TEACHER GUIDE
EXPLAIN LESSON 23

Food and Agriculture Center for Science Education

Module Question: *How can we improve on the costs and risks of the dairy system?*

What We Figure Out:

We figure out that the best solutions to the problems we identified in the dairy system are those help us more responsibly produce dairy products while also having less impact on the environment. The best solutions also improve on the costs and risks of the system while maintaining or improving on the benefits. Some solutions improve on one cost and risk, while other solutions improve on multiple.

3D Learning Objective:

Students evaluate competing design solutions that can redesign components of the dairy system to improve on the problems of the dairy system while considering a variety of criteria and constraints, including those from cost, safety, reliability, social, cultural, and environmental impacts.

Time estimate:

100 minutes

Materials:

Lesson 23 Student Guide
Lesson 23 Student Handout Solution Cards
Chart Paper
Markers

Targeted Elements

SEP:

ARG-H6:
Evaluate competing design solutions to a real-world problem based on scientific ideas and principles, empirical evidence, and logical arguments regarding relevant factors (e.g., economic, societal, environmental, ethical considerations).

DCI:

ESS3.A-H2:
All forms of energy production and other **resource extraction have associated economic, social, environmental, and geopolitical costs and risks as well as benefits. New technologies and social regulations can change the balance of these factors.**

CCC:

SYS-H1:
Systems can be designed to do specific tasks.

	ESS3.C-H1: **The sustainability of human societies and the biodiversity that supports them requires responsible management of natural resources.** **ETS1.B-H1:** **When evaluating solutions, it is important to take into account a range of constraints including cost, safety, reliability, and aesthetics and to consider social, cultural, and environmental impacts.**	

Directions

Part 1: Our Motivation

Ask students to return to the list of steps of the engineering design process that they created in Lesson 21 Part 1. Ask students what they figured out in the previous lesson and what they think the best next steps are as part of the engineering design process. In student responses, listen for the following ideas:

- We identified the criteria and constraints of our problem. The next step would be to investigate possible solutions to the problem.

Build off student responses to share that to be able to help address the impacts that the dairy system is having on the environment, it will help us to follow the engineering design process and, next, gather information on a variety of possible solutions to the problems we identified. Students can record what they want to figure out and the next step in the engineering design process in Lesson 23 Student Guide Part 1: Our Motivation. This will help students understand how this lesson connects to what they were previously trying to figure out about determining an approach to solving problems.

Part 2: Investigating Solutions for Dairy Production Practices

Students will continue to work in their original problem groups to further investigate the solutions that align with the dairy production problem they chose in Lesson 21. Remind students that the goal of designing a solution in engineering is to find a solution that will improve on the costs and risks of the dairy food system while maintaining or improving on the benefits.

TEACHER SUPPORT

In Lesson 21, students identified the following list of problems:

- Fertilizers and other pollution in waterways
- Biodiversity loss from infrastructure or monocultured crops
- Transit greenhouse gas emissions
- Processing and packaging
- Greenhouse gas emissions from cattle
- Greenhouse gas emissions from manure
- Air pollution from the dairy system

The texts in this lesson correspond to those problems identified. If you allowed students to choose an additional problem, you will have to research and prepare three custom solution options to present to students here.

Give student problem groups the Lesson 23 Student Handout Solution Texts that correspond to the problem their group chose. Each problem identified in Lesson 21 has a set of three short readings about three different potential solutions. Allow students time to read each text together with their group or individually as you think appropriate. As students read, they should annotate each article to help them understand what the solution is that is being proposed and how it functions to solve the problem each group chose. Prompts to support student annotation are given on the Lesson 23 Student Guide Part 2.

STUDENT SUPPORT

If students need additional support in reading the text, consider asking students to use a collaborative reading strategy such as a Read-Aloud-Think-Aloud.

As students work, circulate the room and ask students pressing questions. Questions may include:

- What solution is being proposed by the text?
- Have you heard of a solution like this before? If so, how did this article build on your understanding?
- How will this solution change the design of the dairy system?
- What impact will that change have on the outputs of the dairy system or on its externalized costs?

- How will this solution improve the responsible management of natural resources by the dairy system?

Example student summaries could include:

- The solution proposed by the text is to selectively breed cattle for traits that reduce the amount of CH_4 produced by the animal. This solution would require careful trait selection and breeding considerations. It changes the system because there would be less CH_4 production, which means the impact of the system is reduced.
- The solution proposed by the text is to use plants that require less fertilizer to reduce the amount of synthetic fertilizer used on crops. This solution presumes that farmers would be willing to grow specific crops, like soybeans or alfalfa, that sequester nitrogen into the soil. It would not change the system because this is a common practice that farmers already implement for their crops, which would mean the impact of the system is not significantly changed.

STUDENT SUPPORT

If students need additional support to summarize how a solution works, consider:

- Directing students to the Lesson 21 activity, where students identified the Problem, Mechanism, and Impact. Ask students to read the passage and try to determine how the solution takes advantage of knowledge of the mechanism to solve the problem.

