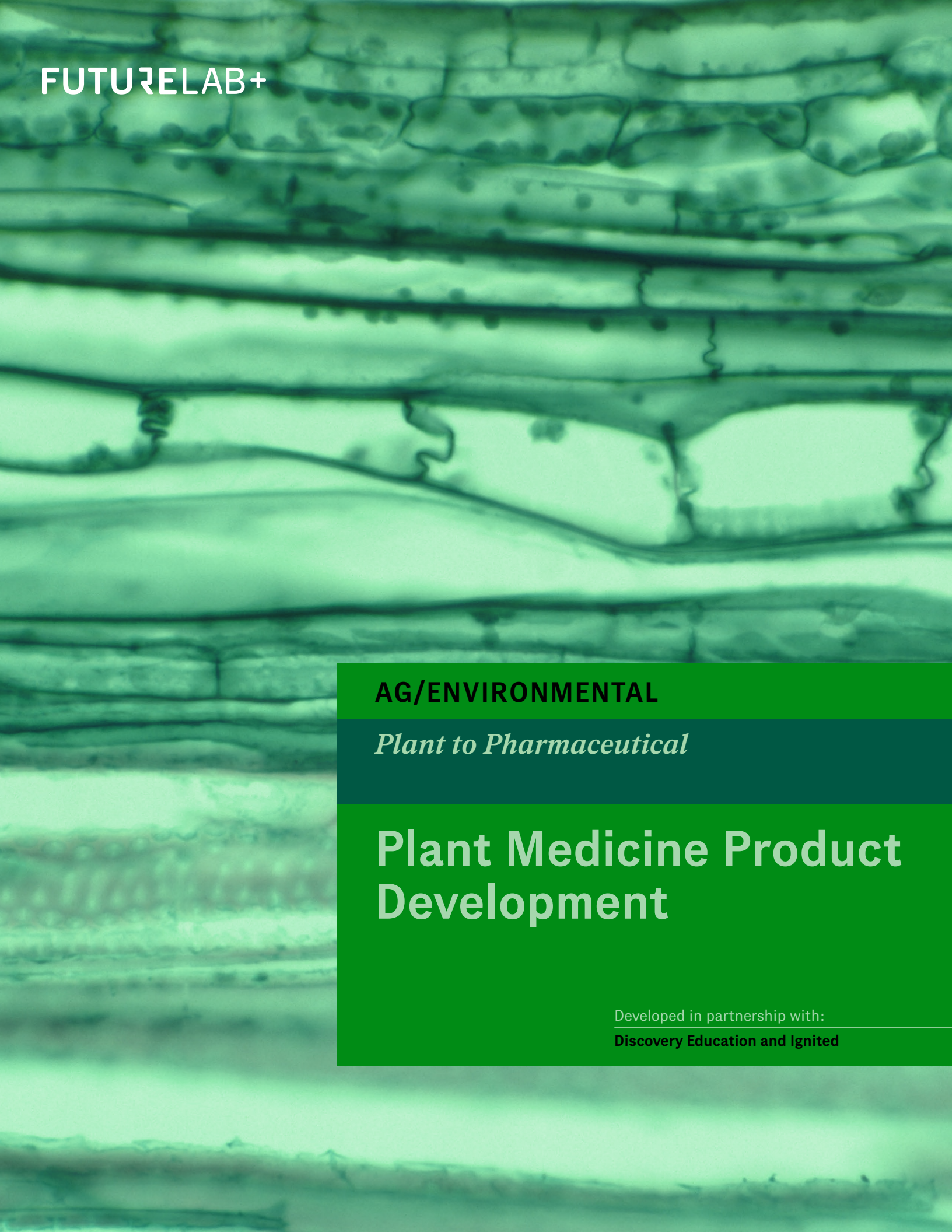

FUTURELAB+

AG/ENVIRONMENTAL

Plant to Pharmaceutical

Plant Medicine Product Development

Developed in partnership with:

Discovery Education and Ignited

In this Lesson Plan:

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This document is separated into two sections, For Teachers [T] *and* Student Resources [S]*, which can be printed independently.*

Select the appropriate printer icon above to print either section in its entirety.

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Single Pages (use a comma): T3, T6

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Cover Image
The Solanaceae plant family is rich in bioactive metabolites and has played an essential role in traditional medicine.

AG/ENVIRONMENTAL / PLANT TO PHARMACEUTICALS

Plant Medicine Product Development

ACTIVITY DURATION

Five class sessions
(45 minutes each)

DRIVING QUESTION

How do individuals collaborate on Project Teams to create a plant-based medicine, identify a patient population, and plan to scale and manufacture that medicine?

ESSENTIAL QUESTIONS

How do we design and scale the production of drugs that were derived from plants?

How do we identify patient populations and ensure access to affordable medicine?

How do we ethically collaborate with Indigenous communities?

OVERVIEW

After identifying a plant compound of interest, our Project Teams are ready to explore their medicine more deeply. As they work through diverse challenges, students will learn new collaboration and feedback skills, and will push their understanding of the connections of cellular biology to human health and the role of manufacturing decisions in getting a drug to market. By the end of the week, each Project Sub-Team will have created a draft product, representing key parts of the product life cycle.

In this lesson, students will collaborate on three project Sub-Teams:

The Molecular Modeling Team will build a two- or three-dimensional model demonstrating how a plant compound interacts with cell structures to treat a particular human disease or condition.

The Communications Strategy Team will identify a patient population and develop a communication strategy for the plant-based medicine, describing the target audience and communication product format.

The Finance Team will create a Benefits Sharing Agreement honoring the contributions of key stakeholders to the discovery of the plant-based medicine and will analyze the mode of manufacturing that will best get the plant compound to market at scale.

OBJECTIVES

Students will be able to:

Design a molecular model for how their plant molecule interacts with cells.

Analyze whether a sustainable farming/purification approach or an organic/biologic synthesis approach makes more financial and environmental sense.

Develop a marketing and communication plan.

Identify a specific patient population for which the plant medicine is relevant.

