Supplemental Material

CBE—Life Sciences Education

Lie *et al.*

SUPPLEMENTAL MATERIALS

Supplemental figure legends

Supplemental Figure S1. Students' demographics based on an anonymous pre-course survey. *n* = 69 students. (A) Quarter in the Master's program. (B) Students' ethnicity (C) Frequencies of students' responses to the question "How have you previously been exposed to reading scientific papers? Select all that apply". Response choices are shown on the Y axis. (D) UCSD biology major affiliations as an undergraduate.

Supplemental Figure S2. Category of challenges described in individual quarters: (A) Fall 2012, (B) Winter 2013, (C) Fall 2013, (D) Winter 2014.

Supplemental Figure S3. Number of challenges aligned with Lower Order Cognitive Skills (LOCS) and Higher Order Cognitive Skills (HOCS), in individual quarters: (A) Fall 2012, (C) Winter 2013, (E) Fall 2013, (F) Winter 2014. Number of challenges at the given Bloom's level in individual quarters: (B) Fall 2012, (D) Winter 2013, (F) Fall 2013, (H) Winter 2014.

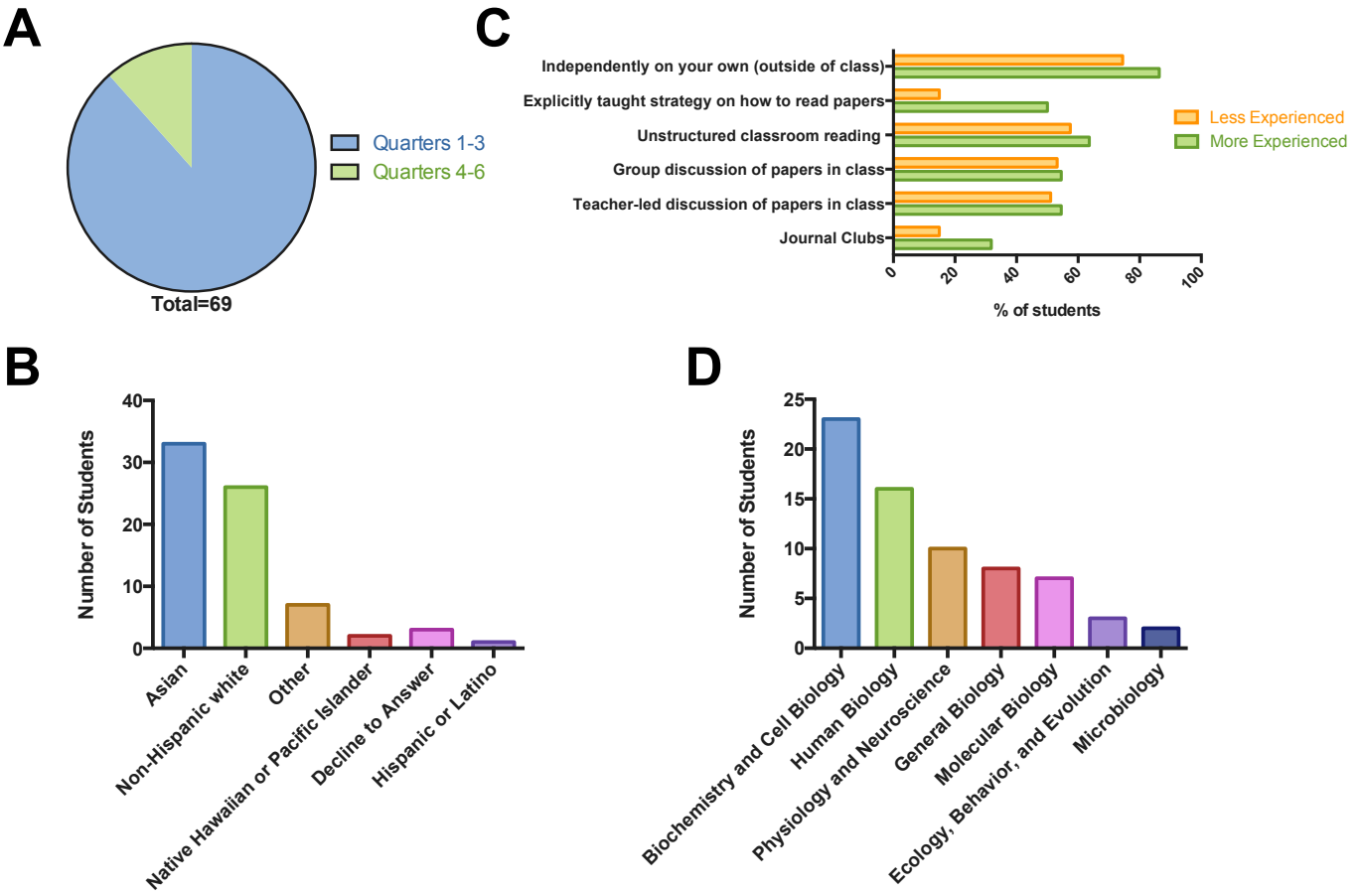
Supplemental Table S1. Association of the demographics variables with being in the more experienced group. Year in Program was designated as a binary variable: year 1 (quarters 1-3) or year 2 (quarters 4 and higher). GPA was also analyzed as a binary variable, where the 3.5 was used as cut-off for deciding high versus low GPA. Relative risk indicates the relative probability of being in the more experienced reader group for the stated condition versus the opposition. For example, second-year students are 20.4% more likely to be in the more experienced reader group. Relative risk was calculated as follows: Relative Risk = probability of being more experienced reader ("prob_more") / probability of being less experienced reader ("prob_less"). Odds ratio was calculated as follows: Odds Ratio = odds_more / odds_less, where odds_more = prob_more / (1 - prob_more) and odds_less = prob_less / (1 - prob_less). Statistical analysis was performed using a paired t-test followed by the Benjamini-Hochberg false discovery rate correction for multiple comparisons.

