RESEARCH ON LEARNING

Building Argumentation Skills in the Biology Classroom: An Evolution Unit That Develops Students' Capacity to Construct Arguments from Evidence

SHEILA A. HOMBURGER, DINA DRITS-ESSER, MOLLY MALONE, LOUISA A. STARK

Abstract

Arguing from evidence is one of eight key science practices in which students should engage. It is an essential component of science, yet students have difficulties with this practice. We describe a scaffolded claims-evidence-reasoning (CER) argumentation framework that is embedded within a new eight-week, freely available curriculum unit developed by the Genetic Science Learning Center – Evolution: DNA and the Unity of Life. *The scaffold provides high school students with practice in both developing and evaluating written arguments. It is designed to incrementally build student skill week-by-week, starting with an introduction to the CER components of an argument, and ending with students evaluating data and constructing a supported written argument. We also present evaluation findings from field testing the argumentation scaffold in the context of the complete* Evolution *unit in dozens of classrooms. And we discuss how this integrated, scaffolded approach to argumentation influenced both student and teacher learning.*

Key Words: *biology; evolution; science practices; NGSS; argumentation; high school.*

○ Introduction

Building arguments from evidence is a central component of science. The authors of the *Next Generation Science Standards* (NGSS; NGSS Lead States, 2013) agree: they included it as one of eight key science practices in which students should engage. Further, research has shown that when argumentation is an explicit part of instruction, students better understand science concepts (Osborne, 2010).

The benefits of including argumentation are evident in evolution (Catley et al., 2005) and genetics (Zohar & Nemet, 2002) instruction. For example, students who engaged explicitly in argumentation showed significantly improved learning gains and retention of evolution concepts (Asterhan & Schwarz, 2007). In a genetics unit that included argumentation, students scored significantly higher than the comparison group in both genetics and argumentation (Zohar & Nemet, 2002). Yet, despite its importance, this practice is difficult for students (McNeill et al., 2006).

To meet the call for instruction that includes argumentation, we have developed an embedded argumentation scaffold within our newly developed, free, integrated evolution and heredity curriculum unit for ninth- and 10th-grade biology. Titled *Evolution: DNA and the Unity of Life*, the unit incorporates a claims-evidence-reasoning (CER) argumentation framework (Berland & McNeill, 2010) that incrementally builds students' skill in both developing and evaluating written arguments (Osborne et al., 2016). Here, we focus on describing this argumentation scaffold, how teachers have used it in classrooms, results from classroom testing, and how this practice helps students make sense of the phenomena in the unit. For details on the whole unit's theoretical framework, curriculum descriptions, and pilot testing, see Homburger et al. (2019).

○ Evolution Unit & Argumentation Scaffold Overview

Developed by the Genetic Science Learning Center at the University of Utah, *Evolution: DNA and the Unity of Life* is freely available on our teacher website (https://teach.genetics.utah.edu/content/evolution/) and student website (https://learn.genetics.utah.edu/content/evolution/). The eight-week, five-module, comprehensive curriculum unit illuminates the underlying role of genetics in evolution by maintaining a conceptual connection to DNA and heredity throughout. The unit's paper-based and interactive multimedia lessons were designed for the NGSS. They engage students in high-interest phenomena, and they incorporate relevant science practices (arguing from evidence, and analyzing and interpreting data) and crosscutting concepts (patterns, systems and system models, and cause and effect).

We developed, classroom tested, and revised the argumentation scaffold over several cycles, as we developed the entire unit. During each testing phase, we gathered written and verbal feedback from teachers to inform the unit's content and flow.

The topic of evolution lends itself well to argumentation from evidence. In an early draft of the unit, we asked students to carry out this practice. However, testing revealed that although