CCSS SUPPORT

RST 9-10.2: Determine the central ideas or conclusions of a text; trace the text's explanation or depiction of a complex process, phenomenon, or concept; provide an accurate summary of the text. Students will engage in this standard by identifying the central ideas of each text and using the information that they find to answer the Module Question.

Once the summaries are complete, instruct the student groups to analyze one solution at a time by reflecting on the benefits and potential costs and risks of implementing the solution. Students can record what they find on the Lesson 23 Student Guide.

As students work, circulate the room and ask pressing questions. For example:

- How does this solution help solve the problem you identified?
- Were the benefits of the system maintained or improved? How?
- Were the costs and/or risks improved on? How?

Example student response could include:

- Benefits: Dairy cattle can be bred for low CH_4 production by looking at the genetic traits of sires and relying on artificial insemination to ensure those traits are more likely to be expressed in offspring. The trait selection index can be expanded as new genetic technologies become available.
- Costs and Risks: Genetic traits may not always be expressed accurately, leading to unexpected outcomes. Other expressed traits may counterbalance low CH_4 production if not accounted for. Genotype and environmental interaction may occur due to a lack of information or unknown biological regulation of relationships of the trait.

Once students have assessed the benefits, costs, and risks, they should each answer the following question in the space provided in their Lesson 23 Student Guide: Overall, how do you think these solutions increase or maintain the benefits of the dairy system, while decreasing its costs and/or risks of the problem your group is focusing on?

Example student response could include:

- This solution allows us to still have a large number of dairy cattle producing a significant volume of milk, maintaining the benefit of dairy production. Simultaneously, it improves the costs of the system by decreasing the amount of greenhouse gases produced by the cattle.

STUDENT SUPPORT

If students need additional support to consider how a solution influences the benefits, costs, and risks of the system, consider having students return to the list of costs, risks, and benefits from Lesson 21 and ask students how they think this solution might impact any of these costs, risks, and benefits.

After students finish, they will share their analysis with another group who has chosen the same problem. The group should work towards consensus using the Consensus Conversations Routine to discuss how the solution maintains the system benefits while improving on its costs and risks.

Use the following steps for the Consensus Conversations Routine:

1. As a group, go through each idea one by one, discussing its potential benefits, costs, and risks.
2. Encourage constructive criticism and ask clarifying questions to ensure everyone comprehends each proposal.
3. Look for areas of agreement among the ideas presented.
4. Highlight shared elements that can be integrated into a comprehensive solution.

STUDENT SUPPORT

If students disagree, provide them with these tips:

- Encourage students to respect differing opinions and try to understand the underlying concerns.
- Ask students to work together to find compromises or alternative solutions that address the concerns of all group members.

Part 3: Evaluating Possible Solutions

Next, share with students that they will use an Engineering Design Matrix to evaluate their solutions using the criteria and constraints decided on in Lesson 22 and recorded in the Lesson 22 Student Guide Part 3: Developing Specific Criteria and Constraints. These tools will help students figure out which solution they may want to implement.

Direct students' attention to the Engineering Design Matrix found in Lesson 23 Student Guide Part 3: Evaluating Possible Solutions. Share that this is a tool used to systematically compare how well different solutions to a problem meet the criteria for the design. To introduce students to how to use the tool, guide student groups through these directions for analyzing solutions using an Engineering Design Matrix:

1. Students begin by reviewing the specific criteria they developed in Lesson 22 for evaluating potential solutions.
2. Once students have reviewed the criteria, they will complete the Engineering Design Matrix by listing the proposed solutions across the top row and the criteria they want to choose in the first column on the left side.
3. Next, students will assign a weight for each criterion based on its importance to the problem they are addressing. Use a scale of 1 to 5, where 5 indicates the highest importance. Students can assign the same weight to multiple criteria if they choose.
4. Now, for each proposed solution, students will evaluate how well it meets each listed criterion. Use a scale of 1 to 5, where 5 indicates the best alignment with the criterion.
5. Once students have evaluated how well each proposed solution meets each of the listed criteria, multiply the weight assigned to each criterion by the score given to the solution for that criterion. This will yield the weighted score for each solution for that specific criterion.
6. Students will then compare overall scores for each potential solution. The solution with the highest total weighted score is considered the most favorable based on the students' chosen criteria.

Allow students time to work through the Engineering Design Matrix. As students work, circulate the groups to ask pressing questions. Questions may include:

- Why did you rate this solution first/second/third in this criterion?
- Which solution do you think meets this criterion the best? Why?
- Why do you think this criterion is most important? Did you consider...

- There are social, economic, environmental, and scientific considerations for each of these solutions. How are you deciding which is most important? What are the implications of this choice?
- What tradeoffs in choosing a solution may be involved if you rank the solutions this way?

