Traceability in Hydroponic Greens

FACILITATOR GUIDE | AGRICULTURAL CYBERBIOSECURITY ACTIVITY

https://doi.org/10.21061/cyberbiosecurity

Activity overview and background information:

The purpose of this activity is to enhance interest in STEM fields through an activity designed to facilitate problem-solving, critical thinking, and scientific observation. Using the lens of cyberbiosecurity concerns in fresh produce, specifically leafy greens, participants encounter a real-life problem where they will have to observe, document, and critically evaluate the problem, given the collected information to make science-informed decision(s).

For background information on cyberbiosecurity concepts in this activity, please see the following Fact Sheets in the Cyberbiosecurity Education Resource Collection at https://doi.org/10.21061/cyberbiosecurity

- Cyberbiosecurity
- Biosecurity
- Sensors
- Bioeconomy

Important Note: This hands-on activity is designed to be implemented using an existing hydroponic unit. You can also build your own hydroponic system to utilize in this activity by following existing guidance. **Throughout the growing cycle in this activity, follow the directions from your hydroponics system's manufacturer**. Recommended resources:

- University of Minnesota Extension Small-scale hydroponics how to guide
- Exploring Hydroponics Guide from Kids Gardening

SOLs and CTE competencies:

- CS 6.6: identify physical and digital security measures used to protect electronic information.
- Sci 6.6: investigate and understand that water has unique physical properties and has a role in the natural and human-made environment.
- Ag 8002: 42. Describe the interdependency of agriculture and other segments of society. 44. Identify basic requirements for plant growth and development.
- Ag 8003: 60. Explain the use of hydroponics and aquaponics in growing plants.
- Ag 8004: 70. Discuss the importance of water to agriculture. 77. Explore the food industry as it relates to agriculture, agriscience, and agribusiness.
- CTE Prof Comp: Demonstrate an understanding of information security. Includes: describing cybersecurity (e.g., risks, threats, vulnerabilities).

Learning objectives:

1. Describe the role of monitoring water pH, water temperature, amount of water, and amount of nutrients in hydroponic systems.
2. Describe the importance of biosecurity in hydroponic growing systems.
3. Explain the role of traceability in the food system.

Safety:

Follow all relevant safety procedures as recommended by your hydroponics system manufacturer and general laboratory safety rules, including but not limited to:

1. Proper handling of all materials
2. Personal Protective Equipment (PPE)
3. Proper disposal and storage of chemicals and materials

Time:

Lesson "days" will depend on the time your actual system takes to grow. This is a suggested flow of content. You may need to teach other lessons while the plants are growing. Example of other things you can do on "off days" include looking at plant cuttings, exploring other plants that can be grown hydroponically, search for what is grown hydroponically in the grocery store, etc.

Vocabulary:

1. **Cybersecurity**: Protection of computer systems and networks from the theft of or damage to their hardware, software, or electronic data, as well as from the disruption or misdirection of the services they provide.
2. **Cyberbiosecurity**: identification of the weak spots between biosecurity, cybersecurity, and cyber-physical security to safeguard data and systems
3. **Hydroponics**: the process of growing plants in sand, gravel, or liquid.
4. **Automated**: carried out by machines or computers without needing human control.
5. **Food safety**: the practices and conditions and that ensure the quality of food to prevent contamination and food-borne illnesses.
6. **Growing medium**: the substance that plants are grown in.
7. **Fertilizer**: a substance added to soil to increase its fertility
8. **Water soluble**: able to be dissolved in water
9. **Germinate**: to begin to grow from a seed
10. **pH**: a number representing how acidic or alkaline a solution is
11. **Traceability**: the ability to find information about where and how a product was made

Materials, supplies, and activity prep:

For this activity, you will need:

1. Seeds (leaf lettuce, microgreens, and/or basil). There are many varieties of lettuce and leafy green seeds that exist and can be used in your hydroponic system of choice.
2. Growing medium
3. Water soluble fertilizer
4. pH strips or meter
5. Personal Protective Equipment
6. Examples of computer-based or automated systems (temperature sensors, lighting systems) – photos or your own system
7. Youth Activity Guide for each participant
8. Video: Down on the Farm- Apple Sorting: USDA-ARS https://youtu.be/21SB9FJjf2M
9. Video: What is Hydroponics? https://www.youtube.com/watch?v=slkv7WgSXK8

