A NEW Twist on DNA Extraction

Collaborative argumentation and student protocol design

JEANNE TING CHOWNING, REGINA WU, CAREN BRINKEMA, WENDY DAVIS CROCKER, KRYSTAL BASS, AND DEBBIE LAZERTE

DNA extraction from strawberries is a well-known procedure that allows students to visualize DNA and to recognize that living things contain DNA (NHGRI 2018, Science Buddies 2013). Many similar protocols exist, and most involve simple materials that can be readily obtained (Marek, Mulvihill, and Bell 2009). In this article, we describe a modification to the traditional DNA extraction protocol that promotes student agency in experimental design and also emphasizes important social dimensions of argumentation.

The lesson provides ample opportunities for students to engage deeply in the social dimensions of argumentation. First, small groups of students design their own DNA extraction protocols based on their knowledge of cell structure and the properties of biomolecules. Within each group, they collaborate to make claims about a procedure that they expect to be effective, providing reasoning for using certain materials in a certain order. After obtaining their results, they conduct a "lab meeting," in which each group presents its protocol, the rationale for its design decisions, and its results. Students engage in questioning and critiquing the approaches of others as they try to build a collective understanding of the most effective approaches.

The lab meeting introduces a critical aspect of scientific argumentation, one that is often neglected in school settings: collaborative discussion, critique, and sense-making about procedures. Our approach allows teachers to emphasize the central role of collaborative talk in science, as well as the social dimensions of scientific argumentation as students puzzle out the best procedures for repeating the experiment. Argumentation is a central scientific practice in the *Next Generation Science Standards* (NGSS Lead States 2013); broadening student conceptions of what this practice entails helps highlight the central roles discussion, critique, and collaborative problem-solving play in science. Structures such as lab meetings help provide students with insight into the roles of argumentation and sense-making in professional scientific communities.

Lesson introduction

The question *"How can we get DNA out of cells?"* begins the initial discussion and provides the opportunity to draw upon prior knowledge. The teacher can briefly review relevant cell components using a "bag-in-a-bag" cell model. For example, string representing DNA can be placed in a plastic bag representing the nucleus, which in turn is placed within a larger bag representing the cell membrane. Cytoplasm and organelles are represented by shredded paper and air-filled packing pillows, reminding students that biomolecules also comprise the area between the two membranes. The larger bag can also be put in a cardboard box to represent a plant cell wall (Figure 1).

FIGURE 1

DNA model box

Next, student teams of 2–4 design lab protocols for extracting DNA from strawberries, using their prior knowledge of cell structures and the properties of biomolecules. After showing a test tube of extracted DNA to students to illustrate what the final product should look like, the teacher notes that there are many ways to remove DNA from cells, and that this remains an active area of research for scientists.

Double-sided cards detail the properties of various materials available to them for the procedure (Figure 2). The cards have enough information so that students have some idea of the role the material might play. For example, the ethanol card reads: *pH: 7.33 (mostly neutral) Description: Alcohol (in this case, ethanol) is a small molecule that has a reactive OH (hydroxyl) group present. Function: Ethanol does not interact with DNA, allowing the DNA to resist being dissolved in water. DNA clumps together in the presence of ethanol. Type of molecule: A polar molecule containing covalent bonds.* It is up to the students to determine the specific materials used, the sequence of use, the amounts needed, and any other elements of their design. Not all materials are necessary to extract DNA, and several materials are included as extra options.

Teams document their designs and record the reasoning behind their design choices. At this point, students make claims about which materials will be effective, providing reasons for choosing those materials and putting them in the order they did. They then discuss their protocol with the teacher, explaining their reasoning before proceeding. Students then reflect on how well the group members are communicating and collaborating within their teams using a Communication/Collaboration Check-In sheet (Figure 3).

FIGURE 3

Communication/Collaboration Check-In.