Materials

Construction Materials for Molecular Model
- *Cardboard*
- *Modeling Clay*
- *3D printer (if available)*
- *Popsicle Sticks*
- *Ribbon*
- *Pipe Cleaners*
- *Beads*
- *Toothpicks*
- *Paper (many colors)*
- *Paint*

Student Guide

Project Team Progress Check Capture Sheet

Molecular Modeling Team Day 1: Find a Protein and Medicine Model Using Molview Capture Sheet

Molecular Modeling Team Day 2: Use a Model to Communicate Capture Sheet

Molecular Modeling Team Days 3 and 4: Build Time Capture Sheet

Molecular Modeling Team Day 5: Create a Science Guide Capture Sheet

Materials

Communications Strategy Team Day 1: Identify Your Team's Patient Population Capture Sheet

Communications Strategy Team Day 2: Identify the Audience for Your Communications Plan Capture Sheet

Communications Strategy Team Day 3: Outline Communication Strategy Capture Sheet

Communications Strategy Team Days 4 and 5: Create a Draft of the Communications Product Capture Sheet

Financial Analysis Scaling Team Day 1: Values Discussion and Draft Benefit Sharing Plan Capture Sheet

Financial Analysis Scaling Team Day 2: Question Selection and Research Capture Sheet

Financial Scaling Analysis Team Day 3: Financial Analysis Introduction Capture Sheet

Financial Scaling Analysis Team Day 3: Decision Matrix

Financial Analysis Team Day 4: Complete Draft Quantitative Analysis Capture Sheet

Financial Analysis Team Day 5: Check In and Seek Feedback Capture Sheet

Pedagogical Framing

Instructional materials are designed to meet national education and industry standards to focus on in-demand skills needed across the full product development life cycle—from molecule to medicine—which will also expose students and educators to the breadth of education and career pathways across biotechnology.

Through this collection, educators are equipped with strategies to engage students from diverse racial, ethnic, and cultural groups, providing them with quality, equitable, and liberating educational experiences that validate and affirm student identity.

Units are designed to be problem-based and focus on workforce skill development to empower students with the knowledge and tools to be the change in reducing health disparities in communities.

SOCIAL-EMOTIONAL LEARNING

Students will engage in self-management as they use planning and organizational skills to progress through tasks. They will develop relationship skills by communicating with Project Team members, taking on leadership roles with time management and decision making.

CULTURALLY AND LINGUISTICALLY RESPONSIVE INSTRUCTION

Students will examine social groups while researching and determining patient population groups for a plant-based medicine, considering how those group memberships impact personal health and access to medicine. Project Teams will market a product that advocates for the well-being of patients. Teams will also develop guidelines for ethically collaborating with culturally and linguistically diverse groups.

ADVANCING INCLUSIVE RESEARCH

Roughly 60 percent of the world's population relies primarily on plant-based medicine. Much of that tradition is based on knowledge from Indigenous communities. When developing a medicine, one factor to consider is patient access. In this lesson, student examine tradeoffs during the development of a medicine.

COMPUTATIONAL THINKING PRACTICES

In this lesson, students will curate information from various digital resources as they design a model showing how a plant compound interacts with cell structures to treat a disease. Students will also use digital tools to evaluate and select a manufacturing mode for a plant-based medicine, considering constraints and calculated risks. Project Teams will break problems into component parts and develop artifacts to illustrate complex systems.

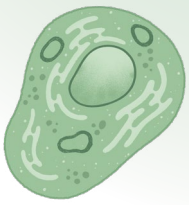
CONNECTION TO THE PRODUCT LIFE CYCLE

This lesson asks students to work as a Project Team at a simulated Biotech Firm and to create learning artifacts that mimic products that would be produced by professionals working in diverse roles. Students on the Communications Team will focus on defining their patient population and format for their final pitch. Students on the Finance Team will create a Benefits Sharing Agreement to honor the intellectual contributions of team members that were essential to the Discovery Phase of the Product Life Cycle. The Molecular Modeling Team will analyze how the plant-based compound alters cell function. Scaffolded internal team feedback cycles will allow students to experience the key role of cross functional teams throughout the full Product Life Cycle.

Have you ever wondered…

Who do biotech companies collaborate with as they work to discover, develop, manufacture, and commercialize a plant-based medicine?

During the discovery phase, biotech companies collaborate with researchers in academic institutions and in other fields to identify novel plant-based compounds. During the develop, manufacture, and commercialize phases, biotech companies collaborate closely with regulators at the FDA and global counterparts to make sure that the plant-based medicine is safe and effective. This involves testing in different patient populations during the develop phase, monitoring of drug ingredients and manufacturing processes during the manufacture phase, and broad scale monitoring of any adverse events as the drug reaches the market after FDA approval during the commercialize phase. All of these steps happen for any drugs that are FDA approved and are essential to producing safe and effective medications.



How do clinical trials help ensure that the medicine being developed is safe and effective?

Pre-clinical trials focus on cell line and animal models to make sure that at the cellular level, a novel medication is targeting the right systems and having an impact in vitro and in vivo. During Phase 1 of a clinical trial, researchers first work with a very small clinical population (1–10 patients), focusing on the question of the safety of the drug. If this data shows that a drug is safe, regulators at the FDA approve the trial to proceed to Phase 2 trials, which examine dosing regimes and efficacy in a slightly larger patient population (10–100 patients). If the data suggest that the drug is safe and effective, the FDA will approve a Phase 3 trial. This stage involves the largest number of patients (1,000–10,000 patients) and will examine how the drug works in comparison to a placebo or to the current standard of care. If a drug passes FDA review of Phase 3, it can then be placed on the market and delivered to the target patient population. If a medicine does not pass the FDA approval process, it will not reach the market in that form, which keeps all United States patients safe as they seek medical care.

MAKE CONNECTIONS!

How does this connect to the larger unit storyline?

How do particular plant compounds address and treat a specific condition? How do drug developers determine who could benefit from their medicine? In assumed roles, students will work on developing and marketing a plant-based medicine, modeling the product life cycle.

As employees of a simulated Biotech Firm, students will collaborate to determine the patient population who would benefit from a plant-based medicine, and an audience to which to market it. Students will research and model the effects of a bioactive plant compound on the human body to communicate the mechanism of action with the target audience. Different methods of drug production will be evaluated to determine the most beneficial production plan for all stakeholder groups.

How does this connect to careers?

Corporate relations professionals are in charge of communicating a diverse array of scientific materials to a wide range of audiences. Their creativity in messaging and close collaboration with researchers, medical professionals, the media, and legal leads to engaging and targeted communication products.

Product and supply chain management professionals are responsible for taking a process that might take place in one lab to a process that scales up in multiple labs to accommodate hundreds, thousands, or even millions of patients, all while maintaining the quality and efficacy of the product. The skills needed include quantitative analysis, collaboration, communication with partners, and an understanding of biochemical processes. and an understanding of logistics and supply chain issues.

Biochemists focus on how small molecules impact molecular processes within cells. They are amazing at figuring out direct and indirect ways to measure cellular changes that cannot be observed by eye or sometimes even with a microscope. They solve problems, create new methods to address questions without answers, and collaborate with other roles at the Biotech Firm to share their most promising work through presentations and written communication.

