected from 370 students taking the course (fall semester of 2023), we found that students self-ranked an increase in their skills with understanding the relationships between course topics, rhetoric, and creating arguments. Specifically, we see an increase in the skills of understanding the relationship between the main concepts of the course (t-value = 6.4695, $p < 0.0001$). Students also self-ranked that they increased their skills with using rhetorical elements to create arguments (t-value=2.5912, $p=0.0098$), as well as critiquing arguments (t-value = 4.1377, $p < 0.0001$). They also gained in their ability to

create arguments using specific rhetorical strategies (t-value=2.8187, p=0.0050).

We found that at least 50% of students at the end of the semester ranked themselves as showing great gains (that is a value of 5 on the Likert scale of 1 to 5) with understanding the main concepts in the course (rhetoric, critical thinking, creative thinking and the process of science), the importance of critical thinking for life science careers and success, critiquing the practice of science, and the role of creative thinking in science (Fig 2). Fifty percent or more of the students felt they increased their skills in developing their creative thinking, their critical thinking, working effectively with others, and creating and producing a product that incorporates critical and creative thinking (Fig 2).

Figure 2

The results of students' self-assessment at the end of the semester as reported by the SALG instrument (Student Assessment of Learning Gains). Students used a Likert scale to self-assess their gains in skills and understanding of course topics (n=333). Results shown here highlight those areas where 50% or more of the students ranked their gains as 5 out of 5 or "great increase" as a result of the course.



Additionally, students on the SALG ranked how much various class activities helped their learning. The highest category was "working with my group members to solve problems during class" where 64% of students (n=331) ranked this as a 5 or "great help". Working on the group project was rated by 55% of the students at the 5 level, and 52% of students ranked participating in discussions or listening to discussions during class. There is definitely value in having students work in

teams throughout the semester.

A second instrument that students also completed was the TTCT - Torrance Test of Creative Thinking at the beginning and end of the semester. This instrument asks students to write their thoughts on a variety of situations to assess fluency, flexibility, and originality. Examples of these situations include asking questions about an image/scene, improving a product, and developing ideas for unusual uses. Students are scored and compared against other college students as well as against students their same age.

Data were analyzed from the Fall semester of 2021 (n=228 students) using the TTCT instrument at the start of the semester and again at the end of the semester. It was found that students improved their creative thinking from the pre-semester TTCT scores compared to the post-semester TTCT scores. Students improved in all three areas tested: fluency (t-test; $p=0.0013$), flexibility ($p=0.0002$), and originality ($p=0.0008$), showing that students can improve these skills as a result of a course and in particular, working on creative thinking strategies throughout a semester (manuscript in preparation).

Best practices

We would like to introduce some of the best practices that we have observed during the time that we have been offering the course, with an emphasis on the current version.

1. Students need to practice applying the intellectual standards for both creative and critical thinking in some meaningful way (e.g., classwork, problem-solving, discussions) with examples highlighted throughout the entire semester.
2. Written reflections by students discussing how they implement critical and creative thinking are essential for relevance to the students and for them to see the connections to other topics and disciplines.
3. A group project is a good way to highlight the major tenets of the course as well as help students with diverse and collaborative learning. The group project should be divided up throughout the semester into smaller steps to help motivate students and keep a common thread throughout the semester.
4. Creative thinking exercises should be used often and occur throughout the semester to promote growth for individual students in this area.
5. To assess course effectiveness fully, having a final exam of some sort is necessary. This can be an open-book exam, where the application of material can be used to address problems or work through a case study.

Implications and Future Work

With the changes described in this paper, the course *Critical and Creative Thinking in the Life Sciences* has evolved into a course that promotes the growth and development of individuals. Students who complete the course comment consistently at the start of the semester that they did not understand why they “had to take the class” only to discover that they enjoyed the course and “actually” learned a lot. Students several years after the course have told us that the course was helpful for their ability to write lab reports well, design experiments, and apply creative thinking to projects in other classes.

We received a notice from a colleague who teaches a capstone course for graduating seniors in Biological Sciences. With permission, the student wrote about this course in response to a reflective prompt asking students to select certain classes and discuss how they have applied skills and knowledge from the class in their experiential learning experience:

In my first semester, I took Critical and Creative Thinking in Life Sciences. This class was foundational in how I process information, adapt my thinking, and learn. The class taught me how to think beyond the surface level and question information. I am applying skills from this class in every situation in my life. Every day I ask specific questions, enhance my knowledge, and challenge my learning. I often get afraid to ask questions, but the class reminded me to think independently and require more information. In addition, the class got me comfortable with being challenged and stepping outside my comfort zone.

Although such comments are anecdotal, there are enough of them that encourage the instructors that the course is meeting its goals and learning objectives. Additionally, colleagues who teach upper-level courses have indicated they see the value of this course and often can identify the students who participated in the course. The university values the course as it is a requirement for students who major in Biological Sciences, Biochemistry, Genetics, Microbiology, Nutrition Science, Plant Biology, and Zoology. This is seen as a foundational course to help build critical and creative thinking skills and increase growth in “soft skills” such as leadership, communication, and collaboration.

Because such skills are valuable for all of our students, we encourage others to consider implementing such a course at their institutions or to incorporate some aspects of this course into existing courses. An existing course can easily be modified with minimal effort to place an emphasis on critical and creative thinking skills and the benefits to the students will be appreciated.

Acknowledgements

The authors thank Jane Lubischer who spearheaded the development of the Life Sciences First Year Program (LSFY) at NC State University and created the course outlined here. We also want to thank the students and instructors who have participated in this course over the years and who have helped carve it into the course it is today. Their feedback and contributions have been very helpful.

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