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Setting the stage:

1. **Show Video**: Down on the Farm- Apple Sorting: USDA-ARS https://youtu.be/21SB9FJjf2M
2. **Discuss**: participants identify any food safety concerns they see in the video. This should be a warm-up/ brainstorming discussion where any and all ideas are welcome.
3. **Introduce participants to the situation**: They will be acting as agricultural workers in a fresh produce operation that grows crops in a hydroponic system to sell at grocery stores. As they grow their crops over the course of the next several weeks, they will be responsible for ensuring that the products are safe, delicious, and ready to sell to customers. You, their supervisor, are concerned that the fresh produce operation may be at risk of cyberbiosecurity threats.
4. **Review safety**: Make sure to reinforce throughout the activity
    a. Proper handling of all materials and PPE
    b. Proper disposal and storage of chemicals and materials
    c. General lab safety rules
5.

Activity facilitation steps:

There are 7 parts to this activity, as described here. Lessons on topics related to hydroponic growing systems and cyberbiosecurity are interspersed with the growing process because of the wait time while the plants are growing. Participants monitor the system throughout as they continue to deepen their knowledge. A suggested flow is provided here, but this activity guide can be modified to fit different educational environments and/or curricular needs. *Completed worksheets with example data and guiding questions for observations are provided at the end of this guide. The blank worksheets are in the Youth Activity Guide.*

Part 1: Introduction to hydroponics and our system

Purpose: Introduce central ideas and to help get participants ready for the project

Instructions:

1. Define hydroponics: A hydroponic system recycles water and nutrients to support the growth of the fresh produce items planted in the system. Review/introduce key plant science concepts, including fertilizer, pH, grow medium, monocot and dicot, plant needs for growth (sunlight, etc.), leading to the idea that you don't always need soil! Then, guide participants to think of examples of computer-based or automated systems in hydroponics (e.g., temperature sensors, lighting systems).
    - This can be done through showing the video (What is Hydroponics? https://www.youtube.com/watch?v=slkv7WgSXK8) and pausing to discuss key concepts throughout.
2. Define cyberbiosecurity threats in food production: Cyberbiosecurity threats are events when an error (or data breach) in a computer monitoring or other automated system could result in a food safety issue that makes your fresh produce unable to be sold because it might make people sick if they eat it.

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Part 1 (cont.): Introduction to hydroponics and our system

3. Examine your hydroponic system: Introduce the system to participants and have them examine it.
    - Ask: What potential opportunities do you see for cyberbiosecurity issues? Why do you think that?
    - You may need to remind participants to look for automated systems in the design of the hydroponic units. Think about water pumps, lights, etc.
4. Assign teams.
    - These participants will be paired together throughout the next six weeks of the activity. It is encouraged that they be provided a way to remember their teammate (nickname, team name, etc.) and a way to save the materials they will need to use over subsequent class periods (assigned folder, clipboard, materials in Google Classroom, etc.).
5. Looking ahead: Let participants know that while they are growing fresh produce, you will guide them to think about different ways your products (or crops in production) might be vulnerable to food safety issues due to a cyberbiosecurity threat.

Part 2: Seeding (can be done first to get the plants going if needed)

Purpose: Educate participants about the origins of their food and all of the ways scientists are needed to help keep that food safe while it grows. The participants will learn about how seeds that will become the food we eat start in a hydroponic operation.

Task: Follow manufacturer's instructions for preparing the seeds for germination

Instructions:

1. Explain the purpose of this step of growing produce to the participants then lead a discussion around growing fresh produce inside versus outside. Guiding questions:
    - What sorts of differences do you see between growing fresh produce inside versus outside?
    - What are cyberbiosecurity issues in hydroponics?
    - Do you think the cyberbiosecurity issues may be different in these two environments? Why or why not?
    - Transition to activity: Even though there are differences between growing food indoors versus outdoors, one similarity is that the plants start as seeds before they grow into food. We will get to participate in the process of turning seeds into food over the next several weeks.
2. Hand out Youth Activity Guide and direct participants to the "Seeding Worksheet" (one per team is recommended). The worksheet should be useful for many types of systems.