1. Everyone has a chance to participate equally in our discussion. Yes/No
2. Everyone is listening well to contributions. Yes/No
3. Someone in our group is taking over. Yes/No
4. I am "keeping up" and understanding what our group is doing and why. Yes/No
5. We have divided up the work fairly. Yes/No
6. I would rate our collaboration as: Non-existent OK Very Good
7. I give this rating because:
8. One improvement I would suggest in order to improve our communication and collaboration is:

DNA investigation and lab meeting

Students conduct their tests and attempt to extract DNA, documenting their results. Although the materials are readily available outside of laboratory settings, the use of safety glasses is recommended. Afterward, the teams convene as a part of a larger class lab meeting to analyze the results collectively, put forward evidence-based claims about the most productive strategies, and use the knowledge gained from all of the results to develop and test a final class-designed protocol.

Classroom norms are key to creating an environment that values student voice and that is equitably structured to support the participation of all students. Before the lab meeting, the class should revisit any class norms developed earlier related to respectful listening and critiquing.

FIGURE 2

Sample resource cards.

Front

Back

DISHWASHING SOAP pH: 6-8 (slightly alkaline)

DESCRIPTION:
Dishwashing soap is a liquid that is added to water to aid in removing dirt and oils from items ranging from dishes to oil-affected birds.

FUNCTION:
Disrupts oils (lipids) and connections (bonds) between fat molecules, allowing them to be easily removed.

TYPE OF MOLECULE:
A surfactant that allows hydrophobic (water-hating) molecules to be broken apart

BAKING SODA pH: 9 (alkaline)

DESCRIPTION:
Baking soda is a salt composed of sodium ions and bicarbonate ions. It is a white solid that is usually a fine powder. It has a slightly salty, alkaline taste.

FUNCTION:
Baking soda is a well-known cooking ingredient used as a leavening agent for breads, cookies and cakes. It has a wide range of applications, including cleaning, deodorizing, maintaining pH, and extinguishing fires.

TYPE OF MOLECULE:
An ionic compound, also known as a salt

SALT pH: 7-8 (mostly neutral)

DESCRIPTION:
When added to water, table salt (NaCl) dissociates (breaks apart) into charged sodium (Na+) and chlorine (Cl-) ions.

FUNCTION:
Salt in water allows free Na+ and Cl- ions to easily interact with polar molecules. In salt solutions, polar molecules can form clumps.

TYPE OF MOLECULE:
An ionic compound

OIL pH: neutral

DESCRIPTION:
Triglycerides are the main component of most food fats and oils. A triglyceride is composed of glycerol and three fatty acids.

FUNCTION:
Plant oils (such as olive or sunflower) assist in heat transfer when cooking. They are also used to add flavor and texture to foods.

TYPE OF MOLECULE:
A triglyceride containing non-polar, covalent bonds; a lipid

ALCOHOL (ETHANOL) pH: 7.33 (mostly neutral)

DESCRIPTION:
Alcohol (in this case, ethanol) is a small molecule that has a reactive OH (hydroxyl) group present.

FUNCTION:
Ethanol does not interact with DNA, allowing the DNA to resist being dissolved in water. DNA clumps together in the presence of ethanol.

TYPE OF MOLECULE:
A polar molecule containing covalent bonds

VINEGAR pH: ~2.4 (acidic)