How does this connect to our world?

Students have the opportunity to experience a specific career role and develop research, communication, and collaboration skills as part of a professional team.

Students will gain experience communicating the relevancy of their work to groups outside of their team, developing real-world skills.

This lesson series is designed for students to embody diverse career roles while also experiencing the product life cycle in a student-centered format.

Day 1

Procedure

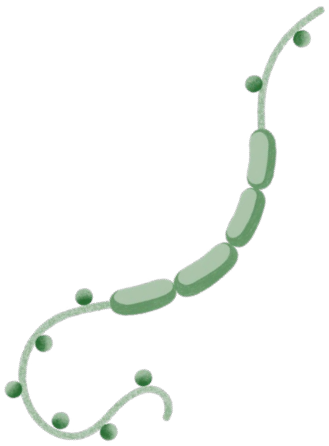
LEARNING OUTCOMES

Students will be able to:

Prioritize tasks to meet the Project Teams' end goals.

Share feedback with Project Team members and establish communication norms.

Reflect on collective progress.



Teacher Note > *This project is designed to be collaborative and student driven. To help support students through this process, each Sub-Team will use the Project Team Process Journal section of the* ***Student Guide*** *to prioritize tasks and assign themselves homework tasks as needed.*

- *It could be collected as an Exit Ticket each day to monitor progress.*
- *Students may choose to use sticky notes to track tasks from one day to the next in the Project Team Progress Check Capture Sheet, or to fill in a new version of the capture sheet every day to track tasks, or to complete the capture sheet digitally.*
- ***Student Guides*** *for each Sub-Team explicitly list daily tasks to accomplish, and provide scaffolding and support so that diverse learners can approach this work. Teachers can check progress to determine if tasks need to be modified for length and timing.*
- *A teacher flowchart in Lesson 8 provides a support structure for how to modify timing for student projects that are proceeding faster or slower than expected.*

Teacher Note > *Each Project Team Sub-Team (Communication, Finance, and Molecular Modeling) has a task outlined in the* ***Student Guide*** *for each day. Please be sure to have Project Sub-Teams accessing their daily* ***Student Guides****.*

Project Teams (5 minutes)

1. Introduce the procedure for using the Project Team Process Journal section of the **Student Guide**. Each Sub-Team uses this to share with the Project Team what the goal is for the day.
   - **a.** Encourage students to reference the specific capture sheets for their Sub-Team as they outline steps needed to complete the task.
2. Invite students to preview the Rubric for Biotech Unit Challenge. Reassure them that this rubric will not be used for a final grade of their project until the end of Lesson 9.
3. Invite students to preview the Sub-Team Specific Capture Sheets for Day 1 as they complete this task.
   - **a.** *Molecular Modeling Team Day 1: Find a Protein and Medicine Model Using Molview Capture Sheet*
   - **b.** *Communications Strategy Team Day 1: Identify Your Team's Patient Population Capture Sheet*
   - **c.** *Financial Analysis Scaling Team Day 1: Values Discussion and Draft Benefit Sharing Plan Capture Sheet*

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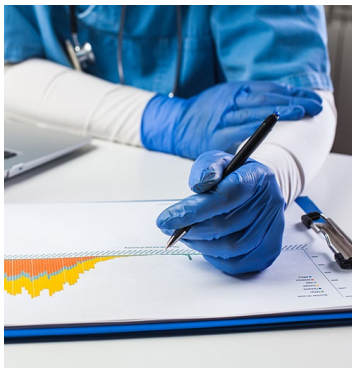
Day 1

Continued

Procedure



Sub-Teams (30 minutes)

1 Students work on the tasks they prioritized during the Project Progress Check Meeting, seeking feedback from other Project Team members if needed.

Teacher Note > *One way to compare the impact of your specific diseases and conditions is by examining a measure known as the DALY (Disability Adjusted Life Years). The WHO describes this measure as such "Mortality does not give a complete picture of the burden of disease borne by individuals in different communities. The summary measure used to give an indication of the burden of disease is the DALY. One DALY represents the loss of the equivalent of one year of full health. Using DALYs, the burden of diseases that cause premature death but little disability (e.g., drowning or measles) can be compared to that of diseases that do not cause death but do cause disability (e.g., cataract causing blindness)." The goal of Day 1 for the Communication Team is to place the experience of individual patients impacted by the disease or condition that their plant drug treats in a larger context of global health.*

2 This is a summary of the main tasks each team will complete during Day 1.

a. Molecular Modeling Team (see **Biochemist** career connection) task: Using the open source web app *MolView*, students will examine different models of their medicinal compound and the protein with which it interacts, and begin to formulate an explanation for how the compound interacts with the body. Consider demonstrating the function of this program for all Molecular Modeling Teams through direct instruction before independent team work time, using the example of aspirin (salicylic acid). Step-by-Step instructions for this can be found in *Molecular Modeling Team Day 1: Task: Find a Protein and Medicine Model Using Molview Capture Sheet*.

This activity connects with the NGSS CCC of structure and function.

b. Communications Team (see **Corporate Relations** career connection) task: Students will identify the patient population for diseases and symptoms treated by the chosen plant compound, and connect an understanding of the impact of diseases using the DALY metric.

This activity connects with the NGSS CCC of creating a system model.

c. Finance Team (see **Manufacturing and Supply Chain Management** career connection) task: Using their Best Practices for Ethical Collaboration from Lesson 7, Day 6, students will identify three to five recommendations to create a Benefits Sharing Agreement. This step will support their future decision making process in their financial analysis.

This activity connects with the NGSS CCC of patterns.

Continues next page >

Day 1

Continued

Procedure

Project Teams (10 minutes)

Students use the Project Team Process Journal section of the **Student Guide** to reflect on their progress and set priorities for the next day according to unfinished tasks and Day 2 of the **Student Guide**. Students assign homework to themselves as needed based on how class time was utilized. Have students use the *Project Team Progress Check Capture Sheet* to move any questions for the Project Team Lead (teacher) into the relevant area on sticky notes for feedback between classes (or invite students to email you or hand in the **Student Guide** as a way to monitor progress).

Day 2

LEARNING OUTCOMES

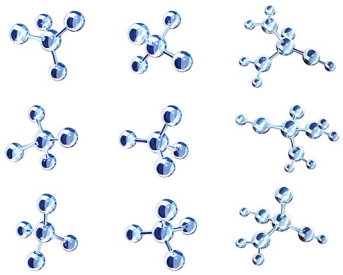
Students will be able to:

Develop a daily goal role and Team-wide goal.

Identify the audience to shape their message.

Brainstorm options for creating their model to represent their medicinal molecule.

