Vitamin C for Colds? Writing LETTERS to Synthesize and Communicate Results from Multiple Studies

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Abstract

Interpreting experimental results is a key part of evidence-based reasoning. However, it is challenging for students to synthesize data from multiple sources to reach their own conclusions. As experimental design is increasingly emphasized in undergraduate biology learning, it is important that students also develop the ability to synthesize and communicate diverse experimental results. This lesson spans a class session and homework assignment asking students to interpret data from three scientific papers, synthesize the results, and write a short personal letter to communicate this synthesis. In class, a group activity scaffolds the interpretation of three different study results about the efficacy of vitamin C for preventing and treating the common cold. Students then work in new groups to synthesize these studies into a more nuanced understanding, comparing the studies' results and designs. Finally, the homework tasks students to write a short letter to a friend or loved one summarizing their synthesis into a recommendation about vitamin C use. This lesson is most appropriate for small class sizes and has been taught for both biology majors and non-majors in both introductory and upper-level courses.

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Supporting Materials: S1. Vitamin C for colds – Initial prompt; S2. Vitamin C for colds – Study 1 worksheet; S3. Vitamin C for colds – Study 2 worksheet; S4. Vitamin C for colds – Study 3 worksheet; S5. Vitamin C for colds – Prompts for study synthesis; S6. Vitamin C for colds – Homework prompt; S7. Vitamin C for colds – Supplemental discussion questions; S8. Vitamin C for colds – Answer key for in-class worksheets; S9. Vitamin C for colds – Rubric for homework; S10. Vitamin C for colds – Student work examples; S11. Vitamin C for colds – Original study worksheets; and S12. Vitamin C for colds – Resources for statistical significance.

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Learning Goal(s)

Students will:

- evaluate, analyze and explain the significance and implications of multiple related studies,
- revise an existing model based on observations or data,
- articulate study limitations and unanswered questions about experimental results,
- communicate complex scientific results to a lay audience.

Learning Objective(s)

Students will:

- analyze and interpret data about the efficacy of vitamin C supplements to treat or prevent the common cold,
- synthesize data from three different experimental studies,
- make a recommendation to a friend or loved one about using vitamin C to treat or prevent the common cold.

INTRODUCTION

Vision and Change highlighted the need for students to learn about biology as a research science, which necessitates learning to design and evaluate experiments and to communicate biological concepts to different audiences (1). Experimental research is foundational in biology and has multiple steps (2,3), including identifying a research question, defining a hypothesis, designing and implementing an experiment, analyzing data, drawing conclusions, and communicating findings. The Advancing Competency Experimentation-Bio (ACE-Bio) network has created a competency framework that sets specific expectations for each component of experimentation (3,4), and several of the learning goals for this lesson come directly from the *Communicate* petal of this framework. Assessments, lessons, and courses focusing on specific competencies can reveal practices that best help students build these skills. For example, course-based undergraduate research experiences (CUREs) can produce large self-reported gains in student research competency and attitudes towards science (5–9).

Many recently developed tools focus on assessing skills for the design of individual experiments (3, 10–14). Our activity, LETTERS (LEarners Trying To Extend, Reflect, and Synthesize), instead focuses on the synthesis of multiple biological experiments, and does so in a single class session. Students *reflect* on selected study results, *synthesize* these varied findings, and then *extend* their thinking as they compose a letter to a friend or loved one for homework. In this letter they must distill the results into a take-home message and explain how to address unanswered questions that were raised by the studies. Some prior efforts to integrate writing across a biology course include emphasis on synthesis and communication (e.g. 15–17); we designed this lesson as a resource to help students improve in these skills in a single course session and homework assignment. The lesson can be incorporated into a variety of classes, including lectures and laboratories, to build skills that are more typically learned in an extended research experience.