Appendix A: Description of the rater's determination of Bloom's level of the described challenges with primary literature.

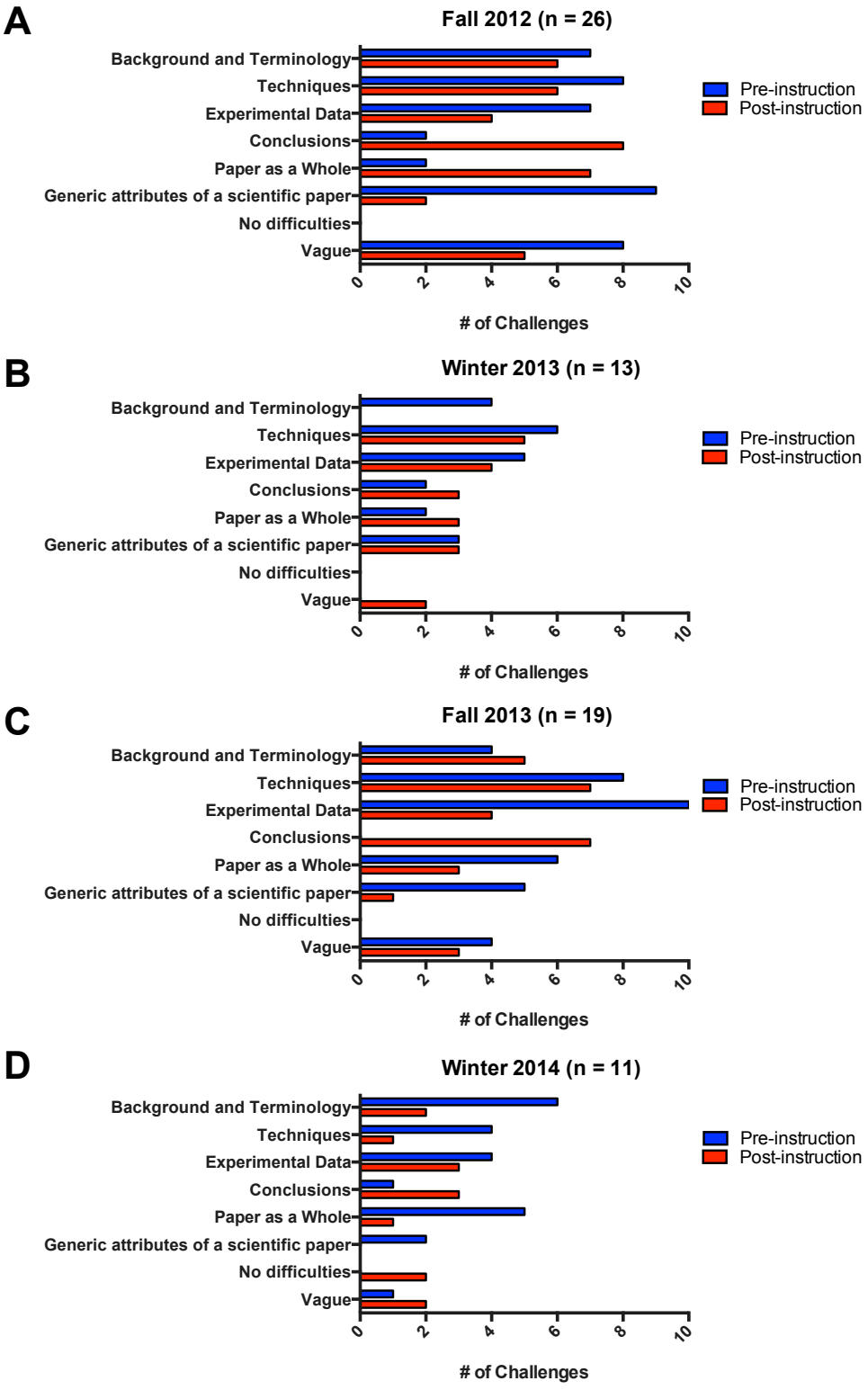
Appendix B: List of papers used in the Fall 2013 and Winter 2014 quarters.