Compare and **contrast** consequences using sustainable agriculture, biological synthesis, and chemical synthesis.



Procedure

Teacher Note > *Remind students to consider the skills and connections using the Career Profile Role Capture Sheet from Lesson 6.*

Project Teams (5 minutes)

1. Using the Project Team Process Journal section of the **Student Guide**, each Sub-Team shares with the Project Team what their goal is for the day.

2. Invite students to consider the next phases of each Sub-Team's work using the following capture sheets:

   a. *Molecular Modeling Team Day 2: Use a Model to Communicate Capture Sheet*

   b. *Communications Strategy Team Day 2: Identify the Audience for Your Communications Plan Capture Sheet*

   c. *Financial Analysis Scaling Team Day 2: Question Selection and Research Capture Sheet*

Sub-Teams (30 minutes)

1. Students work on the tasks they prioritized during the Project Progress Check Meeting, seeking feedback from other Project Team members if needed. This is a summary of the main tasks each team will complete today:

   a. Molecular Modeling Team task: Students will brainstorm different options for creating their model to represent their medicinal molecule and how it alters the function of the human body to treat disease and create a plan for materials.

   This connects with the NGSS CCC of system models.

   b. Communications Team task: Students will identify the audience for their communications plan and determine the style and form of their product after reviewing industry examples.

   This connects to the NGSS CCC of patterns.

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Day 2

Continued

Procedure

c. Finance Team task: Students will compare and contrast advantages and disadvantages of using sustainable agriculture, biological synthesis, and chemical synthesis to produce their plant compound by highlighting a summary table, and think about an initial recommendation for production.

This connects with the NGSS CCC of scale, proportion, and quantity.

Extension: The **Student Guide** structures an option for students to investigate more detailed questions for each production method before making a recommendation.

Project Teams (10 minutes)

Students use the Project Team Process Journal section of the **Student Guide** to reflect on their progress and to set priorities for the next day according to unfinished tasks and Day 3 of the **Student Guide**. Students assign homework to themselves as needed based on how class time was utilized. Have students use the *Project Team Progress Check Capture Sheet* to move any questions for the Project Team Lead (teacher) into the relevant area on sticky notes for feedback between classes.

Day 3

LEARNING OUTCOMES

Students will be able to:

Develop an online communication strategy.

Construct a model and diagram.

Review a spreadsheet to formulate a matrix to rank stakeholder perspectives.

Procedure

Project Teams (5 minutes)

1. Using the Project Team Process Journal section of the **Student Guide**, each Sub-Team shares with the Project Team what their goal is for the day.

2. Invite students to consider the following capture sheets as they make a plan for the day:
   - **a.** *Molecular Modeling Team Day 3 and Day 4: Build Time Capture Sheet*
   - **b.** *Communications Strategy Team Day 3: Outline Communication Strategy Capture Sheet*
   - **c.** *Financial Scaling Analysis Team Day 3: Financial Analysis Introduction Capture Sheet*
   - **d.** *Financial Scaling Analysis Team Day 3: Decision Matrix*

3. Suggest opportunities for collaboration among project Sub-Teams:
   - **a.** The Molecular Modeling Team should share the model details with the Communications Team to provide guidance on how to use the model to best communicate the mechanism of action for the drug to their specific audience.
   - **b.** The Finance Team should share the Benefit Sharing Agreement with the Communications Team.

Sub-Teams (30 minutes)

1. Students work on the tasks they prioritized during the Project Progress Check Meeting, seeking feedback from other Project Team members if needed. This is a summary of the main tasks each team will complete today:
   - **a.** Molecular Modeling Team task: If students have their materials, they will begin building their models (and have the following day as well). If students do not have their materials, they need to acquire them and may need help or change their plan if certain materials are unavailable. Prompt students to document their building process (i.e., take pictures or create rough diagrams for each step).

     This connects with the NGSS CCC of system models.

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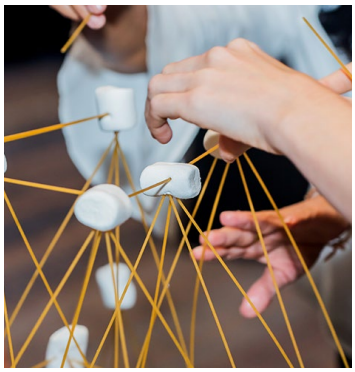
Day 3

Continued

Procedure



b. Communications Team task: Students will outline their communication strategy using the Preliminary Background Research slides deck from Lesson 7, Day 6, their own work from Day 1 of this lesson, and modeling information and the Benefits Sharing Agreement from the Finance Team members.

This connects to the NGSS CCC of patterns.

c. Finance Team task: Students will review and reflect on a completed spreadsheet used as a decision matrix to rank stakeholder perspectives for production methods for aspirin. The sample models the reasoning behind each decision to provide students with an example for completing their own decision matrix.

This connects to the NGSS CCC of scale, proportion, and quantity.

Teacher Note > *It may be helpful to check in with the Finance Team during this task, and/or have all Finance Teams across Project Teams together while they complete their review of the example and check for understanding.*

Project Teams (10 minutes)	
1	Students use the Project Team Process Journal section of the **Student Guide** to reflect on their progress and to set priorities for the next day according to unfinished tasks and Day 4 of the **Student Guide**. Students assign homework to themselves as needed based on how class time was utilized. Have students use the *Project Team Progress Check Capture Sheet* to move any questions for the Project Team Lead (teacher) into the relevant area on sticky notes for feedback between classes.
2	Suggest to students to reexamine the Project Team Process Journal section of the **Student Guide** to:
	a. Understand how their work to this point has connected to the product life cycle.
	b. Acknowledge their own contributions and the contributions of others.

Day 4

Procedure

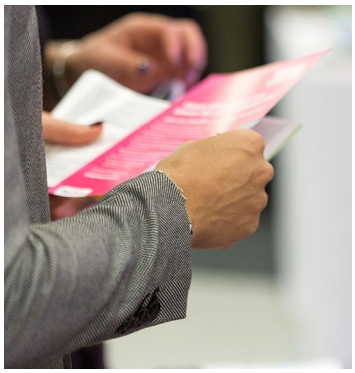
LEARNING OUTCOMES

Students will be able to:

Present progress to the Project Team and seek feedback.

Document progress and process through diagrams.

Conduct financial analysis through decision matrix scores.



Project Teams (5 minutes)

1. Using the Project Team Process Journal section of the **Student Guide**, each Sub-Team shares with the Project Team what their goal is for the day.