If students need additional support in ranking each of the solutions by each of the criteria in the Engineering Design Matrix, consider:

- Filling out an Engineering Design Matrix with the class using a more familiar problem and set of solution options, such as the problem, "What should I eat for lunch?" Provide students with a few example solution options that may be relevant to them (for example, salad, sandwich, tacos, burger, cookies, pizza, etc.) and walk through each step of the process of filling out a sample Engineering Design Matrix.
- Providing sentence stems to support students in ranking their criteria and choosing which solution performs best in a criterion, such as, "I think (criterion) should be ranked the highest because..." or "I think (solution) performs best in (criterion) because..."
- Focusing students' attention on a specific criterion or solution they seem to be overlooking.

After students have finished analyzing the suitability of their solutions using the Engineering Design Matrix, students will use the results of their Engineering Design Matrix to identify which solution they will choose to move forward with. Share with students that they will now select a solution that they think is best to implement. Share it is important to not just choose the solution that was best on the Engineering Design Matrix because, while the Engineering Design Matrix provides a ranking of possible solutions, students still need to consider the specific tradeoffs that may arise when choosing one solution over another.

As students work to choose the solution that they want to move forward with, they can answer the reflection questions in the Lesson 23 Student Guide.

FORMATIVE ASSESSMENT OPPORTUNITY

Students evaluate competing design solutions that can redesign components of the dairy system to improve on the problems of the dairy system while considering a variety of criteria and constraints, including those from cost, safety, reliability, social, cultural, and environmental impacts.

Assessment Artifacts:

- Students' choice of which of the competing design solutions best addresses the problem they have identified (Lesson 23 Student Guide Part 3 Evaluating Possible Solutions).

- Students' reflections on why they chose the solution that they want to move forward with (Lesson 23 Student Guide Part 3 Evaluating Possible Solutions).

Look Fors:

- Students choose a design solution from the competing design solutions and cite at least two pieces of evidence from the texts for their choice (ARG-H6).
- Students name the cost, safety, reliability, social, cultural, and environmental factors they considered when making their choice, and how they balanced these factors in making their choice (ETS1.B-H1).
- Students name the new task(s) that their redesigned system will accomplish when the solution is implemented (SYS-H1).

Assessment Rubric:

	Emerging	Developing	Proficient
Sample Student Response	I think rotational grazing is the best solution because it can help the cattle produce milk while they are still grazing. This solution idea has benefits because it improves on the conditions for the cow and the cow can still make milk.	The solution that is the most promising is rotational grazing. The reason this is the best solution is because it improves the dairy system in many ways. It reduces greenhouse gas emissions (environmental benefit), improves biodiversity loss (environmental benefit), and provides more nutritious milk (social benefit). If this solution is implemented, the dairy system will improve because it now can produce dairy products while also protecting the environment.	According to the matrix, the solution that is the most promising is rotational grazing. The reason it did so well is because it met many criteria including reducing a variety of greenhouse gas emissions, improving biodiversity loss, and protecting waterways. Some tradeoffs are that favors managing cattle to help the environment and produce milk, but it can be labor intensive and require land to graze. This would impact the economics of a dairy system and the ability for a farm to be large scale. I would like to implement rotational grazing. I think this is the solution that addresses the most of my criteria. It helps the environment because it reduces pollution from fertilizers in monocropping that comes from runoff. It also addresses an ethical consideration because it helps the cattle live a happier life by allowing them to use their natural behavior of grazing instead of being in a barn all day. I think it also provides a social benefit because the milk from grazed cows is healthier for people. And finally I

			think it also addresses an economic consideration because the cattle can still produce milk for the farmer. I think the dairy system will now not only be able to produce dairy products, but the parts of the system that feed the cattle will function to protect biodiversity rather than reduce it when monocultured crops are produced. It will also function to make animals have a more happy life.
How to Achieve This Level	Student completes 0 out of 3 Look Fors	Student completes 1-2 out of 4 Look Fors	Student completes 3 out of 3 Look Fors

To Provide Additional Support for Students:
Ask questions such as the following to press their thinking:

- What tradeoffs does choosing this solution over the other two involve? What kind of tradeoffs are they (economic, social, environmental, etc.)?
- Which considerations were the most important in your choice? Ethical, environmental, social, or economic?
- How did the way you ranked the criteria influence your choice of solution?
- Why will this solution lead to more responsible management of natural resources? Compared to other solutions, how will it better improve the dairy system?
- How does this solution meet the constraints of the design?
- What problem in the system does this solution address? How does it solve the problem?

After students respond to the reflection questions, hold a whole class discussion for selected students to share which solutions they chose and their reasoning for choosing them. As students share, record summaries of student reasoning on the board. Facilitate the conversation such that students agree that the best solutions to the problems we identified in the dairy system are those help us more responsibly produce dairy products while also having less impact on the environment. The best solutions also improve on the costs and risks of the system while maintaining or improving on the benefits. Some solutions improve on one cost and risk, while other solutions improve on multiple.

Part 4: Navigation to the Next Lesson

Ask students to return to the list of steps of the engineering design process from the start of the lesson. Ask students which step they now think they can take to move forward in designing solutions to the effects of the dairy industry. Confirm that, next, students will engage in communicating their design choices to their peers by preparing a presentation of their solution for a relevant audience.