Appendix C: Pre-/Post-Survey Questions

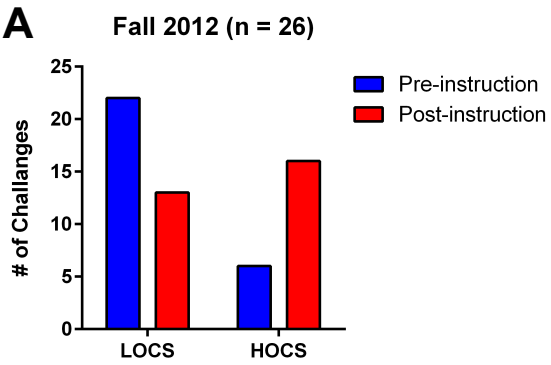
Supplementary Figure S1

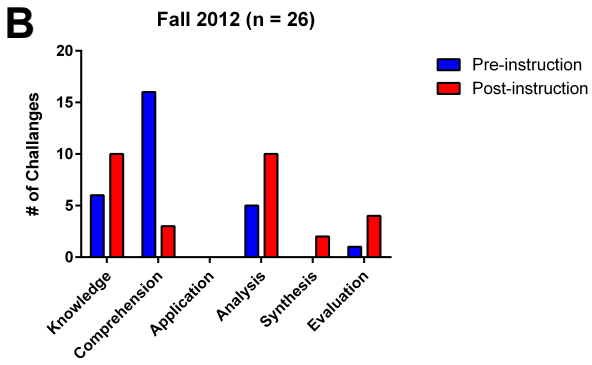


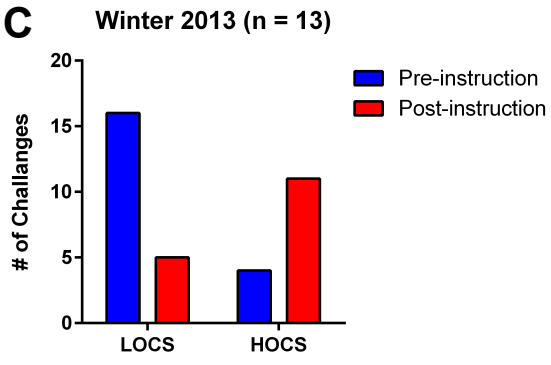
Supplementary Figure S2

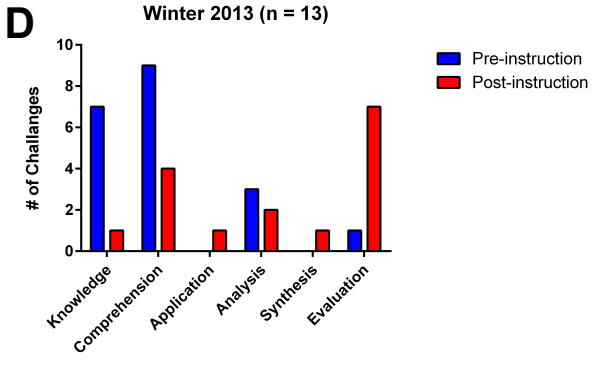