Lessons introducing synthesis and communication of scientific results require substantial scaffolding for students. Students need to first understand each individual scientific result, then apply the process skills of synthesis and communication. This task can be particularly challenging when the results contradict what was expected. Through experience, professional scientists learn to value rejecting hypotheses as ways to make discoveries. The lesson scaffolds this process by eliciting prior knowledge, prompting individual student responses, leveraging small-group discussion to help students refine their thinking, then asking students to teach their newly developed knowledge to a group of peers.

We use the jigsaw (18–20) format to scaffold this challenging synthesis task. To ensure that students have a strong understanding of the results of each individual study, they begin by collaboratively working in small groups to interpret a single figure. After each group develops expertise around a single figure, groups are re-shuffled so that students explain "their" study results to peers who have worked through different figures, some with qualitatively different findings (Figure 1). Jigsaws scaffold the initial interpretation, then provide further opportunity for knowledge-building as the students each take an instructional role. This allows students ample time to process and refine their understanding of the studies before they are challenged to synthesize and communicate the results of multiple studies.

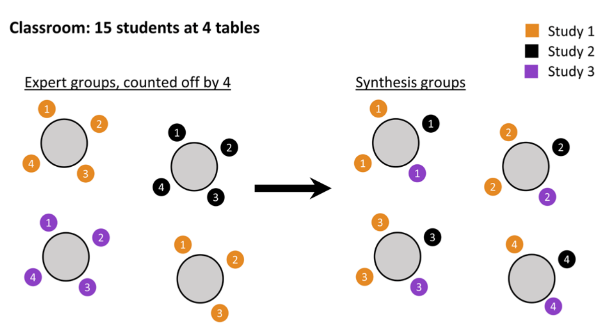

Figure 1. Transitioning from expert groups to synthesis groups. This diagram shows how students can be moved from their initial expert groups (analyzing a single study) to their subsequent synthesis groups (synthesizing the results of all three studies). In this example, there are 15 students around four tables.

We selected this topic for its real-world relevance: all of the research studies focus on the impacts of taking vitamin C to reduce the incidence, duration, or severity of a common cold (21–23). Many students are likely to have encountered claims about vitamin C and the common cold. This lesson introduces controversy because the data challenge deep-rooted, conventional wisdom about the usefulness of vitamin C in preventing and treating colds. We summarize the experimental design and present clear graphs that make the data accessible to students, even those without background knowledge in this area. Lastly, the lesson supports students as they synthesize the data with their own prior knowledge and frame the results in a personal context.

The subsequent homework comprises a short letter to offer advice to a friend or loved one. This personal connection may increase the relevance of the lesson to the students, potentially enhancing learning (24) and shaping students' scientific identities (25). The lesson's focus on personally-relevant studies with varying results can also build critical thinking and communication skills (26).

Synthesizing data from multiple studies is challenging, and this lesson's synthesis is particularly difficult because the topic we explore potentially counters prior student conceptions. However, students will make observations running counter to conventional wisdom throughout their lives, and the practice of critically evaluating contradictory evidence is a key part of scientific reasoning. Lessons spanning multiple related studies can also help students to understand the iterative nature of science, unveiling the process of how conventional wisdom can change over time (27).

Intended Audience

This activity has been taught in three different courses, each at a different institution (here described by their Carnegie Basic classification):

- an introductory biology class of mostly freshmen students with both majors and non-majors at a small, master's degree granting college,
- a sophomore-level research methods course that included students from two institutions - biology majors at a doctoral degree granting, historically black university with high research activity and public health majors at a small, baccalaureate-granting liberal arts college,
- and a junior-level course-based undergraduate research experience with both STEM majors and non-STEM majors at a large, master's degree granting university.

This lesson was designed to be implemented for a wide range of students, including students in general biology for both majors and non-majors, nursing, physiology, or research methods courses. Synthesizing data and communicating results is challenging even for upper-level undergraduates. The lesson may also be appropriate for freshmen or high school students in an advanced biology course, if the students have had some experience interpreting figures and statistical significance. Because this lesson focuses on skill-building, it may be more useful if taught early in a course to build student competencies such as experimental design, reading figures, discussing with peers, and communicating results in plain language. The lesson does not delve into the biological mechanisms of how vitamin C may impact the incidence, severity, or duration of the common cold, so it need not be tightly linked to material about human physiology, nutrition, or viruses. However, the instructor could choose to augment the lesson by doing so. The small group discussions are best suited to a class size of 30 or fewer students, ideally with a flexible teaching space in which students are organized around tables for discussion.