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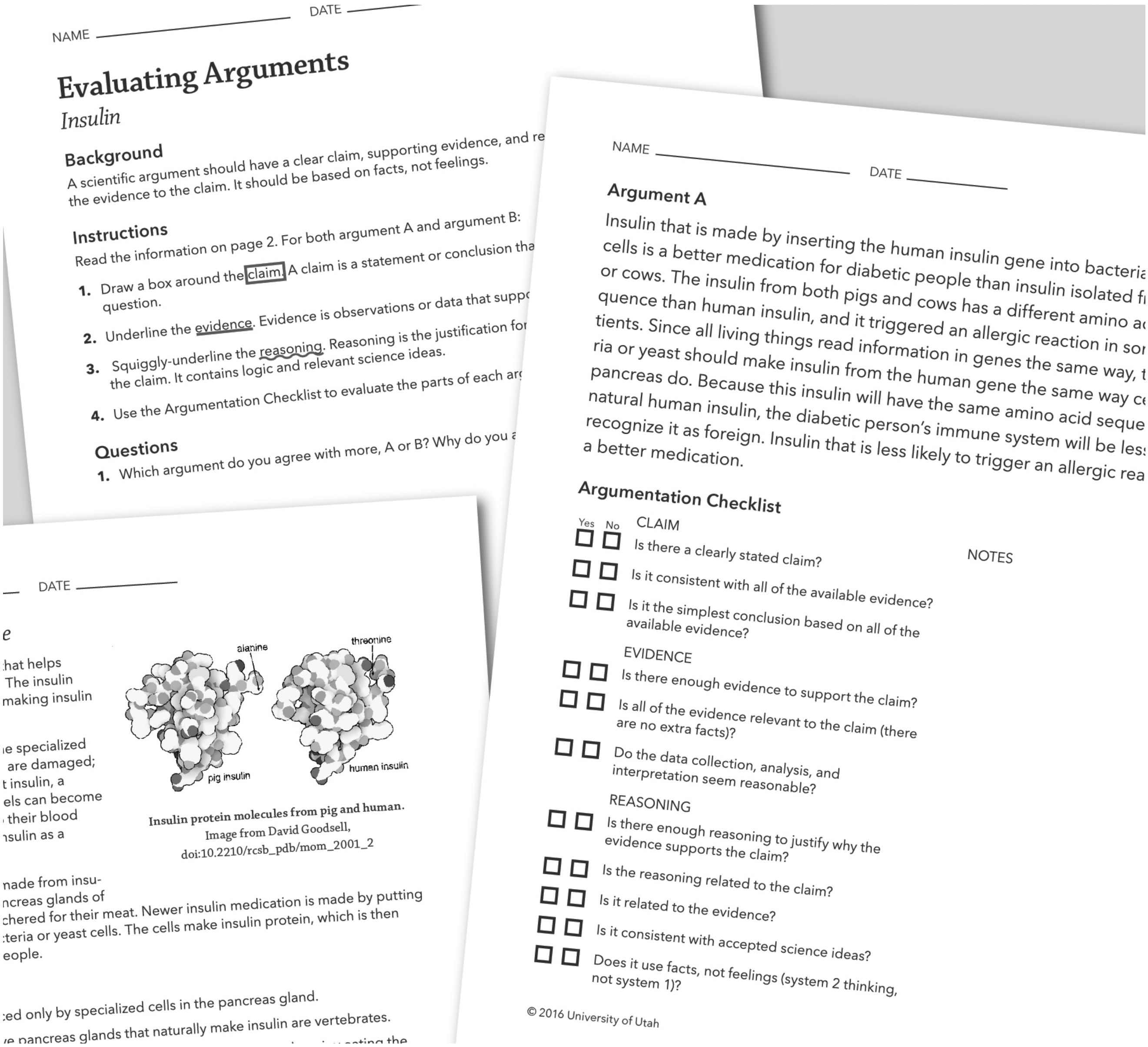
students had some familiarity with the components of an argument, they did not have the skills to effectively develop their own. In response, we added a claims-evidence-reasoning (CER) framework.

The CER lessons built into each of the unit's five modules incrementally build students' capacity to develop an argument from evidence. Students begin with simple identification of each CER component, progress through practice using each one, and finally put them all together to write an argument. The argumentation activities are framed around the same science ideas and phenomena that students are studying in each module. This structure serves to simultaneously reinforce content knowledge and contextualize the CER process. The unit also includes explicit teacher instructions, which support teachers in building comfort and skill in incorporating this science practice into the classroom, and full materials lists. The argumentation lessons embedded within each module are briefly described below.