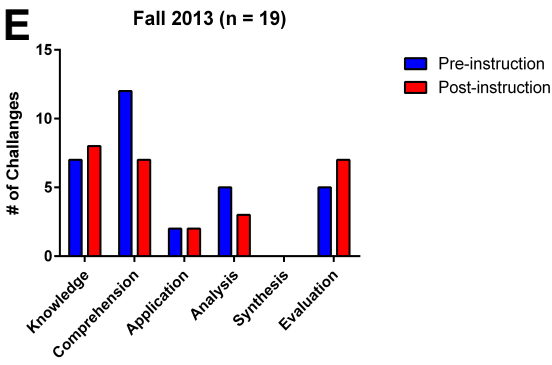
Supplementary Figure S3

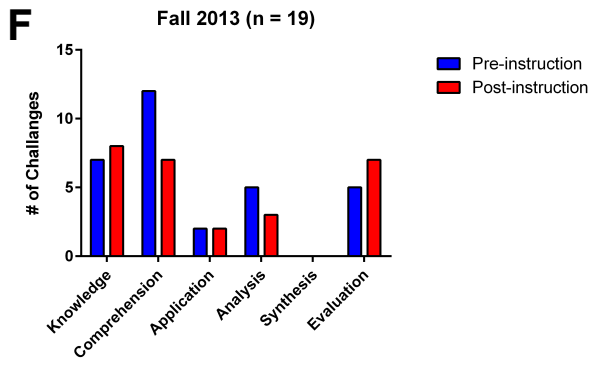


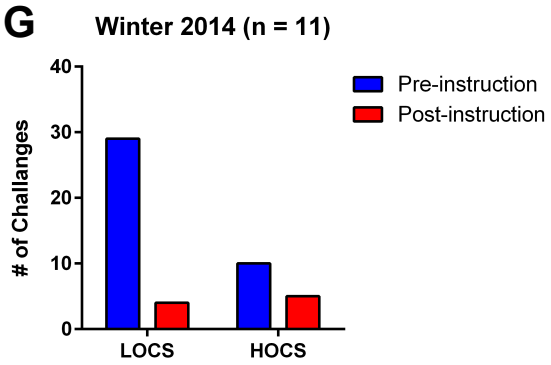


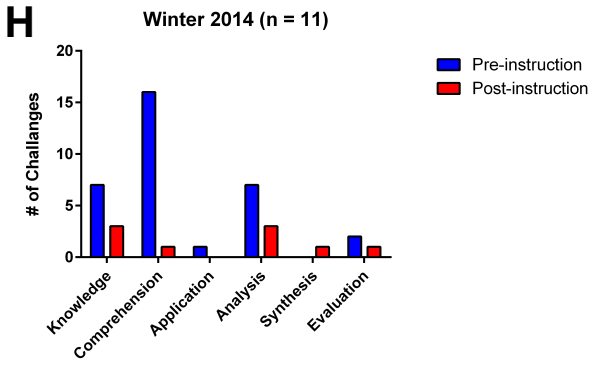












Supplemental Table S1.