Required Learning Time

This lesson will take 50 minutes of class time, with the post-lesson homework assignment taking 30 minutes to an hour for students to complete. However, if time runs short, the class-wide discussion at the end could be shifted to an out-of-class reflection or tackled during a separate class session. If a teacher wants to expand this lesson for a 75-minute class session, additional emphasis could be placed on an exploration of the limitations of each study. We include examples of additional discussion questions that could be covered in student synthesis groups before the final group discussion (Supporting File S7: Vitamin C for colds – Supplemental discussion questions).

Prerequisite Student Knowledge

The content should be generally accessible and of interest to undergraduate biology students, or indeed to any undergraduates who are familiar with interpreting figures or analyzing a research study. In fact, this lesson could be implemented early in a course for freshman or sophomore students to introduce them to interpreting figures, as it takes a structured approach to breaking down the graphs. Similarly, this activity could introduce the fundamentals of study design, although the lesson would need to be modified to explicitly scaffold the study design process. The lesson will be most successful if students already have some experience thinking about the idea of statistical significance. Alternatively, the exercise can be used to introduce the idea of statistical significance, but this may take more than 50 minutes. Instructors may consider assigning introductory readings or videos about statistical significance before the lesson; we include a list of online resources in Supporting File S12: Vitamin C for colds – Resources for statistical significance.

Prerequisite Teacher Knowledge

Before teaching this lesson, teachers should be comfortable with experimental design methods, including the concepts of sample size and placebo effect, and be experienced in thinking about study limitations and the challenges of generalizing research studies. Teachers who wish for a brief refresher in statistics may use the resources discussed in the pre-requisite student knowledge section (Supporting File S12: Vitamin C for colds – Resources for statistical significance). Teachers should also know that there are limited data supporting the conventional wisdom that taking vitamin C decreases the severity or incidence of colds for the general public (28). Studies showing efficacy have focused on individuals subjected to extreme physical activity or cold (endurance runners, skiers, and soldiers), where vitamin C appears to provide approximately a 50% reduction in incidence (28). While it is possible that vitamin C provides other benefits to non-endurance athletes, this specific assignment relates to its impacts on respiratory illnesses such as colds. The three studies we selected for this lesson are all discussed in a comprehensive review paper by Hemilä and Chalker (28); this reference may serve as a useful resource for additional studies about vitamin C and colds, and provides more than enough background for an instructor to lead this lesson. An earlier review which includes the three focal studies in this lesson is available by open-access in the supplement of a short letter by Douglas and Hemilä (29). In addition, instructors may wish to consult the *CBE–Life Sciences Education* Evidence-based Teaching Guide on group work (30) to review resources for best practices in lessons that use group work.

SCIENTIFIC TEACHING THEMES

Active Learning

This lesson is entirely participatory, with no lecturing, and it is structured in the jigsaw (19) format (Figure 1). Students first work independently, thinking about their own preconceptions about vitamin C and then evaluate a figure from one of three particular research studies. They then discuss their evaluations of the data in small groups with other students who studied the same figure, using prepared questions as a guide. After students have established expertise with that material, the groups reshuffle into new groups of three or more students. Each of the three figures should be represented by at least one expert in each group. Each student presents their evaluation of their initial figure to their new groups and answers additional questions on their worksheets to guide their synthesis of results from all three studies. The in-class activity concludes with a class wide discussion. The final step of the activity is a homework assignment that each student completes independently. Students write a letter to a friend or loved one recommending whether or not to take vitamin C if they have or are getting a cold.