Module 1: *Shared Biochemistry*

Students are introduced to argumentation from evidence as a method for combating cognitive bias. A video highlights how bias might distort perceptions of reality and introduces the CER components of an argument. Students learn that scientific argument should include a clear claim, supporting evidence, and reasoning that connects claim and evidence. Next, students receive examples of properly and poorly constructed arguments about bioengineering examples that align with the module's learning objectives. Students identify each CER component in the arguments, then evaluate their merit using a checklist (see Figure 1). Figure 2 shows the online teacher instructions.


NAME
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Evaluating Arguments
Insulin

Background
A scientific argument should have a clear claim, supporting evidence, and re
the evidence to the claim. It should be based on facts, not feelings.

Instructions
Read the information on page 2. For both argument A and argument B:
1. Draw a box around the claim. A claim is a statement or conclusion tha
question.
2. Underline the evidence. Evidence is observations or data that suppo
3. Squiggly-underline the reasoning. Reasoning is the justification for
the claim. It contains logic and relevant science ideas.
4. Use the Argumentation Checklist to evaluate the parts of each ar

Questions
1. Which argument do you agree with more, A or B? Why do you a

DATE

e
hat helps
The insulin
making insulin

e specialized
are damaged;
t insulin, a
els can become
their blood
nsulin as a

alanine
threonine
pig insulin
human insulin

Insulin protein molecules from pig and human.
Image from David Goodsell,
doi:10.2210/rcsb_pdb/mom_2001_2

nade from insu-
ncreas glands of
chered for their meat. Newer insulin medication is made by putting
teria or yeast cells. The cells make insulin protein, which is then
eople.

ced only by specialized cells in the pancreas gland.
e pancreas glands that naturally make insulin are vertebrates.

NAME
DATE

Argument A
Insulin that is made by inserting the human insulin gene into bacteri
cells is a better medication for diabetic people than insulin isolated f
or cows. The insulin from both pigs and cows has a different amino a
quence than human insulin, and it triggered an allergic reaction in so
tients. Since all living things read information in genes the same way,
ria or yeast should make insulin from the human gene the same way
pancreas do. Because this insulin will have the same amino acid seque
natural human insulin, the diabetic person's immune system will be les
recognize it as foreign. Insulin that is less likely to trigger an allergic rea
a better medication.

Argumentation Checklist

Yes No
CLAIM
☐ ☐ Is there a clearly stated claim?
☐ ☐ Is it consistent with all of the available evidence?
☐ ☐ Is it the simplest conclusion based on all of the available evidence?

EVIDENCE
☐ ☐ Is there enough evidence to support the claim?
☐ ☐ Is all of the evidence relevant to the claim (there are no extra facts)?
☐ ☐ Do the data collection, analysis, and interpretation seem reasonable?

REASONING
☐ ☐ Is there enough reasoning to justify why the evidence supports the claim?
☐ ☐ Is the reasoning related to the claim?
☐ ☐ Is it related to the evidence?
☐ ☐ Is it consistent with accepted science ideas?
☐ ☐ Does it use facts, not feelings (system 2 thinking, not system 1)?

NOTES

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Figure 1. In *Evaluating Arguments*, students practice identifying claims, evidence, and reasoning in written arguments. An *Argumentation Checklist* helps them evaluate the quality of each component. They learn what makes a good argument and how to diagnose a poorly written one.