Students' demographics	Relative Risk	Odds Ratio	*p value*	Benjamini-Hochberg FDR *p* value
Being in the second year in the program	1.102	1.321	0.703	0.980
Ethnicity	NA	NA	0.061	0.264
GPA (having a GPA higher than 3.5)	0.557	0.224	0.072	0.264
Gender (being female)	0.724	0.429	0.442	0.810
Undergraduate major	NA	NA	0.959	1.000
Previous exposure to scientific papers				
Independently on your own outside of class	1.234	2.149	0.355	0.781
Explicitly taught strategy on how to read papers	1.868	4.636	0.014	0.154
Unstructured classroom reading	1.085	1.291	0.793	0.980
Group discussion of papers in class	1.018	1.055	1	1.000
Teacher-led discussion of papers in class	1.045	1.148	0.802	0.980
Journal Club	1.586	3.129	0.096	0.264

Appendix A: Determining the Bloom's level of difficulties with primary literature

After categorizing the difficulties described in students' responses, three raters (C.A., R.L., and E.T.) independently rated each of the difficulties described in each of the students' responses. The verbs students used to describe the difficulties were very important in determination of its Bloom's level. Table 2 in the main manuscript provides the verbs frequently used in students' responses and their assigned Bloom's category. However, the context in which the verb was used in students' response was important as well, as demonstrated in the student's response rated at Application level in Table 2. At times, students did not use verbs to describe the difficulties. In these cases, no Bloom's level was assigned to the difficulty, except for the following instances:

1. In the absence of a verb, terminology and background difficulties were always coded as Bloom's Knowledge - level difficulty. Often, students used the expressions "unfamiliar background" or "unfamiliar terminology", which further supported our view that these are Knowledge-level difficulties.
2. In the absence of a verb (or if the verb used was vague), "Scientific language/writing style" difficulties were coded as Comprehension – level difficulties. Examples of such difficulties included "sentence structure" and "getting past the language".

Examples of students' responses containing difficulties at different Bloom's levels are shown in Table 2.

In identifying the Bloom's levels of "Experimental data" challenges, we differentiated between students' responses that described difficulties with *understanding* experimental data (coded as Comprehension) and *interpreting* or *analyzing* experimental data (coded as Analysis). The distinction between Comprehension and Analysis is not always clear in the relevant literature (Bloom et al., 1956, Anderson et al., 2001, Crowe et al., 2008). For example, according to Anderson and colleagues, Comprehension contains activities of

Interpreting and Inferring, while Crowe and colleagues place Inferring in Analysis category (Anderson et al., 2001, Crowe et al., 2008).

How to reconcile this apparent contradiction? Anderson and colleagues emphasize:
"The process categories of Understand, Analyze, and Evaluate are interrelated and often used iteratively in performing cognitive tasks. At the same time, however, it is important to maintain them as separate process categories. A person who understands a communication may not be able to analyze it well. Similarly, someone who is skillful in analyzing a communication may evaluate it poorly". (Anderson et al., 2001, p. 80). Furthermore, Anderson and colleagues provide a crucial clarification on how to distinguish Comprehension from Analysis (italics are our additions to clarify which Bloom's category the authors are referring to): "Attributing *(Analysis)* is broadly applicable to situations in which one must "read between the lines", especially when one is seeking to determine an author's point of view. Inferring *(Comprehension),* on the other hand, occurs in a context that supplies an expectation of what is to be inferred. Alternative terms for inferring are extrapolating, interpolating, predicting, and concluding" (Anderson et al., 2001, p. 74).

Applied to the activities associated with primary literature, we reasoned that understanding the data shown in a figure does not necessarily imply critical analysis of the figure or an attempt to draw an independent conclusion and is, therefore, a Comprehension-level challenge. Likewise, understanding the connection between a hypothesis proposed by the authors and the experiment they perform to test this hypothesis is not, in our minds, a HOCS-level activity, because the difficulty is in *understanding the ideas already outlined by the authors in the paper*, not in, for example, evaluating how well the experiment supports or refutes the hypothesis. Therefore, challenges of this nature were coded as Comprehension-level challenges, whereas challenges where students wrote about interpreting or analyzing the data were coded as Analysis. However, we are aware of that our students may not use the terms "interpret" or "analyze" data in the same way we do, and we discuss this limitation in the Discussion section of the main manuscript.

Appendix B: List of papers used in Fall 2013 and Winter 2014

Fall 2013

Paper 1 (flawed)

Naski MC, Wang Q, Xu J, Ornitz DM (1996) Graded activation of fibroblast growth factor receptor 3 by mutations causing achondroplasia and thanatophoric dysplasia. Nat Genet. *13(2):* 233-7.