2. Invite students to preview their **Student Guides** for the day as they complete this task:

   a. *Molecular Modeling Team Day 3 and Day 4: Build Time Capture Sheet*

   b. *Communications Strategy Team Day 4 and 5 : Create a Draft of the Communications Product Capture Sheet*

   c. *Financial Analysis Team Day 4: Complete Draft Quantitative Analysis Capture Sheet*

Sub-Teams (30 minutes)

1. Students work on the tasks they prioritized during the Project Team Progress Check Meeting, seeking feedback from other Project Team members if needed. This is a summary of the main tasks each team will complete today:

   a. Molecular Modeling Team task: Students will continue building their models. Prompt students to document their building process (i.e., take pictures or create rough diagrams for each step).

   This connects with the NGSS CCC of system models.

   b. Communications Team task: Students will create a draft of their communications product. They will be choosing the mode of communication for their drug, such as a slide deck, brochure, video, or other student choice.

   This connects to the NGSS CCC of patterns.

Continues next page >

Day 4

Continued

Procedure

c. Finance Team task: Students will begin their own financial analysis spreadsheet today. They will need to complete some research to provide decision matrix scores for key questions they choose to rank for each factor (profit, benefit sharing, feasibility, and environmental impact). They do not need to answer and rank all key questions for each factor. For anything students are unsure about how to research or is not emphasized in the Benefits Sharing Agreement, use a 0 (zero) for unknown.

This connects to the NGSS CCC of scale, proportion, and quantity.

Project Team (10 minutes)

Students use the Project Team Process Journal section of the **Student Guide** to reflect on their progress and to set priorities for the next day according to unfinished tasks and Day 5 of the **Student Guide**. Students assign homework to themselves as needed based on how class time was utilized. Have students use the *Project Team Progress Check Capture Sheet* to move any questions for the Project Team Lead (teacher) into the relevant area on sticky notes for feedback between classes.

Day 5

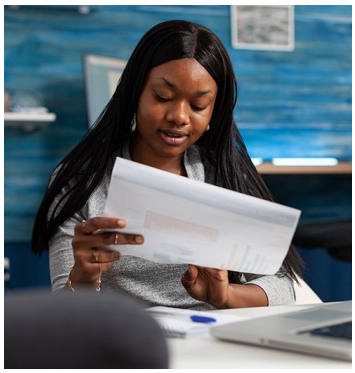
LEARNING OUTCOMES

Students will be able to:

Provide and **seek** peer feedback from Project Team members and Project Team Lead.

Develop a key for a completed diagram to convey part, role, and terms.

Finalize financial analysis and construct a proposal.



Procedure

Project Teams (5 minutes)

1. Using the Project Team Process Journal section of the **Student Guide**, each Sub-Team shares with the Project Team what their goal is for the day.

2. Invite students to consider the following Capture Sheets as they complete this task:

   a. *Molecular Modeling Team Day 5: Create a Science Guide Capture Sheet*

   b. *Communications Strategy Team Day 4 and 5: Create a Draft of the Communications Product Capture Sheet*

   c. As a possible extension, if the Communication Team has time, have them seek feedback from their Team with the final page of their capture sheet.

   d. *Financial Analysis Team Day 5: Check In and Seek Feedback Capture Sheet*

   e. Once the Finance Team is done, they should seek feedback using their capture sheet.

Sub-Teams (30 minutes)

1. Students work on the tasks they prioritized during the Project Progress Check Meeting, seeking feedback from other project Team members if needed. This is a summary of the main tasks each team will complete today:

   a. Molecular Modeling Team task: Students will likely need time to complete their models in the form it will be presented and provide some type of key describing each part, its role, and define key terms. Sub-Team members should share with the Communications Team for feedback and support.

   This connects with the NGSS CCC of system models.

   b. Communications Team task: Students will complete a draft of their communications product, using the mode they selected (slide deck, brochure, video, or other). If time, Sub-Teams will seek feedback from the Molecular Modeling and Finance Teams.

   This connects to the NGSS CCC of patterns.

Continues next page >

Day 5

Continued

Procedure

c. Finance Team task: Students will likely need time to complete their financial analysis spreadsheets and complete the proposals from Day 4 of the **Student Guide**. Sub-Team members should share their proposal with Project Lead (teacher) and receive peer feedback.

This connects to the NGSS CCC of scale, proportion, and quantity.

Project Teams (10 minutes)	
1	Students use the Project Team Process Journal section of the **Student Guide** to reflect on the stage of completion of their **Student Guides** and assign homework to themselves as needed to complete them. Move any questions for the Project Lead (teacher) into the relevant Progress Check area on sticky notes for feedback between classes.
2	Share that Teams with completed drafts will begin the peer review and revision process in the next lesson.

National Standards

Next Generation Science Standards

LS1-2 From Molecules to Organisms: Structures and Processes
Develop and use a model to illustrate the hierarchical organization of interacting systems that provide specific functions within multicellular organisms.

LS1-6 From Molecules to Organisms: Structures and Processes
Construct and revise an explanation based on evidence for how carbon, hydrogen, and oxygen from sugar molecules may combine with other elements to form amino acids and/or other large carbon-based molecules.

ETS1-2 Engineering Design
Design a solution to a complex real-world problem by breaking it down into smaller, more manageable problems that can be solved through engineering.

ETS1-4 Engineering Design
Use a computer simulation to model the impact of proposed solutions to a complex real-world problem with numerous criteria and constraints on interactions within and between systems relevant to the problem.

Science and Engineering Practices

Developing and Using Models
(Molecular Modeling Team)
Develop, revise, and/or use a model based on evidence to illustrate and/or predict the relationships between systems or between components of a system.

Constructing Explanations and Designing Solutions
(Communications Team)
Design, evaluate, and/or refine a solution to a complex real-world problem, based on scientific knowledge, student-generated sources of evidence, prioritized criteria, and tradeoff considerations.

Obtaining, Evaluating, and Communicating Information
(Finance Team)
Compare, integrate and evaluate sources of information presented in different media or formats (e.g., visually, quantitatively) as well as in words in order to address a scientific question or solve a problem.

Continues next page >

National Standards

Career and Technical Education (CTE)

A2.6
Prepare a presentation comparing the benefits and harm that can be the result of biotechnology innovations in both the research and application phases and which course of action will result in the best outcomes.

A4.5
Discuss the structure and function of the macromolecules that compose cells, including carbohydrates, lipids, DNA, RNA, and protein molecules

A7.3
Describe intellectual property.

A7.6
Articulate issues of ethical concern, including plagiarism, copyrights, trademarks, and patents and use online data resources and searchable databases to investigate a copyright, trademark, or patent.

A9.4
Cite examples of plant parts or extracts used as pharmaceuticals.