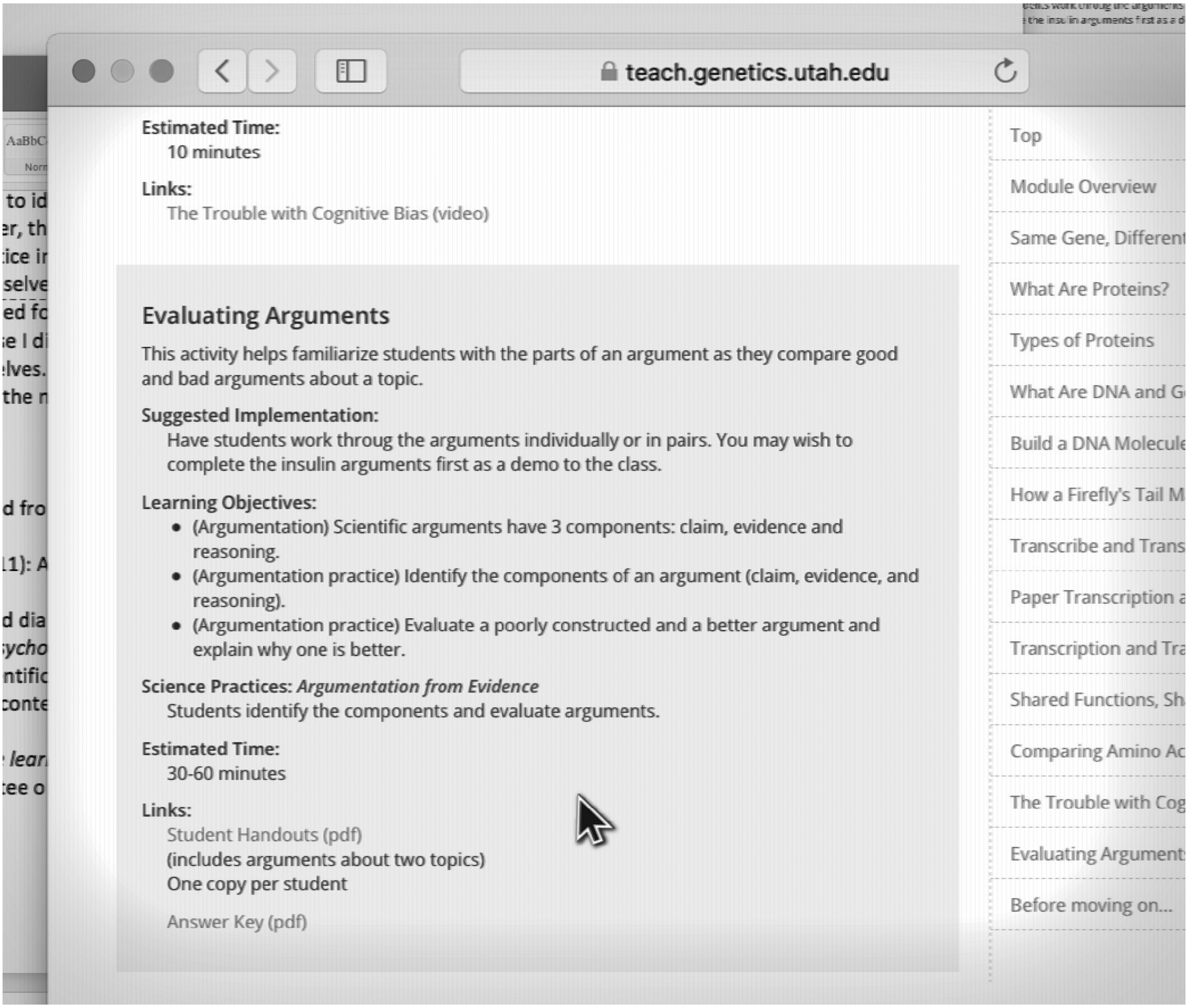


Figure 2. Online teacher instructions for *Evaluating Arguments*. The teacher web pages include at-a-glance goals, student learning objectives, suggested implementation, connections to NGSS, and implementation time for each activity in the unit. Where relevant, they also include detailed teacher guides, materials lists, links to web pages and handouts, and answer keys.

Module 2: *Common Ancestry*

Much of this module is framed around a case study of cetacean ancestry, in which students work with data from anatomy, fossils, embryology, and DNA. Now familiar with the components of an argument, students begin exploring each one in more detail. As they progress through the case study, prompts on an "evidence organizer" guide them in making data-based evidence statements. Next, students are given claim and reasoning statements about cetacean ancestry. They must identify the pieces of evidence from their organizer that both support the claim and are consistent with the reasoning provided. Figure 3 shows the key for the evidence organizer.

Module 3: *Heredity*

During an early pilot test of the unit, students tended to include all accurate evidence in their written arguments, even if the evidence was not relevant to the claim. Therefore, we added more practice with reasoning – the justification for why the evidence supports the claim. Students are given a set of claims and supporting evidence, and they must choose the reasoning statement that best connects the two. This exercise also serves as a review of the concepts explored in the module, including the role of mutation and sexual reproduction in generating genetic variation (Figure 4).