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Part 2 (cont.): Seeding (can be done first to get the plants going if needed)

3. Task one participant with observing the "data" (state of the seeds) and another with documenting the "data" (writing it on the worksheet). They may switch roles each week if you choose.
    - You may show an example to the participants of how one would observe and the other document the data.
4. Seeding: Follow manufacturer's instructions for preparing the seeds for germination.
5. Observe: Observe and document the seeds for changes (sprouting) every class day until it is time to transplant the seeds to the hydroponic unit. *Follow package information for approximate time to germination.
    - You may need to remind the participants to place their seeds in a dark part of the classroom - just like how we place seeds in soil when grown outside.
    - During this time, discuss basics of germination: The seed contains almost everything it needs to turn into a plant. The seed contains a covering that protects the nutrients inside. When the environment is right for growth, a seed will break open and sprout, or germinate. You will be able to observe this. It is your job to monitor your seeds each class period to see if, when, and how many seeds sprout.
    - Before participants can transfer their plants to the hydroponic system, they must first sprout.

Part 3: Preparing to transplant

Purpose: Prepare participants to move their seeds from the foam into the hydroponic unit.

Task: Check progress on data collection or remind participants to observe their seeds and document whether or not they sprouted.

Instructions:

1. Introduce the concept of transplanting seedlings.
    - By now seeds should have sprouted and be growing nice and tall. This means they are almost ready to transplant to the hydroponic unit.
    - Transplanting is the process of moving a fully sprouted seedling and replanting in a new, permanent location while it grows. They will stay here until they are ready to be harvested and shipped to grocery stores
    - Ask: Have all of your seeds sprouted? Are there any that have not? Why do you think some seeds sprouted and others did not?
    - Remind them to think about all factors that we know help seeds germinate and grow.
2. Remind participants to continue to observe and document whether their seeds sprouted.
    - participants should add any additional observations in the "Notes" section of their Youth Activity Guide.
3. Participants should have recorded their observations in every class period. If they have days missing, do not ask them to fill in the information. Instead, tell them to cross out that day or leave it blank.
    - Any missing data should be explained in the "Notes" section of their seeding worksheet.

Part 4: Transplanting and preparation for monitoring

Purpose: Show participants how much work and precision goes into the science of growing food and all of the ways the process may be vulnerable to contamination.
Task: Transplant seedlings into hydroponic unit.

Instructions:

1. Reinforce the purpose of transplanting and why it is important for allowing the seedlings to grow into food. Talking points:
    - This week you will transplant your seedlings to the hydroponic system.
    - This is important to give the seedlings space to grow into the plants you will ship to grocery stores to eat as food.
    - As you transplant, look for any opportunities where cyberbiosecurity issues might happen?
2. Transplant: Instruct the participants how to transfer their seedlings following manufacturer's guidance. You may watch videos online or provide step-by-step instructions.
3. Have participants record the transplanting event and data on the "Transplanting worksheet" (in Youth Activity Guide) in the way they have been collecting and monitoring data so far.
    - One participant should take the lead on observing information and the other should record it.
4. Prepare for monitoring: There are lots of factors that impact how well plants do or do not grow. You will examine some of these in the next few weeks, including water pH, water temperature, amount of water, and amount of nutrients.
    - Show participants how to collect each of the types of data for this part of the activity. If they will monitor pH with strips, show them how to read it. If they will be visually monitoring water height, show them how to record that or place a line on the unit so they know when more water should be added.
5. Assign existing participant teams to the activities they will monitor now that the seedlings have been transplanted to the hydroponic unit
    - One group should monitor each tray using "Growing worksheet 1" (in Youth Activity Guide).
    - One group should monitor the status of the entire system using "Growing worksheet 2" (in Youth Activity Guide).
    - You may choose to either have larger groups monitor these events or have multiple smaller groups conducting the same activities. The latter option may provide a more interesting discussion during the traceability activity in a few weeks.

