Implementation of Critical Thinking Exercises in Introductory Biology

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Abstract: Critical thinking is an important proficiency for undergraduates to gain, yet rarely is it formally taught in the classroom. The goal of this study was to determine whether a 4-week module on critical thinking in a team-taught biology major introductory course could enhance students' general critical thinking skills. Results suggest a trend toward an increase in student aptitude as demonstrated by gains on a standardized critical thinking test assessment, and a statistically significant greater ability of students to analyze scientific claims. These results support the notion that even small exposures to critical thinking can enhance students' skills beyond discipline-specific knowledge.

Key words: Critical thinking; undergraduate; introductory biology; scientific claims; reasoning

The shifted view of science teaching espoused by policy groups as well as many instructors at institutions of higher education is that science should be taught in a manner in which student learning is at the focus (AAAS, 1990; Dehaan, 2005; NRC, 2003). This type of instruction deviates from traditional approaches that rely solely on large volumes of content delivery without providing students opportunities to make meaning of the information (AAAS, 2009).

Within introductory biology courses at colleges and universities, a major objective is for students to acquire foundational knowledge within the discipline. To achieve these ends, such courses often survey specific biological topics and concepts deemed important by the departmental curriculum. Instructors of these classes often face the compromise between presenting content and encouraging students to engage in application, discovery, and other activities that utilize higher-order thinking skills. One major reason is that there are several challenges to designing such learning environments. At research heavy institutions, conducting and publishing the results of scientific research is often more highly rewarded, leaving professors less time to devote to improving teaching practices (Boyer, 1990; Serow, 2000). Some instructors insist upon only teaching the way they have been taught independent of the effectiveness of their methods (Handelsman et al., 2004). Environmental challenges such as large class sizes, multi-section course teaching consistency, and lack of departmental support to implement change can also leave instructors less motivated to change their practices, although resources are fully available for such reform.

As a result, introductory biology courses can become negatively labeled because a large volume of content may be required to be learned during an early time point within the students' undergraduate experience where many have not yet developed college-level study skills (Seymour & Hewitt, 1997). On the contrary, a more pragmatic view of these courses, is, rather, an opportunistic setting in which to encourage students to not only develop their content knowledge within biology, but also their general thinking skills. At a forefront of educational research in the 1980's, critical thinking remains a valuable aptitude for students to gain proficiency within various contexts (McMillian, 1987; van Gelder, 2005).

Critical thinking has been described as using good reasoning to make informed decisions (Ennis, 1996). Good reasoning is important in the sciences in that the scientific method relies heavily upon the skills of inductive and deductive reasoning as scientists make hypotheses about phenomena, draw conclusions with evidence gathered, and form theories about the world around them (Halpern, 1998; Proulx, 2004). Critical thinking also includes analysis, evaluation, forming inferences, as well as having a flexible mindset (Facione, 1990). This reasoning is essential to scientific literacy. A scientifically literate person, in addition to having knowledge of particular science content, should be capable of using higher-order thinking to assess the validity of scientific claims that are encountered daily. Critical thinking is also seemingly important outside of academic endeavors. Studies have suggested that college students do not learn essential critical thinking skills within their early university years, and those with underdeveloped skills are more likely to exhibit poor life outcomes such as unemployment and massive credit card debt post-graduation (Arum & Roska, 2011; Arum et al., 2012).

Within undergraduate biology, there is documented integration of critical thinking into the curriculum and its effects. When critical thinking-based writing components are incorporated into undergraduate biology laboratories, students experience more critical thinking gains compared to those with only quizzes (Quitadamo & Kurtz, 2007). Another avenue by which to incorporate critical thinking is through student assessment of claims in science-related articles. Students engaging in several of these exercises during the semester have been found to formulate better arguments compared to those not engaged in as many exercises (Tyser and Cerbin, 1991). Others have also described the analysis of claims in articles in the popular press as a means by which to develop critical thinking skills in biology (Rutledge, 2005).