Assessment

This lesson includes multiple opportunities to assess student thinking. In the classroom activity, students write down answers to questions on the study worksheet (Supporting Files S2-S4: Vitamin C for colds – Study worksheets). Teachers can use these responses to evaluate if the students are interpreting the study appropriately. Because the classroom activities are organized around small group work and discussion, teachers can formatively assess student thinking throughout the class session. Finally, the letters that students write for their homework assignment (Supporting File S6: Vitamin C for colds – Homework prompt) allow teachers to assess how effectively students synthesized the results of multiple studies, how they are thinking about study limitations, and how they are generalizing and making real-world decisions based on limited data. We include examples of stronger and weaker student responses to selected prompts, worksheets, and the homework (Supporting File S10: Vitamin C for colds – Student work examples).

Inclusive Teaching

This lesson is organized around structured, small-group work. Increasing the structure of a classroom in this way benefits all students, but especially those who are first generation or racial minorities (31). The jigsaw format minimizes the chances of one student dominating conversation within a small group (32). Each course activity also begins with an opportunity for students to think through the material on their own, which ensures that students are engaged in the material before joining small groups for discussion. Finally, the synthesis groups start their discussion with a "whip around" (33) – each student sharing out their answers to their group – to ensure that each student has the chance to present.

LESSON PLAN

Pre-Class Preparation

Instructors will need to print a copy of the lesson overview (Supporting File S1: Vitamin C for colds - Initial prompt) and the three worksheets (Supporting Files S2-S4: Vitamin C for colds - Study worksheets) for each student. Some instructors might find it beneficial to print each figure/worksheet on a different colored piece of paper to keep track of group organization in the jigsaw. The instructor will also need to have the synthesis questions available for students: either written on a board, projected, or printed out on paper (Supporting File S5: Vitamin C for colds - Prompts for study synthesis).

Classroom activities

Introduction and expert group work

To begin, divide students into at least three groups of 2-4 students each. We will refer to these groups as expert groups, as they will work together to build expertise about a particular study. After students are in their groups, hand out the lesson overview (Supporting File S1: Vitamin C for colds - Initial prompt). Briefly introduce the structure of the lesson, explaining that students will first develop expertise to explain a result from a single study. Encourage their engagement by emphasizing that they will then be an essential participant in a synthesis group, helping their peers understand this study result and learning the main takeaways from students who had focused on a result from a different study. Prompt students to answer the overview questions by themselves for three to five minutes. Then, encourage them to share within their groups, revising their answers as necessary.

As students are checking in with their group members, hand out the worksheets with figures to interpret. Each expert group will receive a figure from a single study (from Supporting Files S2-S4: Vitamin C for colds - Study worksheets) to work through as a team. Every member within a group should have the same example. Minimally, there should be three groups: one group with Example 1; one group with Example 2; and one group with Example 3.

Each 2-page worksheet outlines a different blinded, randomized, placebo-controlled study of the impact of taking Vitamin C on either the duration or severity of the common cold. All studies are real, and the figures presented accurately reflect the results that were presented in peer-reviewed publications, with the appropriate citations. Of note, the results were presented in tabular format; the authors of this publication created visual figures using that tabular data. Students are instructed to read through their example, then work through questions that assess comprehension of the study and figure. Prompts also ask students to relate this information to their prior thinking, and to reassess their conclusions about Vitamin C and colds.

This worksheet should take about 10 minutes for students to complete, and the instructor can informally assess student understanding by listening to students' small group discussions. Depending on the students' experience with data interpretation, they may need help understanding how to interpret significant and non-significant results.

Synthesis group work

Once the expert groups are comfortable with the data they have analyzed, the instructor re-distributes students into synthesis groups. These new groups should include at least one expert student for each of the three figures. To create the groups, choose the number of synthesis groups you would like to create, and ask students to count off by that number. Create the synthesis groups from students with shared numbers. For example, with 16 students who were originally around 4 tables, you may want to form 4 synthesis groups, thus asking students to count off by 4. Because students will be counting off adjacent to others within their original example group, they will mostly be divided into different synthesis groups. This works with as few as 6 students at three tables (starting with 3 expert groups of 2 students each, and ending with 2 synthesis groups of 3 students each), and you have some flexibility about the size of your synthesis groups depending on classroom space and number of tables. Figure 1 presents an example of the transition from expert groups to synthesis groups.