Module 4: *Natural Selection*

This module is centered around a real-world case study of stickleback fish, where a body armor trait changes over time in a population. Figure 5 shows a teacher working with students on gathering evidence for stickleback evolution. One exercise reviews how the CER components work together in an argument. Here, students match "evidence cards" to reasoning statements, and use their

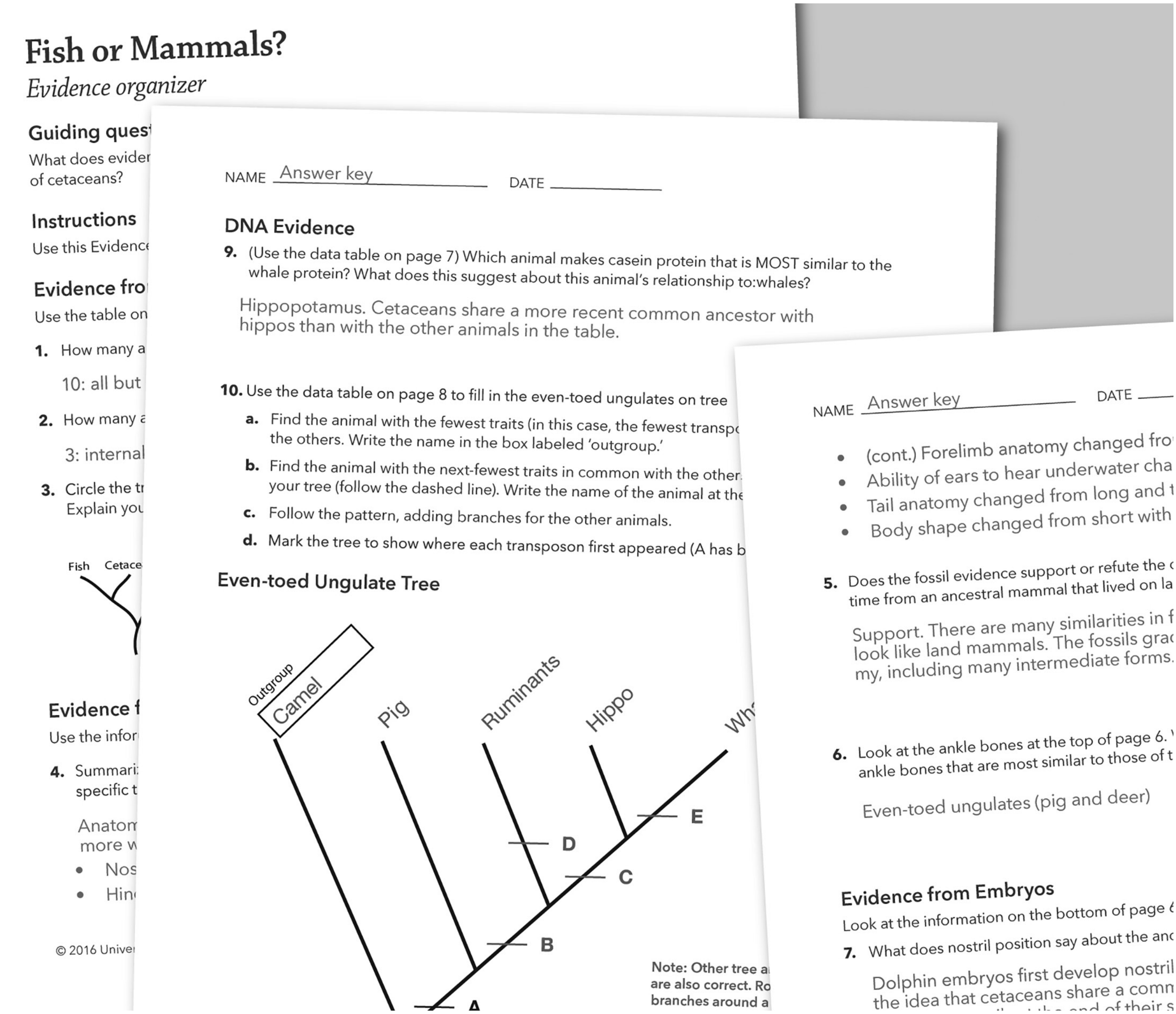


Figure 3. An *Evidence Organizer* helps students collect and analyze various lines of evidence about cetacean ancestry. Later, they use this evidence to support a set of provided claims.

matches to identify correct and plausible claims about body armor and reproductive advantage (Figure 6). Then, for the first time, students write their own supported arguments. They gather evidence from a suite of data analysis activities and summarize them onto an organizer. Next they use this evidence to write an argument about whether the change over time in stickleback body armor is a result of natural selection. Students peer review the arguments with the aid of the "evaluating arguments" checklist from module 1. The checklist helps students assess whether each component of CER is present and is used appropriately. Students use feedback from peer review to revise their arguments (Figure 7). Teacher instructions detail common student misconceptions to look out for in the written arguments.