A9.5
Use the Internet to find information about traditional pharmaceuticals, herbal remedies, and recombinant pharmaceuticals.

A9.7
Design a flow chart describing the steps for creating a new drug from hypothesis to distribution.

Continues next page >

National Standards

CTE *Continued*	**5.3** Use systems thinking to analyze how various components interact with each other to produce outcomes in a complex work environment.
	5.4 Interpret information and draw conclusions, based on the best analysis, to make informed decisions.
	5.6 Read, interpret, and extract information from documents.
	9.2 Identify the characteristics of successful teams, including leadership, cooperation, collaboration, and effective decision-making skills as applied in groups, teams, and career technical student organization activities.

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Project Team Progress Check Capture Sheet

Directions
Complete this activity using sticky notes at the start of each work period during the Plant Medicine Biotech Project.

Project Team Name	*Project Team Members*
Communication Team Members	

Communications Team Progress Check

	Brainstorm	Draft	I need feedback from my team members on:	I need feedback from another team on:	I need feedback from the Project Team Lead on:
My goal(s) for day:					
My goal(s) for day:					

We need help on:

Tasks completed:

Questions?

Continues next page >

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Project Team Progress Check Capture Sheet

Continued

Project Team Name	*Project Team Members*
Finance Team Members	

Finance Team Progress Check

	Brainstorm	Draft	I need feedback from my team members on:	I need feedback from another team on:	I need feedback from the Project Team Lead on:
My goal(s) for day:					
My goal(s) for day:					

We need help on:

Tasks completed

Questions?

Continues next page >

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Project Team Progress Check Capture Sheet

Continued

Project Team Name	*Project Team Members*
Molecular Modeling Team Members	

Molecular Modeling Team Progress Check

	Brainstorm	Draft	I need feedback from my team members on:	I need feedback from another team on:	I need feedback from the Project Team Lead on:
My goal(s) for day:					
My goal(s) for day:					

We need help on:

Tasks completed

Questions?

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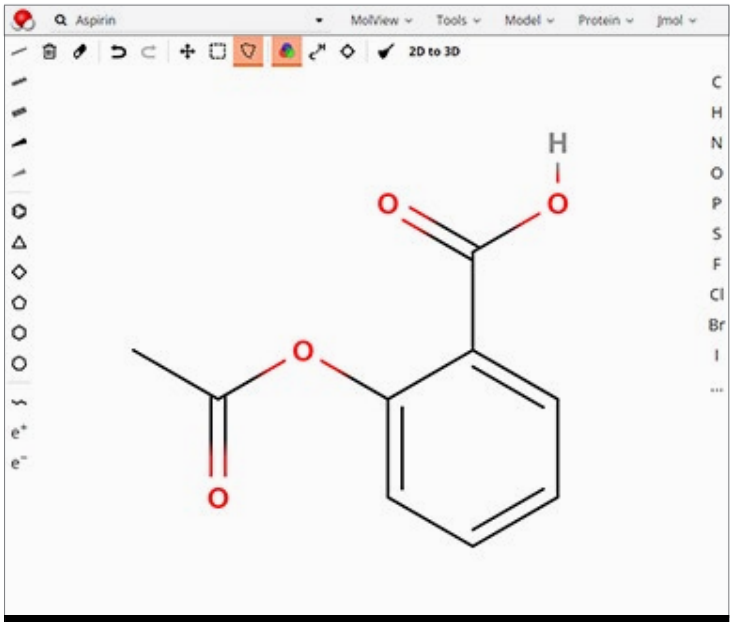
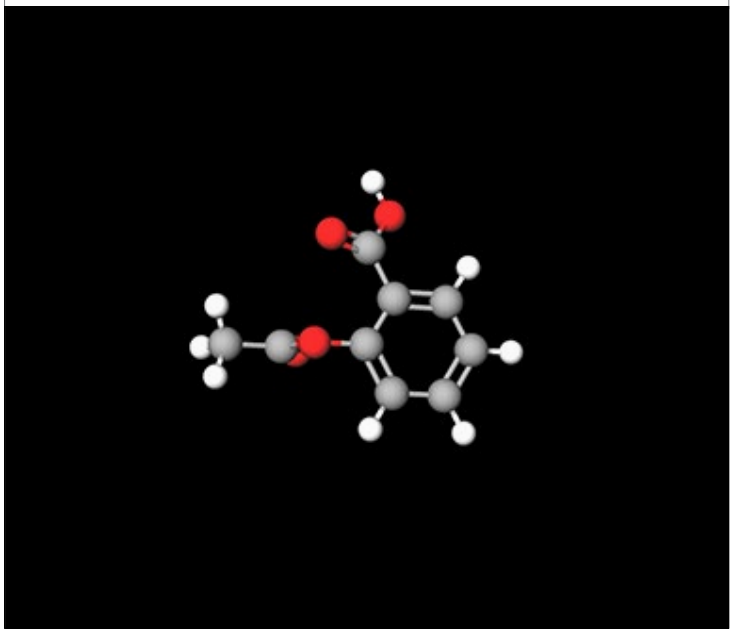
Molecular Modeling Team Day 1:
Find a Protein and Medicine Model
Using Molview Capture Sheet

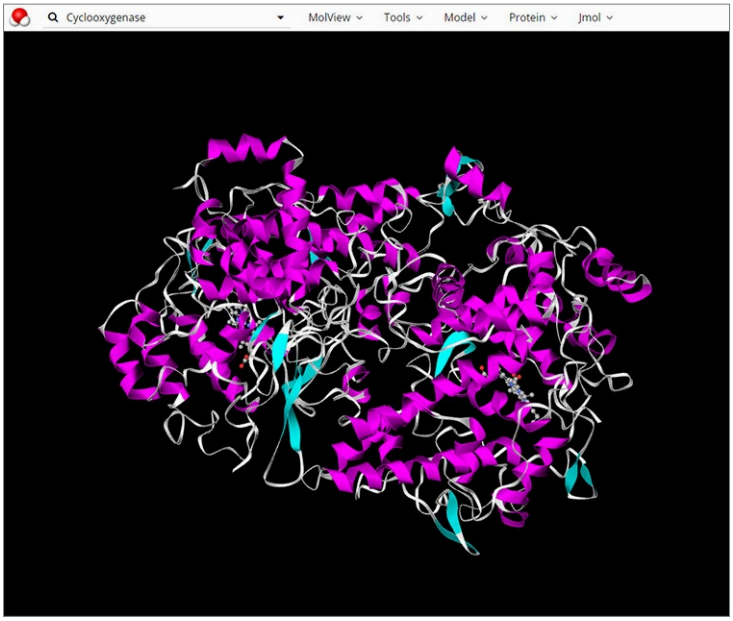
Directions
Use MolView to find a model of the medicinal compound and the protein with which the compound interacts. View different representations of your molecule with the Model tool. Recall that aspirin inhibits the enzyme cyclooxygenase.