After the synthesis groups are formed, prompt students to "whip around" (33) their group, with each student sharing the details of their study and the overall results. In a whip around each student shares a concise response (here summarizing their study result to their group). Whip arounds create space for every student to participate and can also be a powerful tool for informal formative assessment. After this is complete (about 5 minutes), hand out the full set of all three worksheets to all students. Instruct students to complete the other two worksheets individually in 5-10 minutes. Instructors could also do this more fluidly, by combining the whip around with student conversation about the worksheet prompts for each study or by having the groups collectively complete only one shared set of the three worksheets. However, for simplicity we present our lesson plan and timeline assuming each student will complete and turn in all worksheets.

To guide a more explicit conversation about synthesizing results from multiple studies, the synthesis prompts (Supporting File S5: Vitamin C for colds - Prompts for study synthesis) should either be written on a board, projected on a slide, or handed out to each group as a half-sheet of paper. These questions prompt students to compare the three studies, analyze why the results differ, and reflect on the limitations and benefits of different study approaches. Ask students to take 2 minutes to reflect on their own, then use 8 minutes to talk through these questions with their group. Depending on available class time, these small group discussions and the ensuing full class discussion could be expanded in length. Additional discussion questions related to specific details of each study are found in Supporting File S7: Vitamin C for colds - Supplemental discussion questions. If instead there is limited remaining class time, the synthesis prompts could be converted to a short, written reflection for students to complete after class.

Full class discussion

When you overhear groups having worked through all the prompts, bring the class together for an open discussion. To ensure a diversity of voices during discussion, consider asking students to take one minute to silently organize their thoughts, then elicit multiple raised hands before starting the discussion. At the conclusion of this discussion, collect all three study worksheets (Supporting Files S2-S4: Vitamin C for colds - Study worksheets) to assess for completion. We did not assess responses to the synthesis questions (Supporting File S5: Vitamin C for colds - Prompts for study synthesis).

Homework

In the homework assignment (Supporting File S6: Vitamin C for colds - Homework prompt), students are asked to compose a short letter, fewer than 250 words, to a friend or loved one recommending whether or not to take a vitamin C supplement when they have a cold. This is an opportunity for students to synthesize the three results in their own words, and reflect on how these disparate results can be combined for a more nuanced understanding of the effects of vitamin C. By taking the form of a letter, it encourages students to imagine bringing this new knowledge to bear on their own real-life thinking and organize their knowledge to be convincing and comprehensible to a non-technical audience. Prior to receiving the homework assignment, each student should have access to all three original figures (Supporting Files S2-S4: Vitamin C for colds - Study worksheets).

Assessment

Instructors should consider their own goals when deciding how to assess the homework. For example, if students struggle with correctly interpreting the individual figures, instructors may want to give a separate grade for interpreting individual figures prior to grading the synthesis letter. Additionally, interpreting the synthesis results can be challenging. If instructors want students to only provide advice that has supporting positive evidence, they should explicitly tell the students this, and a correct answer means that a student cannot recommend taking vitamin C without the qualification that the target individual is engaged in long-distance running or some comparable endurance activity. However, instructors might also consider the value of encouraging students to use the limitations to discuss why a particular piece of data might not make them change their mind. For example, a study with a small sample size with unknown demographics might not be relevant to a particular group of individuals. Or a student might mention that vitamin C may not prevent or treat colds, but it has other benefits and should be taken for those reasons.