Paper 2 (exemplary)

Macfarlan TS, Gifford WD, Driscoll S, Lettieri K, Rowe HM, Bonanomi D, Firth A, Singer O, Trono D, Pfaff SL. (2012) Embryonic stem cell potency fluctuates with endogenous retrovirus activity. Nature. *487(7405):* 57-63. doi: 10.1038/nature11244

Papers 3 and 4 (conflicting)

Lee JK, Geoffroy CG, Chan AF, Tolentino KE, Crawford MJ, Leal MA, Kang B, Zheng B. (2010) Assessing spinal axon regeneration and sprouting in Nogo-, MAG-, and OMgp-deficient mice. Neuron. *66(5):* 663-70. doi: 10.1016/j.neuron.2010.05.002.

Cafferty WB, Duffy P, Huebner E, Strittmatter SM (2010) MAG and OMgp synergize with Nogo-A to restrict axonal growth and neurological recovery after spinal cord trauma. J Neurosci. *30(20):* 6825-37. doi:10.1523/JNEUROSCI.6239-09.2010.

Winter 2014

Paper 1 (flawed)

Naski MC, Wang Q, Xu J, Ornitz DM (1996) Graded activation of fibroblast growth factor receptor 3 by mutations causing achondroplasia and thanatophoric dysplasia. Nat Genet. *13(2):* 233-7.

Paper 2 (exemplary)

Lee JK, Geoffroy CG, Chan AF, Tolentino KE, Crawford MJ, Leal MA, Kang B, Zheng B. (2010) Assessing spinal axon regeneration and sprouting in Nogo-, MAG-, and OMgp-deficient mice. Neuron. *66(5):* 663-70. doi: 10.1016/j.neuron.2010.05.002.

Papers 3 and 4 (conflicting)

Ronshaugen M, McGinnis N, McGinnis W (2002) Hox protein mutation and macroevolution of the insect body plan. Nature *415(6874):* 914-7

Gallant R, Carroll SB (2002) Evolution of a transcriptional repression domain in an insect Hox protein. Nature *415(6874*): 910-3

Appendix C:

Pre-instruction Survey

*These items were incorporated only during Fall 2013 and Winter 2014 surveys

1. Please enter the last four digits of your cellphone number (or a primary phone number). This will allow us to compare your responses to this survey and the survey you will complete at the end of the class, while preserving the anonymity of your responses. (open ended response)
2. Your current quarter in the Master's program is:
    a. Quarters 1-3
    b. Quarters 4-6
3. Your ethnicity (feel free to choose one or select all that apply)
    a. Asian
    b. Black or African American
    c. Hispanic or Latino
    d. Native Hawaiian or Other Pacific Islander
    e. Non-Hispanic White
    f. Other
    g. Decline to answer
4. Your undergraduate major:
    a. Bioinformatics
    b. Biochemistry & Cell Biology
    c. Ecology, Behavior, & Evolution
    d. General Biology
    e. Human Biology
    f. Microbiology
    g. Molecular Biology
    h. Physiology & Neuroscience
5. Your gender*
    a. Male
    b. Female
6. What was your undergraduate GPA?*
    a. 3.00-3.25

b. 3.26-3.50
c. 3.51-3.75
d. 3.76-4.00

7. What are your career aspirations? Select all options you are currently considering.
    a. Physician (MD or DO)
    b. Physician Researcher (MD-PhD or equivalent)
    c. Research in academia
    d. Dentist
    e. Pharmacist
    f. Nursing
    g. Allied health professions (not physician, nurse, pharmacist, dentist)
    h. Biotechnology
    i. Teaching
    j. Other (please specify)
8. Training in critical analysis of scientific papers, data interpretation, and scientific writing are among the major goals of this course. I would like to know about your previous exposure to scientific literature. Approximately how many research papers have you carefully read and analyzed during your undergraduate and graduate studies?
    a. 1-5
    b. 6-10
    c. 11-15
    d. 16-20
    e. 21-25
    f. 26-30
    g. 31-35
    h. 36-40
    i. 41-45
    j. 45-50
    k. More than 50
9. What opportunities have you had to critically read and analyze research papers (select all that apply):
    a. Undergraduate courses (please indicate which course(s), instructor(s) in the comments box)
    b. Graduate courses (please indicate which course(s), instructor(s) in the comments box)
    c. Journal clubs (not part of a course)
    d. Lab meetings
    e. Independent reading as a part of your research
    f. N/A – haven't had such opportunities so far
    g. Other opportunities, Comments
10. How have you previously been exposed to reading scientific papers? Select all that apply.