1 The molecular structure of aspirin shown on *MolView*





2 The molecular structure of Cyclooxygenase shown on *MoleView*



How to use MoleView

1	Enter the name of the medicinal compound in the upper left search field. Here the example is 'Aspirin.'
2	Click on Protein, and select a representation (shown here is the ribbon representation for 'Cyclooxygenase'). Enter the name of your protein in the search field.
3	Go to *MolView v2.2 manual* for more information about the molecule you are looking at.
4	For more help, watch these *MolView tutorials*.
5	Use the images on this page as reference throughout the rest of the week.

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Molecular Modeling Team Day 1:
Find a Protein and Medicine Model
Using Molview Capture Sheet

Continued

Key Question: Looking at the digital representation of your medicine and the protein target, and the text explanation of how it works from the source table, revise your flow chart from the Lesson 6 *Preliminary Background Research Capture Sheet* to explain what happens in the body with and without the drug. Record your thoughts and revisions below.

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Molecular Modeling Team Day 2:
Use a Model to Communicate Capture Sheet

Directions

The model you found on Day 1 is likely not appropriate for general audiences without interpretation.

Working with the Communications Team, consider the audience you will be attempting to communicate with, and brainstorm a few options to show the function of your drug in the body.

1. Include in your brainstormed ideas:
   a. A key for how you might show your medicinal molecule
   b. How your medicinal molecule alters the function of the human body to treat disease

2. There are many different ways you can create your model based on your mechanism of action. You may choose to model your molecule using one material (such as a 3D paper model) and body response using a different material (such as a drawing) and use them together to create the full product (such as a video).

   Here is a list of potential materials you could choose to utilize to create your model:

Stop motion animation	You can use an app to create a stop motion animation drawing explaining your medicine's role in the human body.
Cell phone videos and photos	You can use your phone to gather images, sounds, photos, and other digital artifacts to create a collage representing your medicine's role in the human body.
Paper	You can search for molecular templates online—see a few examples below.
3D Printing	You can use *Thingiverse.com* to see if a model exists that you can modify.
Modeling kit	You can use a molecular modeling kit that your teacher may have to build your plant medicine.
Clay	You can use these tools to create a 3-D version of your protein or cell function.
Miscellaneous other supplies	Get creative! Cardboard, pipe cleaners, ribbon, toothpicks, paint, foil, glue, recycled materials, such as plastic bottles or milk jugs, can all be transformed into new products for your team. Extra tools, such as paper clips or binder clips, may help hold parts of your model together as they dry if using items that need glue.

3. Look at these examples from the coronavirus pandemic:

A Lego-Illustrated Guide to Covid-19 Variants	Study the first image in the article. This example uses legos to demonstrate what a spike protein mutation might alter functionally on a covid virus, modeled as an orange.
The Viral TikTok That Explains Vaccine Science —And Makes You Laugh	Read about a TikTok that uses comedy and household objects to explain how the mRNA vaccines work to help your immune system prepare for a potential future COVID-19 infection.
The Coronavirus Unveiled	The featured image in this New York Times article is more traditional and uses different colors to symbolize how a drug molecule might block the tip of the coronavirus spike.

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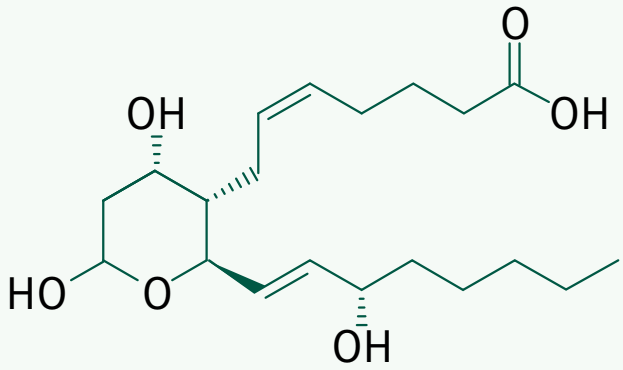
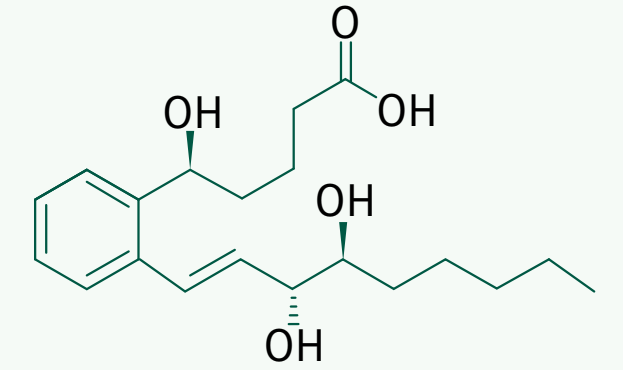
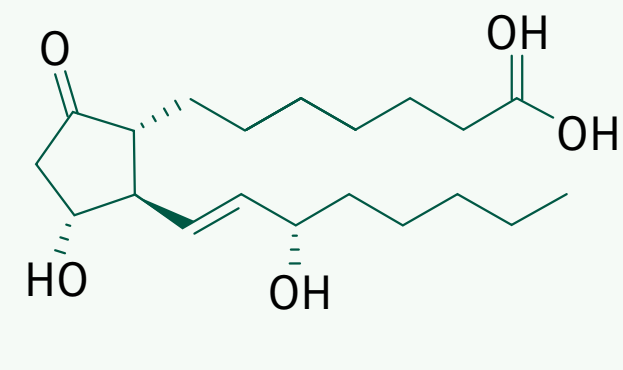
Molecular Modeling Team Day 2:
Use a Model to Communicate Capture Sheet

Continued

4. Finally, consider how this annotated chart is used to model how cells normally function and what changes in the presence of an aspirin molecule.

The PTSG2 enzyme makes thromboxanes (A), which aid in blood clot formation, and prostaglandin (B), which causes inflammation and pain.	A: Thromboxane	
	B: Prostaglandin	
When aspirin is present, it irreversibly binds to the PTGS2 protein's active site, such that the enzyme now makes lipoxin (C), which acts as an anti-inflammatory molecule, reducing clotting, fever, and pain.	C: Lipoxin	

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Molecular Modeling Team Day 2:
Use a Model to Communicate Capture Sheet

Continued

5. Based on all the models you explored above, create a series of options and get feedback from your team members on which option to pursue.