Module 5: *Speciation*

In the final module, students engage in an authentic science investigation to decide whether hawthorn flies living on hawthorn and apple fruit are becoming two species – a question that scientists are still studying. A "speciation organizer" aids students in collecting and sharing several lines of evidence. They evaluate the evidence to decide whether the two fly populations are reproductively isolated and whether different heritable characteristics are being selected for in each population (Figure 8). Students then place the populations on a "same species to different species" continuum and write a supported CER argument that justifies their placement. Teacher materials provide implementation details and answer keys.

○ Using the Language of CER

To help students incorporate the language of CER into their vocabulary, we used this terminology throughout the unit – not just in the argumentation lessons. This consistency helps students identify CER in each activity, reinforces their understanding, and builds

Figure 4. In *Identifying Reasoning*, students choose a reasoning statement that best connects evidence to a claim. This argumentation exercise is based on three heredity scenarios, and it reinforces science ideas presented in the Heredity module's online components, three examples of which are shown here.

their confidence in using the terms. The benefit of this repetition is particularly evident in the final two modules, at which point students are very familiar with the CER language.

The language of CER spans content areas, including the Common Core State Standards (NGA/CCSSO, 2010). Many teachers use CER or similar processes to teach argumentation in other subjects, such as language arts. Applying the same process and language across subjects reinforces interdisciplinary connections and facilitates curriculum integration.

To improve alignment, biology teachers can easily modify our CER terminology to match the terms used in other subjects. For example, one pilot test teacher changed the unit's CER language to "if…and…then…because" deduction statements to better leverage what students were learning from the school's language arts teachers.

○ Built-in Assessment

Each module provides opportunities for teachers to monitor students' progress in developing argumentation skill. The following formative assessment tasks explicitly illuminate student thinking:

- Student-generated written arguments demonstrate individual students' progress.
- Several opportunities to engage in verbal argumentation allow students and teachers to critique and consider others' arguments.

Students' peer review checklists reveal the understanding of both the reviewer and reviewee.

Figure 5. In the *Candidate Gene Approach*, students analyze data about stickleback genotypes and phenotypes. Later, they will use this as evidence in their written arguments.

○ Evaluating the Argumentation Framework

We conducted a national pilot test of the entire *Evolution: DNA and the Unity of Life* unit in the classrooms of 20 teachers. Here, we present the results on the topic of argumentation.

Student Pilot Test Results

We measured students' argumentation knowledge through eleven multiple-choice items on pre/posttests. Test items used different phenomena than were in the unit. They evaluated students' knowledge of CER, their ability to justify why data support a claim, and their ability to select data that support a particular claim. Scores from the 944 students who completed both the pretest and posttest increased significantly from pretest to posttest, $t(943) = 5.0$, $p < .001$, with an average score gain of 14.5%. These findings indicate that students increased in their argumentation skills over the course of the unit.