    a. Independently on your own (outside of class)
    b. Explicitly taught strategy on how to read papers
    c. Unstructured classroom reading (papers assigned by your instructor, but not discussed in class or in sections)
    d. Group discussion of papers in class
    e. Teacher-led discussion of papers in class
    f. Journal clubs in your lab
    g. Other (please specify)
11. Which of the methods you selected in the previous questions has been most beneficial thus far?
    a. Independently on your own (outside of class)
    b. Explicitly taught strategy on how to read papers
    c. Unstructured classroom reading (papers assigned by your instructor, but not discussed in class or in sections)
    d. Group discussion of papers in class
    e. Teacher-led discussion of papers in class
    f. Journal clubs in your lab
    g. Other (please specify)
12. If you are asked to read and describe the most important experiments, their conclusions, and the overall message of a random scientific paper in biology, how confident are you in your ability to do so, on scale from 1 to 10, where 1 = not at all confident and 10 = extremely confident?
13. In order to better help you to improve your paper analysis skills, I would like to know what aspects of understanding and analyzing scientific papers do you find most challenging? (Open ended)
14. Which aspect or part of a scientific paper do you find the easiest to understand and analyze? (Open ended)
15. When you encounter an unfamiliar terminology in a scientific paper, how likely (on scale from 1-10, where 1 is not likely and 10 is very likely) are you to try to figure out what it means on your own?
16. If your answer is more than 1 on the previous question, what resources do you use? (Open ended)
17. When encountering an unfamiliar experimental technique in the Results section of a paper, how likely (on scale from 1-10) are you to try to figure out how does the technique work?
18. If your answer to the previous question is more than 1, what resources do you use? (Open ended)
19. When trying to understand and interpret a result presented in a paper, which of the following do you usually rely on? Select all resources you use.
    a. Introduction
    b. The text in the Results section of the paper that describes this result
    c. The figure or the table that presents this result, including the figure legend

    d. Materials and Methods section where the methodology of the experiment used to obtain this is described
    e. Discussion section
    f. Other papers that did related experiments
    g. None of the above
    h. Other sources, please specify which
20. What opportunities have you had to practice scientific writing?
    a. Lab report
    b. Analyses/critiques of scientific papers in undergraduate courses
    c. Analyses/critiques of scientific papers in graduate courses
    d. Writing Master's research proposal
    e. Writing a research proposal for a fellowship or a grant
    f. Participating in writing of a large-scale a grant proposal with your mentor
    g. Writing or participating in writing of a research paper or a review article
    h. Other (please specify)
21. In order to better help you to improve your writing skills, I would like to know what aspects of scientific writing do you find the most challenging? (Open-ended)
22. Please evaluate your current skills in: (Likert Scale)
    a. Interpreting data in a paper within my area of research
    b. When encountering terminology or concept you don't understand, being able to figure out what it means on your own
    c. When encountering a result obtained using a method you know little about, being able to independently figure out how the method works
    d. Independently drawing conclusions from data presented in a paper in your area of research
    e. Independently drawing conclusions from data presented in a paper outside of your area of research
    f. Critically evaluating authors' conclusions in a paper in your area of research
    g. Critically evaluating authors' conclusions in a paper outside of your area of research
    h. Proposing an experiment, with the appropriate controls, that would follow up on a paper in your area of research
    i. Proposing an experiment, with the appropriate controls, that would follow up on a paper outside of your area of research
    j. Talking about scientific ideas related to your research in public
    k. Talking about scientific ideas NOT related to your research in public
    l. Writing about topics related to your research thesis
    m. Writing about science in general

Post instruction Survey

1. Please enter the last five digits of your cellphone number (or a primary phone number). This will allow us to compare your responses to this survey and the

survey you completed at beginning of the end of the class, while preserving the anonymity of your responses. (Open-ended)