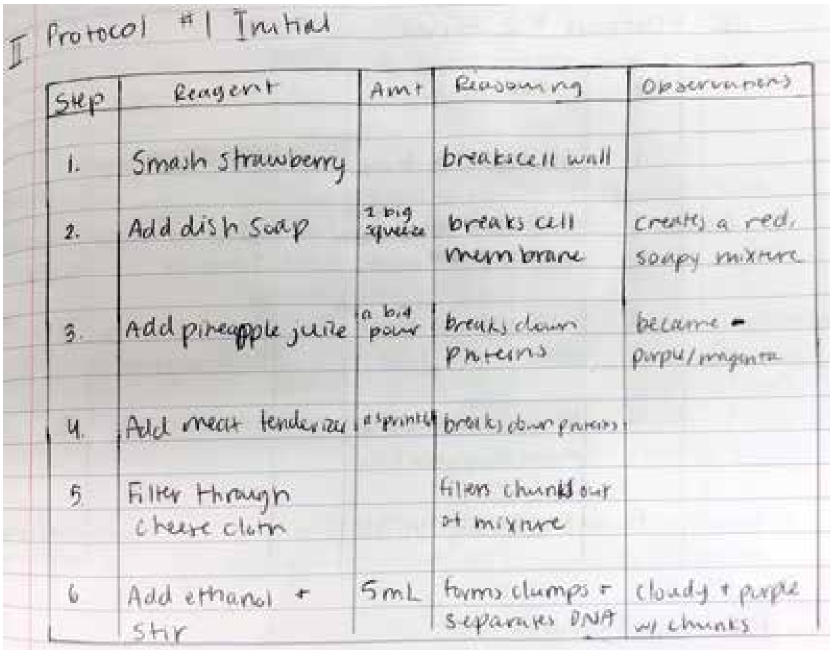
DESCRIPTION:
Vinegar is a liquid produced from the fermentation of ethanol into acetic acid. The fermentation is carried out by bacteria. Vinegar consists of acetic acid (CH3COOH), water and trace amounts of other chemicals.

FUNCTION:
A cooking ingredient, it is also used for pickling.

TYPE OF MOLECULE:
Acetic acid is a polar molecule consisting of covalent bonds.

FIGURE 4

Sample student protocol #1.

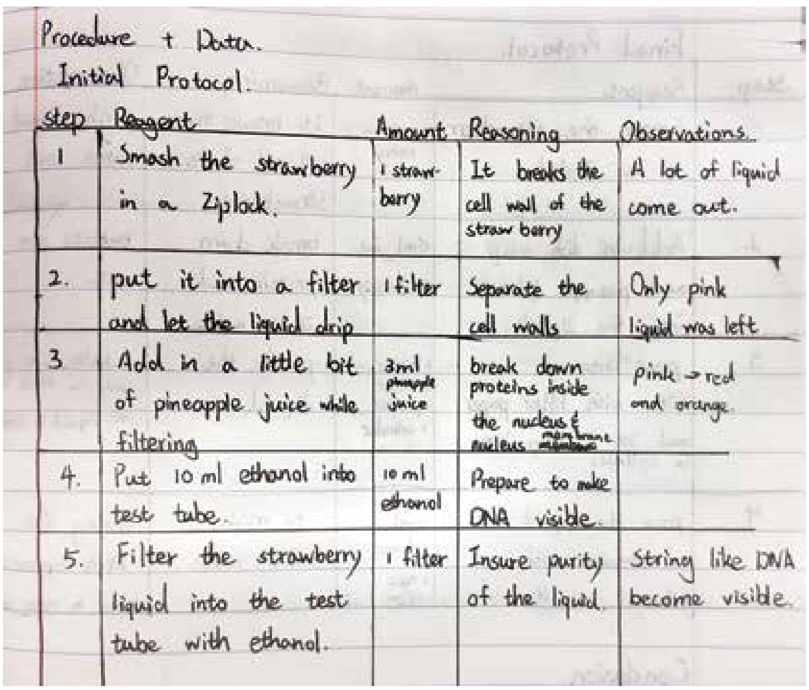


Protocol #1 Initial

Step	Reagent	Amt	Reasoning	Observations
1.	Smash strawberry		break cell wall	
2.	Add dish soap	1 big squeeze	breaks cell membrane	creates a red, soapy mixture
3.	Add pineapple juice	a bit pour	breaks down proteins	became purple/magenta
4.	Add meat tenderizer	a sprinkle	breaks down proteins	
5.	Filter through cheese cloth		filters chunks out of mixture	
6	Add ethanol + stir	5mL	forms clumps + separates DNA	cloudy + purple w/ chunks

FIGURE 5

Sample student protocol #2.



Procedure + Data.

Initial Protocol.

step	Reagent	Amount	Reasoning	Observations
1	Smash the strawberry in a Ziplock.	1 strawberry	It breaks the cell wall of the strawberry	A lot of liquid come out.
2.	put it into a filter and let the liquid drip	1 filter	Separate the cell walls	Only pink liquid was left
3	Add in a little bit of pineapple juice while filtering	3ml pineapple juice	break down proteins inside the nucleus & nucleus membrane	pink → red and orange
4.	Put 10 ml ethanol into test tube.	10 ml ethanol	Prepare to make DNA visible.	
5.	Filter the strawberry liquid into the test tube with ethanol.	1 filter	Insure purity of the liquid.	String like DNA become visible.