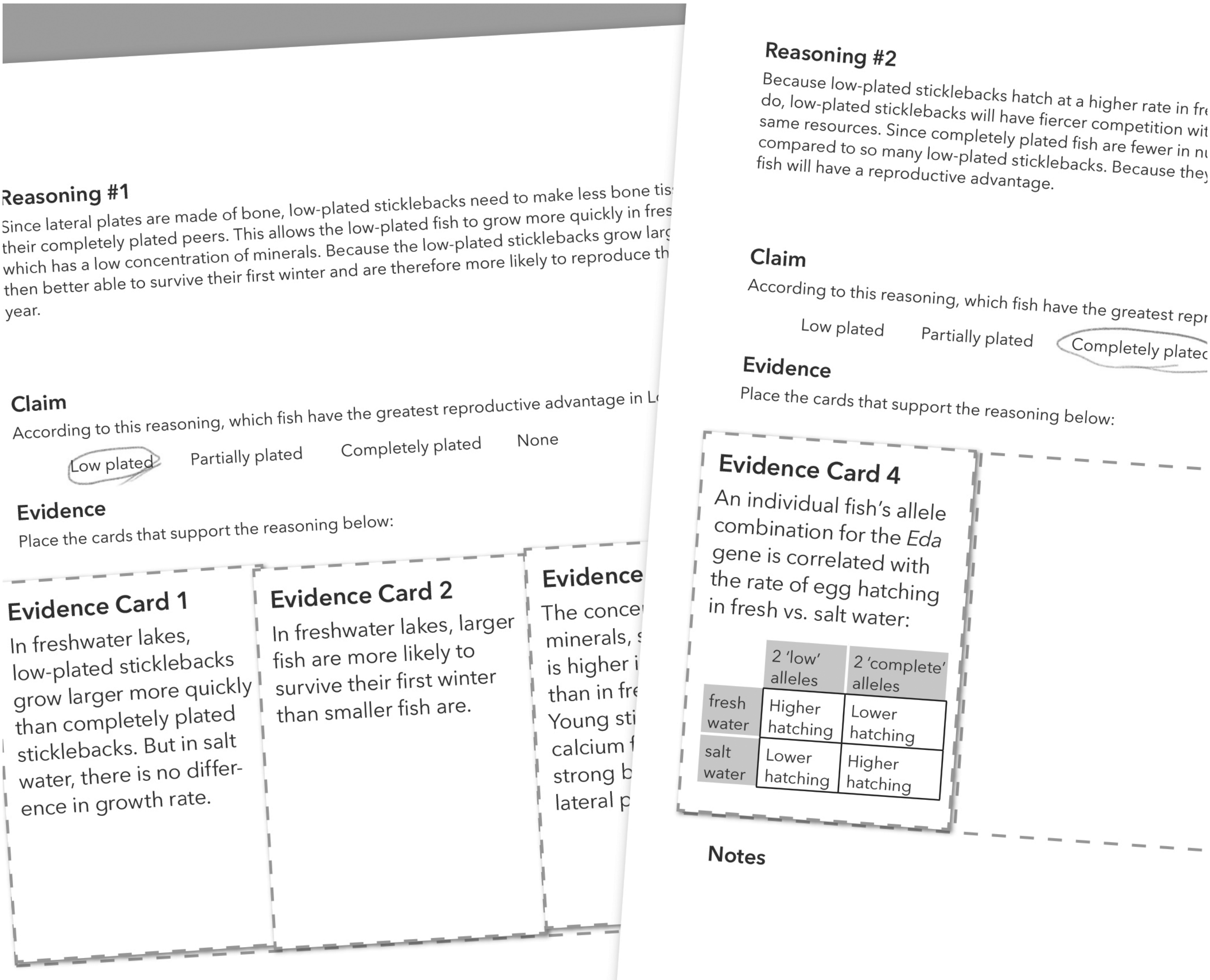
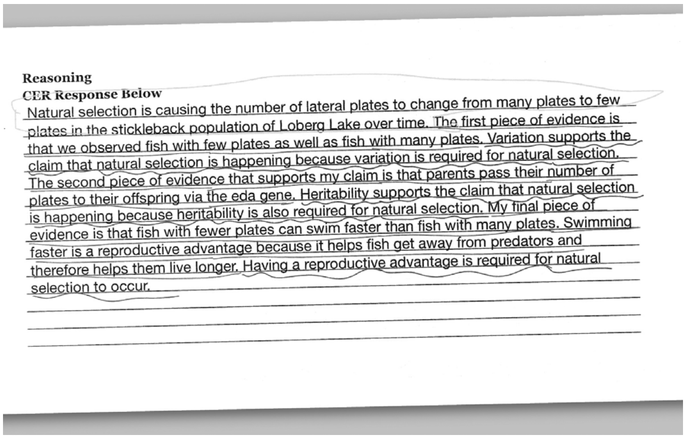


Figure 6. Student work sample from *Reproductive Advantage in Sticklebacks: Plausible Arguments*. Provided with reasoning statements, the student chose the claims and evidence cards that best completed an argument.