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Part 5: Growth and monitoring (several weeks, time dependent on crop) and background on properties being monitored

Purpose: Follow directions, grow individual autonomy and sense of responsibility. Learn about the importance of monitoring water pH, water temperature, amount of water, and amount of nutrients.
Task: Daily (e.g., each class period) monitor growth parameters using appropriate worksheet for each group. Periodic group discussion on progress. When it makes sense for your individual schedule during this time, discuss the background and key concepts for each of the things that the teams are monitoring for: water pH, water temperature, amount of water, and amount of nutrients.

Instructions:

1. Monitoring: Instruct the participants to (on their own) observe and collect their data each class period through the end of the growing period.
    - Teams will follow the same pattern they have been for the last parts - one team member will collect the data and the other team member will record the data. You may switch who performs these roles each week if you choose. Be sure that you use the correct "Growth Worksheet" for your team's job.
    - If participants are neglecting to keep up with their data on their own, you may need to remind them of their responsibility to their respective tasks.
2. Discussion on progress: Guiding questions to ask ~weekly:
    - You have now been monitoring your seedlings for [amount of time]. What have you noticed? What types of cyberbiosecurity issues do you see the potential for?

pH key concepts:

1. pH in hydroponic systems
    - What is pH? You can think of pH as being similar to acidity, or how acidic something is. You probably already notice this in your life. How does a lemon taste compared to a carrot? A lemon is more acidic (and has a lower pH) than a carrot.
    - Why is it important for plants? Just like you, plants have pH ranges that best help them grow. In hydroponic systems, crops may have different ranges they prefer compared to when they are grown outside and in soil.
    - Special considerations for hydroponic systems: pH is also important for making sure your sanitizer is working well. Fresh produce growers will often add sanitizers to wash water or hydroponic systems to prevent foodborne pathogens, or the microorganisms that make you sick after eating them, from spreading between crops. When you are monitoring your pH readings, know that this is helping the plants grow and helping keep them safe!
2. pH in our system: Explain to participants which pH range and optimum they should be monitoring for and what sanitizer you have added to your hydroponic system.

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Part 5 (cont.): Growth and monitoring (several weeks, time dependent on crop) and background on properties being monitored

Temperature key concepts:

1. Temperature in hydroponic systems:
    - Why does temperature matter in hydroponic systems? Once again, similar to you, plants have temperature ranges that are best for growth. If the water in the hydroponic system is too hot or too cold, they will not grow as quickly or as well.
    - Water temperature may also impact how well the sanitizer works, so know that this factor is also important for helping your seedlings grow safely!
2. Temperature in our system: Explain to participants which temperature range and optimum they should be monitoring for.

Amount of water key concepts:

1. Amount of water in hydroponic systems:
    - The amount of water in the hydroponic system is important to provide the plant access to nutrients to grow.
    - If the water is too low, the roots will be able to expand and take in water and the nutrients dissolved in it up to the leaves. If the water is too high, the plants may hold on to too much water and not be able to grow.
2. Amount of water in our system: Explain to participants what the appropriate range and optimum is for the water level and what they should be monitoring for.

Nutrients key concepts:

1. Nutrients in hydroponic systems:
    - The amount of nutrients dissolved in the hydroponic system is important because these contain all of the major nutrients (or food) that the plants need to grow.
    - If the nutrient amount is too low, the plants may grow slowly or develop disorders that make them not possible to sell or eat. If the nutrient amount is too high, it can harm (or "burn") the plants, which also prevents your business from being able to sell them at the grocery store.
2. Nutrients in our system: Explain to participants what the appropriate range and optimum is for nutrients and what they should be monitoring for.

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Part 6: Harvest

Purpose: Follow directions, grow individual autonomy and sense of responsibility, learn about the practices associated with harvest in hydroponic systems.
Task: Daily (each class period) monitor growth parameters using appropriate worksheet for each group. When ready, harvest the crop.