Such critical thinking-based studies are commonly implemented over the course of an academic semester leaving unanswered the pragmatic question as to whether smaller exposures of critical thinking-based instruction can enhance students' skills. Additionally, the effectiveness of different types of teaching methods at promoting higher order thinking in more limited circumstances has not be thoroughly investigated. In order to provide insight into these questions, the goal of the current study was to determine whether students' critical thinking skills could improve after a four-week module teaching such skills within a team-taught introductory biology course.

Theoretical Framework and Assumptions

There are several fundamental attributes that govern how students learn that are described within cognitive science. They include, but are not limited to: prior knowledge, organization of the newfound knowledge, motivation, practice, and application as well as feedback (Ambrose et al., 2010). Learning is more effective when there is an understanding by the instructor of the knowledge that students bring to the classroom setting, when the information is organized in a way that makes sense to the learner, and there is motivation on the part of the student to learn the new material. Additionally, the student must practice using their new knowledge, be provided with frequent and timely feedback and monitor their own thinking through metacognition.

This project was based heavily upon these ideals of learning theory. The following assumptions were made in this investigation: (1) critical thinking skills can be taught if students are provided explicit instruction, as well as a multitude of opportunities to practice and reflect upon what they have learned in the classroom or laboratory setting (Halpern, 1998); (2) the development of critical thinking skills can be measured through a variety of assessments including established standardized tests as well as student artifacts (Arum and Roska, 2011; Ennis, 1996; Facione, 2011); and (3) students will be capable of transferring critical thinking skills outside of their particular discipline if given explicit teaching and practice in how to do so (van Gelder, 2005).

Methods

Course Context. A four-week critical thinking module was embedded within the curriculum of our team-taught General Biology II majors course, the latter of which was comprised mostly of freshman biology majors as well as a few students in behavioral neuroscience and biomedical-related majors. There were 3 sections of this course totaling approximately 85 students. Students were explicitly taught the critical thinking skills of induction, deduction, assessing the credibility of sources, and finding fallacies in logic in class. They were first introduced to the latter concepts by the lead author and then required to apply them to everyday situations. These skills were related to the biological content that students were required to know for the course for the particular unit in which the module took place. For example, during a unit on classification, one group activity required students to deduce from information provided under which phylum an unidentified organism most likely belonged. Additionally, case studies were integrated within other units of the course to encourage critical thinking.

For the critical thinking modules, the method of teaching was the “flipped classroom,” where students were required to view audio lecture recordings via Camtasia Relay as homework and were quizzed during the subsequent class on major topics that were described in the lecture as a measure of accountability. In-class lecture time was devoted to review, application, and critical thinking activities (Brunsell & Horejsi, 2011; Khan, 2012; Bergmann & Simms, 2012). Questions asked in the 15 minute quizzes were based upon focus areas highlighted for students at the end of the recorded lecture material. After the quiz, the instructor went over the answers with the class and integrated a review of important topics prior to group activities. For the purposes of this study, the flipped classroom served as a basis through which the instructor could teach students foundational content within general biology while simultaneously focusing upon developing critical thinking skills in class.

Assessment of Student Learning. All students completed the Cornell Critical Thinking Test Level Z (CCTT-Z) at the beginning and end of the four-week module to assess change via the university server in a timed setting. The pre-test was given prior to any instruction on critical thinking. The CCTT-Z is a 52-question multiple-choice test that measures general critical thinking skills of deduction, induction, fallacies, meaning, and is targeted for advanced high school students, college students and beyond (Ennis & Millman, 2005) (See Table 1). The CCTT-Z has been described as a reliable and valid instrument in measuring critical thinking skills by test makers in the Illinois Critical Thinking Project (Ennis & Millman, 2005). Agreement has consistently been reached on answer choices as well as the instrument’s capability of assessing critical thinking. Individual questions may test for more than one critical thinking skill. The CCTT-Z has been correlated with other critical thinking tests such as the Watson-Glaser Critical Thinking Appraisal at a value of 0.71 illustrating criterion validity. With regards to construct validity, relationships between other variables have been correlated to critical thinking measured by the CCTT-Z. For example, IQ/Aptitude/Admissions tests correlate roughly 0.5 with the CCTT-Z. There is no apparent relationship between CCTT and gender, and a large amount of variance when comparing to academic accomplishments, most likely attributed to the differences by which varying educational systems emphasize critical thinking. Overall, the CCTT-Z was a valid instrument for its usage as a measurement of critical thinking in our students, and a reliable measure given numerous studies showing the apparent heterogeneity to be expected on different populations.