2. Please evaluate your current skills in: (Likert Scale)
    a. Interpreting data in a paper within my area of research
    b. When encountering terminology or concept you don't understand, being able to figure out what it means on your own
    c. When encountering a result obtained using a method you know little about, being able to independently figure out how the method works
    d. Independently drawing conclusions from data presented in a paper in your area of research
    e. Independently drawing conclusions from data presented in a paper outside of your area of research
    f. Critically evaluating authors' conclusions in a paper in your area of research
    g. Critically evaluating authors' conclusions in a paper outside of your area of research
    h. Proposing an experiment, with the appropriate controls, that would follow up on a paper in your area of research
    i. Proposing an experiment, with the appropriate controls, that would follow up on a paper outside of your area of research
    j. Talking about scientific ideas related to your research in public
    k. Talking about scientific ideas NOT related to your research in public
    l. Writing about topics related to your research thesis
    m. Writing about science in general
3. If you are asked to read and describe the most important experiments, their conclusions, and the overall message of a random scientific paper in biology, how confident are you in your ability to do so, on scale from 1 to 10, where 1 = not at all confident and 10 = extremely confident?
4. In this class, the following approaches were used to enhance your skills in paper analysis: written critiques (Part 1) in which you wrote about the background of the paper and analyzed three important experiments and in-class paper discussions. Thinking back about what you identified as the most difficult aspect(s) of analyzing a scientific paper in Survey #1, were these approaches helpful in addressing these difficulties? Did some of the difficulties remain unaddressed? If so, do you have suggestions how to address them? (Open-ended)
5. Rate each paper discussed on a scale from 1-10 (10 being the most difficult) after reading and analyzing it.
6. Rate each paper discussed on a scale from 1-10 (10 being the most difficult) after reading and analyzing it.
    a. Achondroplasia paper
    b. Spinal cord neurons regeneration
    c. Evolution of Ubx protein and insect body plan

7. For papers you rated as difficult (6 and higher), what was the most difficult aspect? (Open-ended)
8. Thinking back about the 4 papers we discussed this quarter, which of them did you find particularly interesting (or not - please let us know)? Discussion of which of these papers (if any) was particularly helpful to you in increasing your skills of paper analysis?
    a. Paper 1: Achondroplasia
    b. Paper 2: Spinal chord injury
    c. Papers 3 and 4: Evolution of insect body plan
9. What aspects of understanding and analyzing scientific papers do you find the most challenging now? (Open-ended)
10. Which aspect or part of a scientific paper do you find the easiest to understand and analyze?
11. When you encounter an unfamiliar terminology in a scientific paper, how likely (on scale from 1-10, where 1 is not likely and 10 is very likely) are you to try to figure out what it means on your own?
12. If your answer in Question 8 is more than 1, what resources would you use? (Open-ended)
13. When encountering an unfamiliar experimental technique in the Results section of a paper, how likely (on scale from 1-10) are you to try to figure out how does the technique work? (Open-ended)
14. If your answer in Question 10 is more than 1, what resources would you use?
15. Please evaluate the usefulness of the following approaches in enhancing your skills of scientific writing: (Likert Scale)
    a. Writing paper critiques
    b. Designing a plan of your mini-review
    c. Writing the first draft of your mini-review
    d. Obtaining the feedback on your first draft from the instructor
    e. Reading Pechenik's "A short guide to writing in biology"
    f. Reading Gopen and Swan's "The science of scientific writing
    g. Writing the final draft of your mini-review
    h. Comments (Open-ended)
16. What effect (if any) did writing of the mini-review on the topic of your thesis have on the way you think about your project or in preparing you to write your Master's thesis? (Open-ended)
17. Please comment on the work of your group. Did your group work effectively? Did working as part of the group contribute to your learning or would you prefer to work individually? Do you have any suggestions about the group work in the future? (Open-ended)
18. The amount of work in this class was
    a. Manageable, just right
    b. Barely manageable, a little too much
    c. Overwhelming, way too much

19. If there was one thing you could change in this class, what would it be? Any comments and suggestions for this class? (Open-ended)