We include a potential rubric (Supporting File S9: Vitamin C for colds - Rubric for homework) for evaluating the homework letter. This rubric arose from reviewing a range of student responses in light of the lesson's learning goals. Different criteria are scored with as one, two, or three based roughly on the SOLO taxonomy categories of prestructural/ unistructural, multistructural, or relational, respectively (34). In this framework, higher scores for a criterion correspond to a more integrated response in which students can generalize to new scenarios and demonstrate an understanding of how individual aspects are interrelated. For example, a response that scores highly on the criterion "*Articulate limitations and outline potential future studies*" would not only discuss a future study, but clearly relate it to limitations and open questions arising from the studies they analyzed in class. However, this rubric was designed only after the lesson was taught, so you may find it needs revision to be useful for your own assessment goals. Two examples of student work, along with a discussion of how their homework letter might be evaluated using the rubric, are included in Supporting File S10: Vitamin C for colds - Student work examples. Clicker questions or some sort of pre-post assessment could be used to more directly measure the impact of the lesson on student learning.

However, our goal is not to change students' minds about the efficacy of vitamin C; rather our goal is to help students form evidence-based recommendations. It is how they explain the recommendation that is the more important component of the synthesis exercise than whether they recommend vitamin C or not. Author KMB used this exercise to introduce the idea of synthesis; students later wrote a formal research paper in which they had to synthesize data from multiple studies to introduce what was already known about the topic as well as to explain their results in the context of what is already known. Because students were not tested on their synthesis ability in a pre-post manner, we cannot assess the efficacy of our lesson from that standpoint. In our lesson implementations thus far, we have evaluated the homework in varied manners across institutions - ranging from measuring effort only to measuring reasoning associated with their conclusion.

TEACHING DISCUSSION

Students identified an array of potential limitations to each study. However, one of the challenges that scientists encounter when synthesizing results from different studies is that the populations studied and response variables measured may differ. These differences can confound direct comparisons. Our lesson plan, as written, does not explicitly direct students to compare the samples and response variables of these three studies. Additional study-specific questions may encourage a deeper exploration, such as those included in Supporting File S7: Vitamin C for colds - Supplemental discussion questions. These questions could be used as prompts when discussing with students, or a subset of them could be added directly to the worksheets. Even without these questions, the homework letters revealed rich exploration of study limitations as students were asked to explain what they thought should be studied next. Limitations discussed included issues of dosage, participant demographics and behavior, self-reporting, and the studies' lack of measurements that assessed potential mechanistic underpinnings of a treatment effect. We only analyzed the work of consenting students for all analyses presented in this discussion. This research was approved by the Institutional Review Board of Crown College (protocol not numbered) and ruled exempt by the Institutional Review Boards of UW Bothell (STUDY00005822) and NC A&T (19-0004).

Although the jigsaw structure did help to scaffold the interpretation of the figures and their corresponding studies, evaluating the meaning of any particular mean difference in the study figures proved challenging for many students. Some students were prone to interpreting small, non-significant differences as potentially meaningful. This lesson might be particularly useful if it is used soon after coursework related to reading figures and evaluating data. This could minimize the variation in student preparation for interpreting the statistical significance of a result. We note that the individual study worksheets (Supporting Files S2-S4: Vitamin C for colds

- Study worksheets) have been modified after the initial year of teaching this lesson in order to explain non-significance in more detail, and to prompt the students more directly to think about statistical significance in their interpretation of the results. The original worksheets are also available (Supporting File S11: Vitamin C for colds - Original study worksheets).

We also found that, while some students rejected conventional wisdom based on the results presented, others continued to recommend that vitamin C be used to prevent or minimize the effects of colds. Some students made the case that even a small chance of a benefit might be worth the minor cost and lack of detrimental side effects of vitamin C supplements. Others were not comfortable modifying their behaviors based solely on these few studies that have substantial limitations. An important reminder for teachers is that the goal of this assignment is not to change what students think, but rather teach them how to critically evaluate and synthesize disparate data and to apply that information to everyday life decisions. A more explicit prompt could be built into the homework to clarify exactly how students were reconciling these outside factors with the study results. For example, a potential sentence in the homework prompt could be added - "Please explain how you are synthesizing these results with your prior understanding to reach your final recommendation."