Table 1. Description of Cornell Critical Thinking Test Level Z subscales (based upon Ennis & Millman, 2005)

Subscale	Number of Questions	Assessment
Deduction	10	Is the conclusion valid?
Meaning & Fallacies	11	Is the statement logical?
Observations & Credibility	4	Is the assertion credible?
Induction	17	Is the hypothesis valid? What is the best experimental design?
Assumptions	10	Does the statement exhibit better reasoning than another?
Total	52	

In addition to taking the CCTT-Z, students were also required to complete two scientific claims writing assignments at the beginning and end of the unit, where they evaluated articles in the media or other sources on the basis of their scientific claims. The first assignment was given prior to any instruction on critical thinking. A draft critical thinking rubric developed by our institution was used to assess whether their abilities to analyze scientific claims changed over the course of the module (see Table 2). Essays were initially scored independently by the first author who taught the course and the second author who did not teach the course. For each writing assignment, each category on the rubric was separately scored as 1-Ineffective, 2-Effective, 3-Advanced, or 4-Outstanding by each rater. The scores of both raters were compared and differences negotiated to arrive at a final score.

Example directions given for an article entitled "Why the Blood Typing Diet is So Important for Losing Weight" (D'Adamo, 2012) are shown below. This assignment corresponded with a unit in which students learned Mendelian and Non-Mendelian genetics, which included an analysis of the inheritance of blood type:

> For the remainder of class write an essay analyzing the claims made in the article below. Your essay must have an introduction, body and conclusion and be roughly 1-2 pages in length (double-spaced) and demonstrate clarity in thought and language. Spend the first few minutes making an outline and the remainder writing a cohesive paper. Upload your essay as a Microsoft Word document to the submission link in Blackboard before class is over. Your response should be thorough. You may not use any outside sources including the Internet.

Below is an example of an excerpt from a student essay:

> *I believe that this article is not supported by proper evidence that would lead people…[to]…believe that this article is true. The article does not provide first-hand experience that people had endured and accomplished this diet by eating certain foods that would not affect their blood. This article might be more believable if more doctors had given examples of how the food would truly affect the blood itself. This would prove if the food and the blood type really work hand in hand with each other. The Blood Type Diet states that the diet will work for the A and O blood types but that's not the only blood type that's around, they did not even mention the B blood type, which is also an important blood type.*

Quizzes, critical thinking tests and scientific claims writing assignments accounted for 6% of students' grades in the course. Critical thinking tests were not graded for scores, but rather for thoughtful completion. The scientific claims writing assignments were graded as a typical course writing assignment (with a separate rubric for class purposes).

Table 2. Summary attributes of critical thinking rubric for scientific claim analysis

Rubric Category	**Description**
Identification of Problem	Accurately identifies the problem, provides a well-developed, comprehensive summary and carefully evaluates the relevance of context.
Assessing Evidence	Provides a well-developed examination of the evidence. Questions its accuracy and relevance to develop a comprehensive analysis. Clearly distinguishes between fact/opinion, and own/others' assumptions.
Taking a Position	Specific position is imaginative, taking into account the complexities of an issue. Limitations are acknowledged and other viewpoints are synthesized with position.
Forming Conclusions	Accurately identifies logical conclusions and implications. Provides an objective reflection and informed evaluation, with supporting evidence of own/others' viewpoints.