Reasoning
CER Response Below
Natural selection is causing the number of lateral plates to change from many plates to few plates in the stickleback population of Loberg Lake over time. The first piece of evidence is that we observed fish with few plates as well as fish with many plates. Variation supports the claim that natural selection is happening because variation is required for natural selection. The second piece of evidence that supports my claim is that parents pass their number of plates to their offspring via the eda gene. Heritability supports the claim that natural selection is happening because heritability is also required for natural selection. My final piece of evidence is that fish with fewer plates can swim faster than fish with many plates. Swimming faster is a reproductive advantage because it helps fish get away from predators and therefore helps them live longer. Having a reproductive advantage is required for natural selection to occur.

Figure 7. An example of a complete student argument, following peer review and revision. The student drew a yellow box around the claim, underlined the evidence in red, and drew a wavy blue underline under the reasoning.

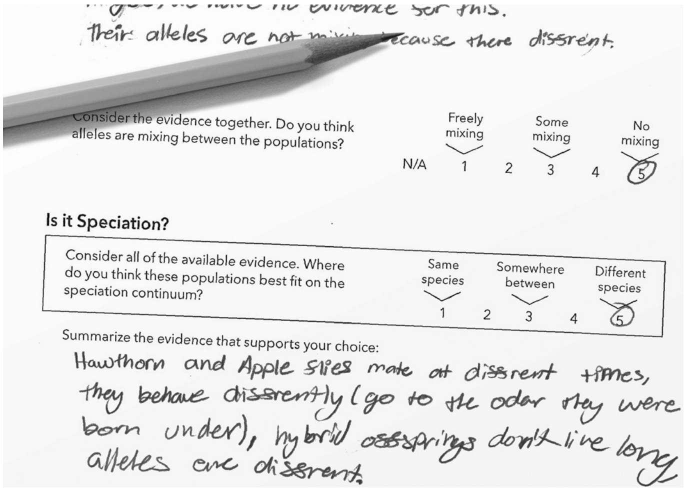


Figure 8. Students examine several lines of evidence to decide whether or not a population of *Rhagoletis* flies that moved to apples is differentiating into a new species and construct an argument to support their claim. Student work from one step in the process is shown here.

Teacher Pilot Test Feedback

We collected teacher feedback from the 20 pilot test teachers during an in-person, 3.5-day summer institute, as well as during and after curriculum classroom pilot testing through interviews, daily teaching logs, and classroom observations. Our findings showed the following.

(1) The argumentation framework and scaffolding built students' skills in arguing from evidence. Many teachers indicated that the framework was their favorite part of the unit because it provided an accessible formula for a process that would otherwise be very complicated. As one teacher explained: "I want curricula to continue this kind of approach to the rest of biology…. I'll definitely be doing more student writing, defending using evidence, the CER, for argumentation…. It's a scientific approach." Another teacher described how "students learn about claim, evidence, and reasoning. They construct arguments from real data. This unit does more than just give students information about evolution. Through an eight-week scientific experiment, students prove it to themselves."

(2) Teachers are applying the unit's argumentation scaffold to their other classes, and 36% indicated that they shared it with colleagues. For example: "I was able to use what I learned about claim, evidence, reasoning activities for my freshman physics class as well." And: "I led a professional development for my colleagues…. I showed them how each module advanced a set of skills from NGSS…. I used argumentation as an example and how the practice is methodically developed…. I emphasized the student struggle and how well they understood the content after the struggle."

(3) The unit educates teachers about integrating NGSS science practices. For example: "The argumentation [lessons] give a great way to provide student feedback…. The better I've gotten at giving students feedback, the better their arguments get." And: "The evolution curriculum is now our go-to model for how to design an NGSS-aligned lesson."

○ Conclusion

Data from teachers and students show that the argumentation scaffold built into the *Evolution: DNA and the Unity of Life* unit supports students' capacity to identify elements of CER and to create written arguments from scientific evidence. Further, the scaffold has educative value for teachers in incorporating this NGSS science practice into their classroom teaching, particularly as they are learning the science practices themselves. The unit provides a model that teachers can use in other lessons. As one teacher explained following the pilot test: "My favorite part of the unit was the argumentation. Simply because I didn't have to convince students about the scientific principles, they found the proof themselves. Watching them defend their positions, I could see how much they had learned from the unit's activities."

○ Acknowledgments

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