In summary, we have found that this lesson is effective at introducing students to the challenges of synthesizing data from different papers. Moreover, students explore primary data that contradict conventional wisdom, collaborating with peers to reconcile these results with their prior conceptions and then communicate their synthesis in writing. Students work to explain their interpretation of the data in a letter to a friend or loved one. Some conclude that the data presented here indicate that taking vitamin C lowers the incidence of colds in ultramarathon runners, but not in the general public. Some students recognize that none of these data support the conclusion that vitamin C minimizes the severity of colds. These conclusions are understandably harder for other students to reach. Learning how to synthesize data takes practice.

SUPPORTING MATERIALS

- S1. Vitamin C for colds – Initial prompt
- S2. Vitamin C for colds – Study 1 worksheet
- S3. Vitamin C for colds – Study 2 worksheet
- S4. Vitamin C for colds – Study 3 worksheet
- S5. Vitamin C for colds – Prompts for study synthesis
- S6. Vitamin C for colds – Homework prompt
- S7. Vitamin C for colds – Supplemental discussion questions
- S8. Vitamin C for colds – Answer key for in-class worksheets
- S9. Vitamin C for colds – Rubric for homework
- S10. Vitamin C for colds – Student work examples
- S11. Vitamin C for colds – Original study worksheets
- S12. Vitamin C for colds – Resources for statistical significance

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Table 1. Vitamin C for colds? Teaching Timeline

Activity	Description	Time	Notes
Preparation for Class			
Print and prepare all materials	1. Print the lesson overview (Supporting File S1). One for each student. 2. Print the study worksheets (Supporting Files S2-S4). Each student will need a copy of each sheet. It may be helpful to use a different colored paper for each study. 3. Prepare to present synthesis questions from Supporting File S5. The instructor may print, project, or write them on the board.	10 minutes	
Class Session			
In-Class Startup	1. Divide students into at least 3 groups of 2-4 students. 2. Hand out lesson overview (Supporting File S1), introduce lesson, and instruct students to answer the questions individually.	5 minutes	It is critical that you have at least three groups, to ensure that all three study figures will be analyzed.
Expert Individual Work	1. Encourage students to share their responses with peers while handing out the study worksheets (Supporting Files S2-S4). 2. Create expert groups: each group will receive just one study worksheet (S2, S3 or S4). If you used different colored paper for each study, then students in the same group will have the same color paper. 3. Direct students to complete the sheets individually.	10 minutes	Make sure that students take some time to think by themselves and work through the questions before they start discussing their responses.
Expert Group Discussion	1. Direct students to discuss their responses within groups.	5 minutes	
Transition to Synthesis Groups	1. Organize students into synthesis groups. Each group should have at least one expert for each experiment. If you used different colored paper for each study, then students in the same group should now have mostly different colored papers.	2 minutes	
Synthesis Whip-around	1. Once the synthesis groups are organized, prompt students to whip-around, with each student sharing their study. 2. While students are talking, hand out the additional worksheets so that each student now has a copy of all three study worksheets (Supporting Files S2-S4).	5 minutes	Individual student expertise is critical to the learning benefits of jigsaw lessons, so be sure that each expert has an opportunity to share their initial interpretations before all students get copies of all the study worksheets.
Synthesis Individual Work	1. Direct students to complete the worksheets individually.	8 minutes	
Synthesis Group Discussion	1. Direct students to discuss their responses within groups. 2. Hand out, project or write synthesis questions (Supporting File S5). 3. Direct students to discuss the questions as a group (both this discussion and the following class-wide discussion could be expanded, time permitting).	10+ minutes	
Class-wide Discussion	1. Direct brief class discussion with the entire class. 2. Collect all three study worksheets for each student at the end of class.	5+ minutes	Supporting File S7 has additional questions to prompt deeper explorations of study limitations.
Homework			
Letter to a Friend	Assign letter (Supporting File S6). Ensure that you also provide study worksheets (Supporting Files S2-S4) so that students can use them for reference.	30-60 minutes	Estimated time refers to expected student time to complete assignment.