Instructions:

1. During a session close to the end of the growing period, introduce the concept of harvesting during fresh produce production. Discussion points:
    - Once your crops are fully matured, you will be able to harvest them and prepare to ship them to grocery stores where your customers will purchase and eat them. This is an important part of the process of growing fresh produce - it's what you've worked so hard for!
    - How many of your plants do you think will be ready to harvest next time we meet?
    - Have you noticed any cyberbiosecurity issues while you have been collecting and recording data these last few weeks? Did you write them down on your worksheet?
2. Harvesting timing
    - Watch a video (either the hydroponic unit's manufacturer's or another appropriate option) with participants to show them how to tell when the plants are ready to be harvested.
3. Harvesting techniques
    - Watch a video (either the hydroponic unit's manufacturer's or another appropriate option) with participants to show them how to harvest their crops.
4. Harvest: Allow each participant an opportunity to harvest some of the crop.
    - Using "Transplanting Worksheet", harvest the crop - and maybe sneak a taste!
    - Ask: What did you learn during this part of the exercise? Where do you anticipate cyberbiosecurity issues might exist?

Part 7: Traceability exercise

Purpose: Use critical thinking and problem-solving skills to a timely problem in the agricultural industry
Task: Participate fully in cyberbiosecurity activity. 30 minutes.

Instructions:
Facilitate the cyberbiosecurity exercise with the participants in the next session after harvest. This scenario puts the participants in a real world scenario in which they think that their produce was contaminated. Use your judgment to modify the scenario as you see fit for your group. For example, you may want to keep it hypothetical. Or, you could say that there is a concern, but it's not clear if it came from our crop. Details should be updated with as much as possible to match the growing experience that participants had in terms of where the produce was "shipped." The key is that they have to engage with the idea of traceability and use their data as a record.

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Part 7 (cont.): Traceability exercise

You can use the content and flow here as a basis for your scenario:

1. Provide participants with “Traceability Worksheet” in the Youth Activity Guide
2. Introduce scenario: *Uh oh - I just got a call from the Food and Drug Administration saying your fresh produce is contaminated with foodborne pathogens! The Food and Drug Administration (or the FDA) is the branch of the U.S. government charged with making sure the food that is sold to the public is safe for them to eat. You now have to contact the grocery store and tell them to recall your product. But which products do you need to recall? How do you know which ones were contaminated? Let’s trace back your product from the grocery store all the way back to the seeds to see if we can figure out when the product was contaminated so we can tell the grocery store which crops cannot be sold.*
3. The task: Can you figure out when the crops were contaminated and tell the grocery stores which ones they cannot sell? Participants use the ““Traceability Worksheet” to guide their thinking.
4. Discuss: When appropriate, bring the participants back together to discuss. See what their recommendations are and what they have to say. Were they really linked to cyberbiosecurity issues?
5. New information: *Your supervisor conducted their own investigation and found the following: a computer hacker group hacked the automatic sanitizer system the operation was using in the hydroponic system. Instead of adding sanitizer to the water when it was needed, the automatic system was turned off and no sanitizer was added to the unit. This allowed foodborne pathogens to cross-contaminate all the produce in the hydroponic system. Cross-contamination occurs when something is contaminated and transfers that contamination to an uncontaminated piece of equipment, the water, or even the produce itself. This means that all the produce you grew has to be recalled and cannot be sold.*
6. Discussion (no more than 5 minutes since no one was monitoring this): Why do you think this happened? Who was monitoring the automatic sanitizer system?
7. Wrap-up discussion on prevention: What do you think you could do to prevent this cybersecurity threat from happening in your operation? How would you help other fresh produce growers from having this same problem?

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Processing questions

Share

1. What did you find interesting in growing your plants?
2. What did you learn about cyberbiosecurity?
3. What are some important things you learned that impact hydroponic growing systems?