Results

Effect of the Critical Thinking Module on Critical Thinking Pre-/Post- Test Scores

The Wilcoxon signed rank test, a non-parametric complement of the paired t-test, was used to compare median values of the pre- and post- scores on the CCTT-Z based upon the total raw number correct. Of the combined student data for those completing both the pre- and post-tests, there was a trend favoring gains in scores at the end of the units ($p = 0.0655$; $n = 62$; $\alpha = 0.05$) (see Table 3 and Figure 1).

Table 3. Descriptive statistics of raw critical thinking scores (3 course sections combined)

	N	Mean	Std. Deviation	Median	Minimum	Maximum
Pre-Score	62	25.93	3.88	28.25	16	36
Post-Score	62	26.82	4.57	30.25	12	34

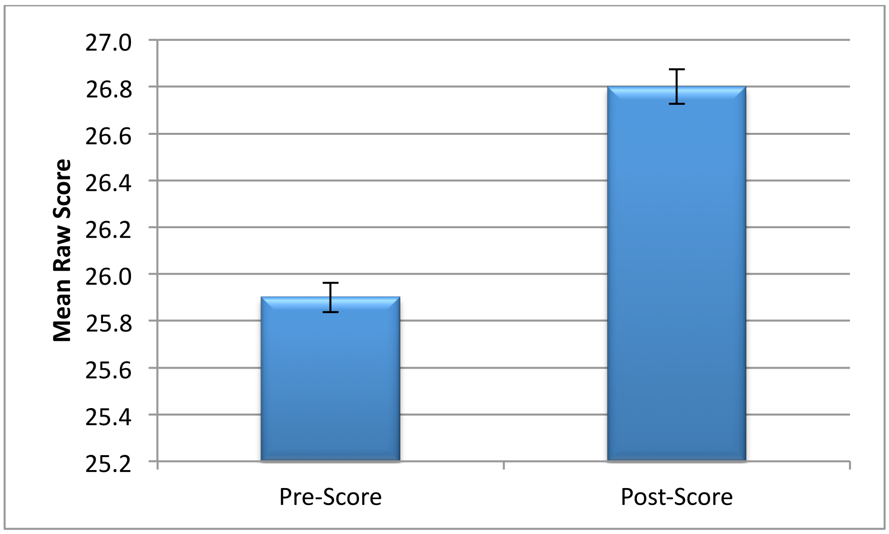

Figure 1. Effect of the critical thinking module on mean critical thinking scores (3 course sections combined)

To determine whether critical thinking score gains varied by course section, the same statistical procedures as described above were used to analyze data by course section (see Figure 2 and Table 4). All sections experienced raw gains in scores at the end of the module, with sections MA and MB experiencing trends toward significance ($p = 0.185$ and $p = 0.123$, respectively).

To provide insight into whether there were particular subscales within the CCTT-Z that students appeared to improve upon during module, scores were next analyzed by CCTT-Z category and results suggested that scores increased within the Meaning subscale (see Figure 3). No correlation was found between critical thinking test gains and final course grades. Of the 24 males and 38 females who took both pre- and post-tests, there was no apparent correlation between test gains and gender.