The teacher introduces the lab meeting as a method that professional scientists use to share ideas, interpret results, solve problems, and get feedback from others. These types of sense-making discussions can also help scientists improve procedures or techniques. Within the meeting, the scientific importance of *communication* (sharing information with others), *collaboration* (working together toward a goal), and *skepticism* (evaluating information critically and looking for evidence and reasoning behinds claims) is highlighted. The value of inconclusive or negative results should also be emphasized; if a team's procedure has not yielded DNA, their reasoning and results can still provide valuable information to other groups and contribute to a broader understanding of how to best redesign a class protocol.

Each group summarizes its protocol and how well its method of extraction worked (at this point, this can simply be whether or not the procedure produced DNA). Students can also distribute physical copies of their protocol or summarize it on whiteboards or large sticky notes. Students within each group should share the responsibility of presenting to the class, and teachers can use differentiation strategies at this point, such as providing additional scaffolding and prompts for the presentations for English language learners or allowing students to present their protocols in graphical ways instead of solely in writing.

After hearing results from the group selected first, teachers can open the class up to questions from students. It is easiest if the first group is confident speaking in front of others and able to respond to questions and critique appropriately, in order to help model the process for the class. Teachers may need to provide some facilitation or up-front scaffolds to facilitate discussion. Another approach is to have the class brainstorm the kinds of questions one might ask or statements one might make prior to hearing the first group (for example, ways of adding on to an idea, asking a probing question, respectfully disagreeing with an idea, or asking for evidence and reasoning behind a claim) (Windschitl, Thompson, and Braaten 2018). These questions can remain posted during each group's presentation.

FIGURE 6

Lab meeting

The following are examples of questions that students could use: Why did you decide on that sequence? What was the reasoning behind choosing those particular materials? What evidence do you have for your claims about the outcome of your approach? Can you explain how your data support your claims? What would you do differently next time? Should the whole class use your approach if we were to do this again? Why or why not? Did you learn anything from the other team presentations that could help with your protocol? The teacher repeats this process for each of the teams, allowing questions to be student-driven. Teachers can facilitate the lab meeting by helping students recognize areas in which questioning may be productive.

Collaborative class redesign

The class then brainstorms ways to improve the protocol, which the teacher records, allowing students to revise or interject ideas or questions. The class could also try to determine a procedure that will yield DNA with the fewest steps, or a method that produces "stringy" DNA (the presence of many proteins will make the extraction more globular or "chunky.") There are ample opportunities for students to put forth claims about effectiveness of particular methods based on the evidence and reasoning from their prior attempt at extracting DNA. Once the class has completed and agreed on a revised version, have students return to their groups to run the protocol.

Classroom experience

Three teachers have contributed feedback about their classroom experiences. The first teacher taught the lesson to 10th-grade general biology students at a suburban public high school, with 22 student groups across three biology classes. Two groups (from different classes) successfully isolated DNA with their initial protocols. Her students discussed consensus protocols but did not have time to do a second extraction. The second and third teachers both taught the lesson to biotech classes (one in a suburban public high school, and the other in a private urban high school). All the students in the second teacher's biotech class (six groups of students) were able to isolate DNA after the first extraction, and obtained a larger quantity of DNA after the collaborative redesign. The third teacher had two groups out of six in her first biotech class and two groups out of nine in her second biotech class isolate DNA successfully using their initial protocol, and all groups in both of her classes were able to isolate DNA after the collaborative redesign.

FIGURE 7

Whiteboard example of successful protocol.