Generalize

1. How does leafy greens recall happen?
    a. discuss a recent example to make sure they understand what a recall is (traceability)
2. What could go wrong in a hydroponics system that would be different from what would happen in a field?
    a. discuss environmental versus cyberbiosecurity related threats

Apply

1. What can be done to prevent contamination in hydroponics systems?
2. What ideas do you have for a new technology or software that could help prevent human or computer error within hydroponics systems?

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Seeding Worksheet

Names: _____

Date seeds placed in foam: _____

Circle your crop: Lettuce Microgreens Basil Other: _____

Have your seeds sprouted? Record your data as “Yes” or “No” in the table below. Include the dates or days of the week you examined your samples.

Sample	1 Mon	2 Wed	3 Fri	4 Mon	5 Wed	6 Fri
A1	No	Yes	Yes	Yes	Yes	Yes
A2	No	No	Yes	Yes	Yes	Yes
A3	No	Yes	Yes	Yes	Yes	Yes
A4	No	No	Yes	Yes	Yes	Yes
A5	No	No	No	Yes	Yes	Yes
A6	No	No	Yes	Yes	Yes	Yes
A7	No	No	No	No	No	No
A8	No	No	No	No	No	No

Did you notice anything else interesting about your seeds? Record your notes below.

Guiding questions for facilitator: How tall are your seedlings? What colors are they? What direction are they growing?

_____

_____

_____

_____

_____

_____

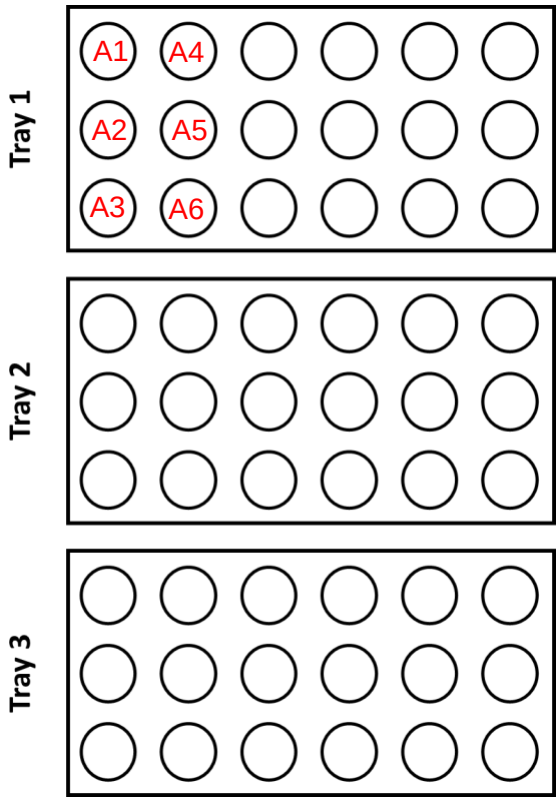
Transplanting Worksheet

Names: _____

Circle your tray: Tray 1 Tray 2 Tray 3 Other: _____

Date sprouts transplanted:_____

Where did you place your sprouted seeds in the hydroponic system? Fill in the example hydroponic system with your samples below.



Record your observations about the transplanting exercise below.

Guiding questions for facilitator: Did the seedlings feel sturdy or fragile? What was difficult or easy about the transplanting process? Why did you pick those locations in the hydroponic unit? What do you think will happen to the seedlings?

_____

_____

_____

_____

Growing Worksheet 1

Names: _____

Circle your tray: Tray 1 Tray 2 Tray 3 Other: _____

Date sprouts transplanted:_____

As you are monitoring your plants, record your observations about the pH of the water in your tray and your observations of plant growth below.

Sample Day	Water pH	Growth Notes
1 - Mon	6.5	
2 - Wed	6.4	
3 - Fri	6.5	
4 - Mon	6.8	
5 - Wed	6.3	
6 - Fri	6.7	

Did you notice anything else interesting about your plants as they grew? Record your notes below.

Guiding questions for facilitator: Are all of your seedlings growing well? Why do you think that is? How many leaves are you seeing on the plants? Are all of the plants growing evenly or at different rates?