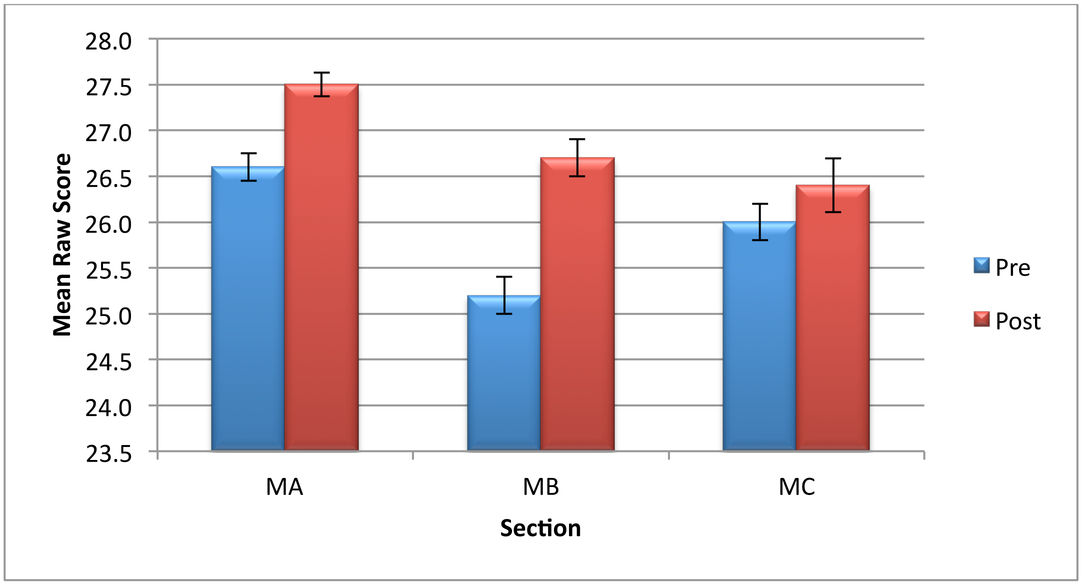

Figure 2. Effect of the critical thinking module on total raw critical thinking scores by section

Table 4. Effect of the critical thinking module on mean critical thinking gains by section

Section	n	Raw Gain
MA	20	0.9
MB	21	1.7
MC	21	0.3

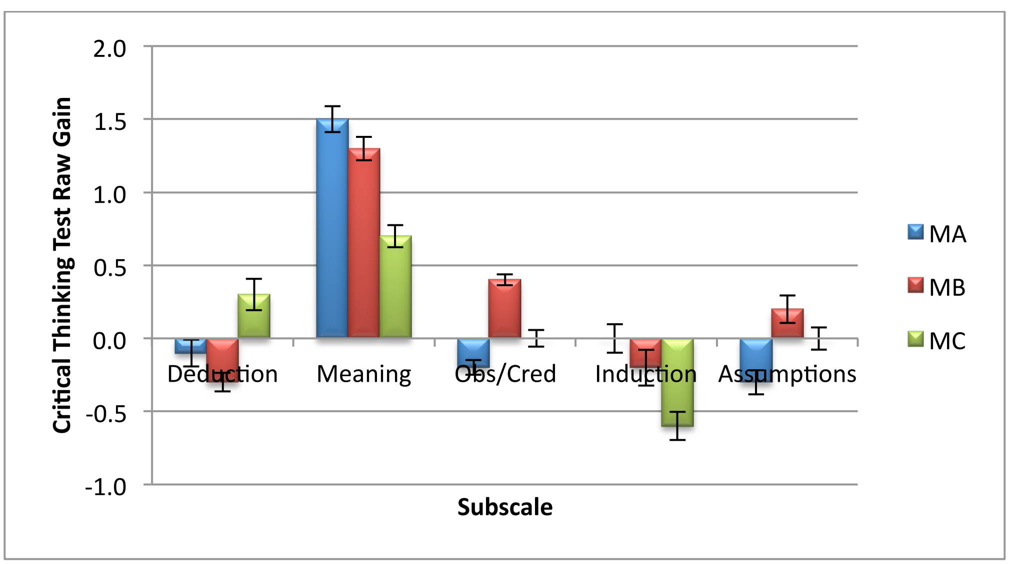

Figure 3. Effect of the critical thinking module on subscale score gains by test section

Effect of Critical Thinking Module on Ability to Analyze Scientific Claims

Pre- and post-essays scores from section MA were analyzed using the Wilcoxon signed rank test (alpha = 0.05). Section MA (n= 24) showed an improvement in student abilities to analyze scientific claims, notably in the area of analyzing evidence to support claims ($p = 0.004$) (see Figure 4). These findings complement the previously described critical thinking test findings where students demonstrated further capabilities for uncovering illogical thinking.