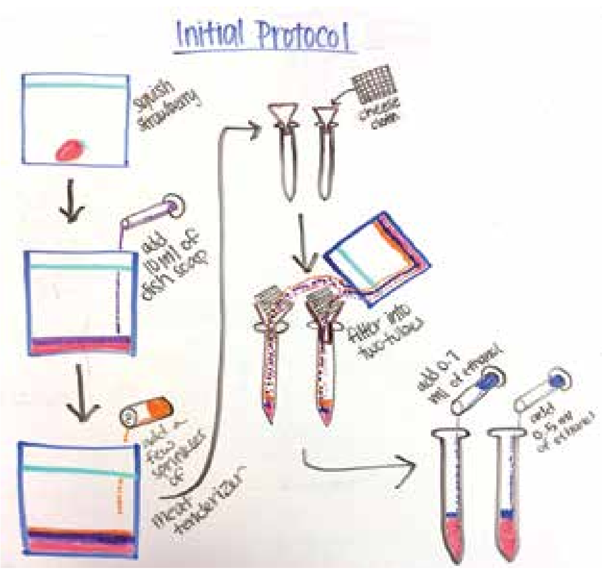
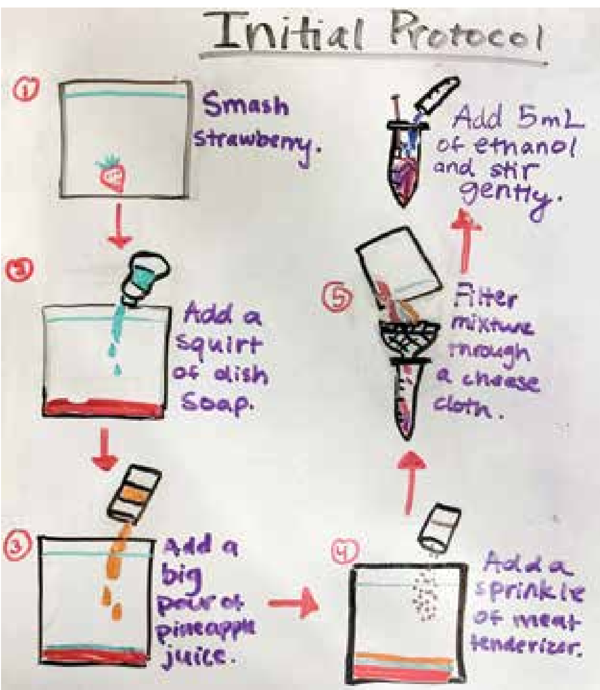


FIGURE 8

Whiteboard example of unsuccessful protocol.



Figures 4 and 5 show sample student protocols. For each step, students listed the material and amount used, and the reasoning behind why they chose that material. During the lab meeting, students shared their protocols with others (see Figure 6). Figures 7 and 8 show whiteboard examples of successful and unsuccessful protocols. After sharing, students made claims about which materials should be used for the final class procedure using evidence from the presentations, and came to consensus about a new approach to try. For example, in one class the students decided the final protocol needed to include adding water, based on the challenges that groups had with filtration of the strawberry pulp.

Teachers observed tremendous student engagement as this was an experiment of the students' own design for which the "correct" answer was not known. Significantly, this strategy increased equitable participation across the classroom: students were on equal footing, with all students readily contributing valuable ideas. Teachers observed less "taking over" by stronger students, as less-assertive students felt more at liberty to offer their ideas, using evidence from the cards. In fact, teachers reported facing a refreshing challenge: to step completely away from student discussions and simply redirect students back to their resources when needed. One teacher noted, "I was so impressed with the ownership my students took for their work, as well as the pride and excitement when they saw how much improved their final protocol ended up being."

Assessment

The assessment included with the lesson is a formative self-assessment focused on communication and collaboration within the group. Some teachers have added further assessments, such as quizzes (related to the properties of the materials used, or the location of various cellular components) or reflections. For example, one teacher asked students to record answers to the following: What was the most beneficial part of collaborating in the lab meeting? What did you find most challenging? Why do you think scientists typically have regularly scheduled lab meetings?