_____

_____

_____

_____

_____

_____

_____

Growing Worksheet 2

Names: _____

You are monitoring: Whole system Other: _____

Date sprouts transplanted:_____

As you are monitoring the hydroponic system, record your observations about the water temperature and whether nutrients or water were added below.

Sample Day	Water Temperature	Were nutrients added?	Was water added?
1 - Mon	72°F	No	No
2 - Wed	72°F	No	No
3 - Fri	72°F	No	No
4 - Mon	73°F	No	No
5 - Wed	72°F	Yes	Yes
6 - Fri	72°F	No	No

Did you notice anything else interesting about the system or the plants? Record your notes below.

Guiding questions for facilitator: Are all of your seedlings growing well? Why do you think that is? How many leaves are you seeing on the plants? Are all of the plants growing evenly or at different rates?

_____

_____

_____

_____

_____

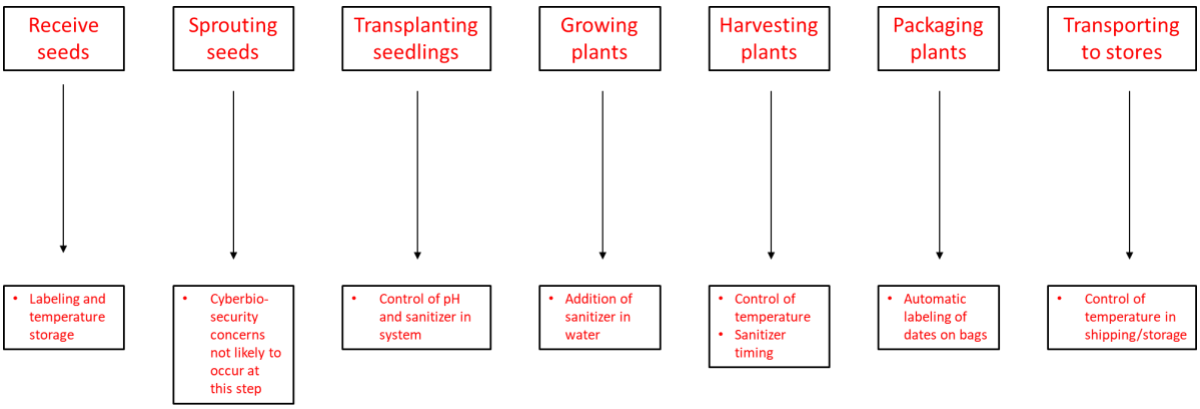
_____

_____

Traceability Worksheet

Names: _____

On the top half of the page, draw the process flow for your crop. Include all the major stages from seeds to the grocery store. Once you have drawn that, draw arrows from each stage to the bottom half of the page. Here, list the potential cyberbiosecurity issues you think may have occurred.



Now, work with other groups to check their data for each of the stages. Were any of the data collected out of the optimum ranges? Did they notice any cyberbiosecurity issues in their data collection? As you determine which stages were not the likely cause of the food safety issue, cross them off on your process flow above. Once you think you have identified the issue, write your thoughts and reasoning down below. Don't forget to tell the grocery store which crops to recall!

_____

_____

Acknowledgments

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About this project

Cyberbiosecurity is an emerging field that focuses on creating security measures for digital aspects of our food and agriculture systems, creating a structure and opportunity for a safe food system that can meet the large needs of a growing population and world. This educational resource was developed as part of a project to support formal and non-formal agricultural educators in integrating cyberbiosecurity topics and research-based strategies for engaging middle-school-aged girls in STEM into their educational programs.

The entire resource collection can be accessed here: https://doi.org/10.21061/cyberbiosecurity

The project is an outreach effort of the Virginia Tech Center for Advanced Innovation in Agriculture.

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This definition of OER is provided by The William and Flora Hewlett Foundation.

How to access these templates

The main landing page for these resources is https://doi.org/10.21061/cyberbiosecurity.

This page includes a downloadable and editable Word document for the:

- Student fact sheet
- Student activity sheet
- Faculty guide

Did you know that you can customize and share your version of this resource?

*Best practice is to list the title, author, source, and license.

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