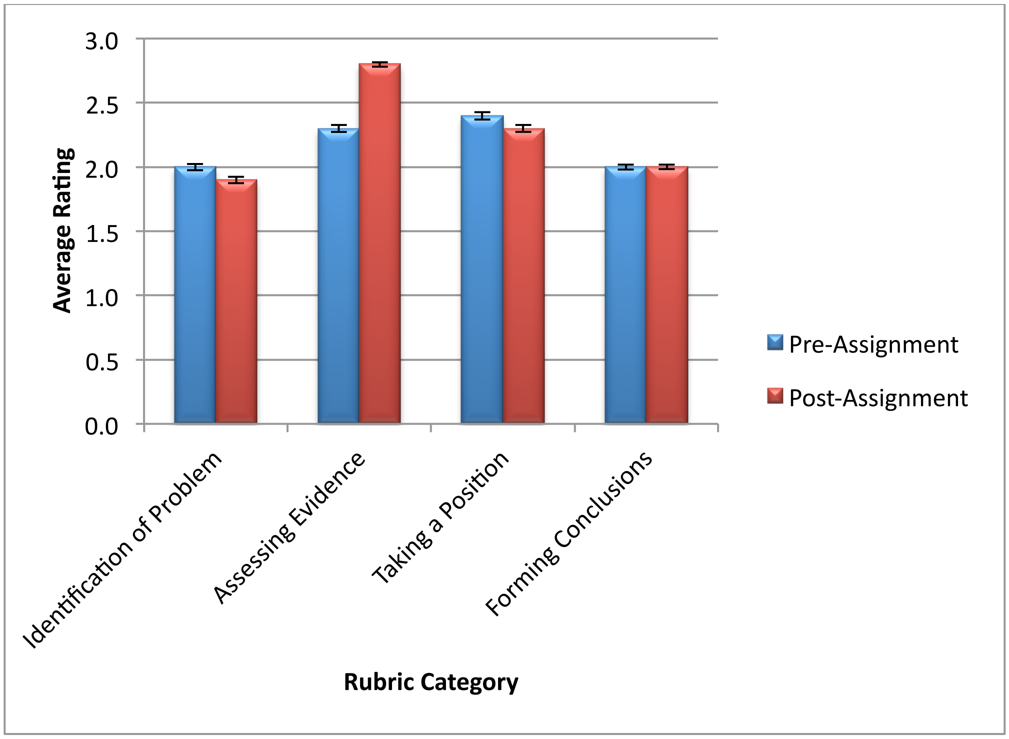

Figure 4. Analysis of scientific claims writing assignments pre-/post-comparison

Student Perceptions of Critical Thinking Gains

At the end of each unit, the students were invited to complete an anonymous evaluation to capture their perceptions of whether the module enhanced their critical thinking abilities. A majority (71%) of students perceived that they were better critical thinkers after the unit (n=79) (see Figure 5). Students who did not perceive the unit as having enhanced their critical thinking skills provided a variety of reasons including the belief that critical thinking was not something that could be taught, that the unit was too brief for them to fully develop into a better critical thinker, and the preference for less critical thinking taught within the course.