Student feedback

Students reported the following:

- I liked that we all had group input and we each got to say what we thought would work best for the assignment.
- This was a time when we could truly test our abilities in the field of science without any instructions. We were simply given background information and could form our ideas and procedures ourselves.
- I thought it was interesting to see which choices worked and which ones didn't, using the info on the back of the cards.
- I enjoyed the independence that we had as a group to come to a consensus.

Students trying out their protocols.

- Personally, I thought this experiment was very helpful for understanding the process actual scientists go through.
- Argumentation is important because it makes everyone think harder and dig deeper. It challenges us to rethink what we thought we knew. I think that this was a great learning possibility.
- It was a great team effort, [students] all chipped in to make this a great learning activity and a lovely experience.

What about Google?

Teachers have several options when addressing the temptation students may have to find protocols online. They can say nothing (field testing has shown students are unlikely to search online for protocols if the issue is not raised; in six classes only one student group did so). Teachers can also emphasize that the purpose of this lab is learning about communication and collaboration, not getting the "right answer."

Conclusion

Reframing the familiar DNA extraction lab activity to emphasize student protocol design and evidence-based problem solving provides an in-depth opportunity for students to engage in collaborative argumentation. Students can sharpen their skills in communicating procedures and results as well as in critiquing and questioning the approaches of different teams. Through such experiences, students gain a deeper appreciation for these important skills, which are foundational to the ways scientists approach their research.

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ON THE WEB

Lesson plan, detailed Teacher Guide, and Student Tech Guide on the Science Education Partnership website: *www.fredhutch.org/sep*

Beyond the Written C-E-R: *http://stemteachingtools.org/brief/17*

The Argumentation Toolkit: *www.argumentationtoolkit.org*

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Connecting to the *Next Generation Science Standards* (NGSS Lead States 2013)

Standard

HS-LS1-1 From Molecules to Organisms: Structures and Processes

Performance Expectation

- The chart below makes one set of connections between the instruction outlined in this article and the *NGSS*. Other valid connections are likely; however, space restrictions prevent us from listing all possibilities.
- The materials, lessons, and activities outlined in the article are just one step toward reaching the performance expectation listed below.

HS-LS1-1. Construct an explanation based on evidence for how the structure of DNA determines the structure of proteins which carry out the essential functions of life through systems of specialized cells.

DIMENSIONS	CLASSROOM CONNECTIONS
Science and Engineering Practice	
Constructing Explanations and Designing Solutions Construct an explanation based on valid and reliable evidence obtained from a variety of sources (including students' own investigations, models, theories, simulations, peer review) and the assumption that theories and laws that describe the natural world operate today as they did in the past and will continue to do so in the future.	Students design their own solutions to address the problem of how to extract DNA from cells. They then plan and carry out an investigation based on their experimental designs. Afterwards, they construct claims for the results they observe based on evidence from their results. They communicate information about their findings with other teams in a classroom "lab meeting" discussion where students respectfully question and critique each other's designs. Finally, students collaboratively argue for how the protocol could best be redesigned, based on evidence from class data.
Disciplinary Core Idea	
LS1.A: Structure and Function All cells contain genetic information in the form of DNA molecules. Genes are regions in the DNA that contain the instructions that code for the formation of proteins, which carry out most of the work of cells.	This activity reinforces that DNA is located in cells and is sequestered/protected within the nucleus.
Crosscutting Concept	
Structure and Function Investigating or designing new systems or structures requires a detailed examination of the properties of different materials, the structures of different components, and connections of components to reveal its function and/or solve a problem.	Students base their solutions to the problem posed in the activity on the properties of different materials made available for use in their protocols and their potential effects on the structures and functions of cellular components.

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Jeanne Ting Chowning (*chowning@fredhutch.org*) is Senior Director, Science Education; **Regina Wu** is Program Manager; and **Caren Brinkema** is Lab Manager and Special Projects, all at Fred Hutchinson Cancer Research Center, Seattle, Washington. **Wendy Crocker** is a science teacher at Shoreline Public Schools, Shoreline, Washington. **Krystal Bass** is a science teacher at Fairbanks Northstar Borough School District, Fairbanks, Alaska. **Debbie LaZerte** is a science teacher at John F. Kennedy Catholic High School, Burien, Washington.