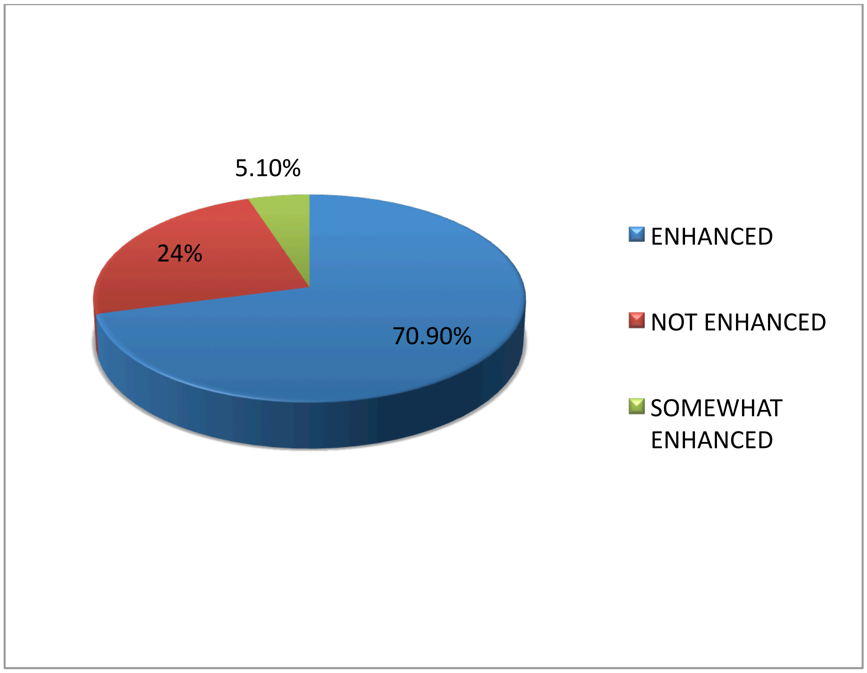

Figure 5. Student perceptions of enhanced critical thinking skills after course module

Discussion

The goal of this study was to determine whether a four-week critical thinking-based module in an introductory biology course could enhance students' critical thinking abilities. Pre- and post-scores on a standardized critical thinking test revealed a trend favoring enhanced critical thinking abilities. Furthermore, students within one course section showed a documented increase in their abilities to analyze evidence in scientific claims made within articles in the popular press. The results from the standardized critical thinking assessment corroborate the scientific claims writing data in that students experienced gains in the "Meaning" subscale which tests for the ability to identify fallacies in the statements given. These results suggest that the learning environment promoted this particular reasoning skill. The writing samples encouraged students to identify fallacies in scientific claims, enabling the most practice within this particular competency, possibly contributing to the higher scores within this subscale. Informally, a few students described other areas (*e.g.* deductive and inductive reasoning) to be more challenging to comprehend and apply, providing additional support as to why these other subscales likely did not experience higher gains.

With regards to students' perceptions, most upheld that the modules were of benefit to their development as critical thinkers. Thus, not only did students' scores show that their skills were improving, they also perceived of themselves as being better critical thinkers.

These findings support the notion that even short-term learning experiences involving critical thinking embedded within curriculum can encourage students' higher order thinking. The results are consistent with the literature suggesting that critical thinking skills can be improved over time with practice (Zohar & Tamir, 1994). They corroborate studies reporting that writing can help enhance students' critical thinking skills through the evaluation of scientific claims (Quitadamo & Kurtz, 2007; Rutledge, 2005; Tyser & Cerbin, 1991). Future research should entail extending this learning environment over an entire semester or academic year, where one would hypothesize even further gains in students' critical thinking capabilities using the flipped classroom teaching method. As the module within this course was brief, further research should be directed at whether students retain their critical thinking competencies at later time points and can transfer them to other disciplines. Because this was a team-taught course and the other instructors did not use the same teaching method as the lead author, a control group was not utilized to ensure equity in experience across teaching sections, but such an experimental design should be employed in future research.

Critical thinking is an essential skill for students to learn within and outside of the sciences. Unfortunately, many students are not developing these aptitudes in their early undergraduate years (Arum & Roska, 2011; Arum et al., 2012). In this digital age where instruction is directly influenced by advances in technology such as OpenCourseWare, lecture recordings and more, our study highlights one avenue through which critical thinking can be embedded within general education biology courses to encourage the development of students as productive citizens.

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