   Use the six spaces below to consider different options of how to build your model. Then, circle the number of the option your team chooses to pursue.

1		**4**	
2		**5**	
3		**6**	

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Molecular Modeling Team Day 2:
Use a Model to Communicate Capture Sheet

Continued

6. What materials will you use to construct your model? How will you obtain the materials needed?

7. Develop a plan for how you will spend your time on Days 3 and 4 to create your model.

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Molecular Modeling Team Day 3 and 4:
Build Time Capture Sheet

Directions

Build your molecular model. You have approximately 70 minutes of class time, plus any time you choose to use at home to do the work. You can elect to collaborate on all steps or you may choose to split up work and create different parts of the model as a modeling team.

1. On Day 3, take images of your process or diagram your progress below:

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Molecular Modeling Team Day 3 and 4:
Build Time Capture Sheet

Continued

2. On Day 4, take images of your process or diagram your progress below:

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Molecular Modeling Team Day 5:
Create a Science Guide Capture Sheet

Directions
Create a key for your model to help the Communications Team accurately explain the science.

1. Make sure to:
    a. Note each part of the model.
    b. Describe the role of each part of the model in the process of altering the human body to treat disease.
2. Complete any unfinished elements of your model or make needed repairs and alterations.
3. Complete any video pieces if your team plans to narrate and record interacting with your model.
4. Use the boxes on this page to draft scripts, explanations, or other communication needed to share your model with your target audience.
5. Seek feedback from your Communications Team prior to recording your script as a video.

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Communications Strategy Team Day 1:
Identify Your Team's Patient Population Capture Sheet

Directions
Consider who is impacted by the disease and symptoms your plant can address.

- *One partner should address Step 1.*
- *Both partners should read Step 2 and understand what a DALY is.*
- *One partner should address Step 3.*
- *Both partners should address Step 4.*

Step 1 **Identify Potential Patients**	Data Type	Patient Population Information
	Age	
	Sex	
	Geographic Ancestry May not apply to all conditions	
	Risk Factors • exposure to pollution • lack of opportunity to exercise • high blood pressure • high cholesterol • exposure to pathogens (i.e., Malaria, COVID-19, Zika) • field of employment or workplace hazard exposure • allergens	
	Is the condition your plant medicine treats: • chronic (i.e., heart disease)? • intermittent (i.e., common cold)? • once in a lifetime (i.e., measles)?	

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Communications Strategy Team Day 1:
Identify Your Team's Patient Population Capture Sheet

Continued

Step 2 **What is a DALY?**

One way to compare the impact of your specific diseases and conditions is by examining a measure known as the DALY (Disability Adjusted Life Years).

The WHO describes this measure like this:

Mortality does not give a complete picture of the burden of disease borne by individuals in different communities. The summary measure used to give an indication of the burden of disease is the DALY. One DALY represents the loss of the equivalent of one year of full health. Using DALYs, the burden of diseases that cause premature death but little disability (e.g., drowning or measles) can be compared to that of diseases that do not cause death but do cause disability (e.g., cataract causing blindness).

The high levels of burden of disease for the WHO African, South-East Asian, and Eastern Mediterranean regions compared to other regions are predominantly due to communicable diseases, and maternal, perinatal, and nutritional conditions, although injury DALY rates are also higher in these regions. Eastern European low- and middle-income countries have a substantially higher noncommunicable disease burden than high-income countries. These countries also have the highest proportion of burden due to injuries of all the regions, followed by the low- and middle income countries of the Americas.

Source: World Health Organization's *Global Health Estimates*.

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Communications Strategy Team Day 1:
Identify Your Team's Patient Population Capture Sheet

Continued

Step 3 **Compare DALYs**

How do DALYs attributed to your condition compare to noncommunicable diseases (i.e., heart disease, asthma, COPD) and communicable disease?

Using the University of Washington's *GBD Compare* (GDB stands for Global Burden of Disease), complete the table below:

	Key DALY	Optional DALYs			
Region	Your disease(s)	Heart Disease	Car Accidents	Malaria	Other Condition of Your Choice
Global					
United States					
Southeast Asia					
Sub-Saharan Africa					
Your State					

Impact

What do you notice about the impact of your condition(s) versus others in the chart?

Who is impacted?

Men, women, or children?

Regions of the world?

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Communications Strategy Team Day 1:
Identify Your Team's Patient Population Capture Sheet

Continued

Step 4 **Collaborative Questions**

Collaboratively, answer the following questions considering data from Steps 1 and 3.

Thinking about the demographic data you generated in Step 1 and the DALY information you gathered in Step 3, how will your plant medicine impact particular patients?

What increases in quality of life will be observed from your drug? *Be as specific as you can, using numbers from Step 3 and patient demographics from Step 1.*	
Describe both the benefits and any potential or known side effects associated with your plant compound. *Consult with the Molecular Modeling Team here to double check your reasoning.*	

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Communications Strategy Team Day 2:
Identify the Audience for Your Communications Plan
Capture Sheet

Directions
The Communications Team needs to create videos, podcasts, articles, or interviews specifically targeted to different audiences for our Biotech Firm.

1. Skim a resource in each audience category below. Your goal is to understand how the resource targets a particular audience, and view different forms and styles of communication across audiences.

   One partner may choose to explore the top two audience categories and the other partner may choose to explore the bottom two categories.

Audience Category	Communication Examples	Features How is the audience targeted? What disclosures are included?	Style and Format What do you like? What would you change?
Patients	*Flu Season Prep Video* from the CDC *Three Actions to Fight Flu* Infographic *The Flu: A Guide for Parents* Parent Guide		
The Media	*Flu* Public Service Announcements (PSA) from the CDC		
Medical Professionals	*Flu and COVID-19* Treatment Guidelines from the NIH *Influenza Background* from the CDC		
Scientists	*Update on Avian Influenza* from New England Journal of Medicine		

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Communications Strategy Team Day 2:
Identify the Audience for Your Communications Plan
Capture Sheet

Continued

2. Based on your analysis, suggest and get approval from your Team for the style and audience for your communication final product.

Choose your format

(e.g. slide presentation, video, podcast, article, press release, brochure, etc.)

Choose your audience

(e.g., patients, the media, medical professionals, scientists, etc.)

Explain your rationale

Why did you select this format and audience?

Sign-off

Signatures from the Finance and Molecular Modeling Teams to indicate their approval of your approach

Signatures:

Recommendations

Are there any recommendations from the Finance and Molecular Modeling Teams?

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Communications Strategy Team Day 3:
Outline Communication Strategy Capture Sheet

Directions
The Communications Team is responsible for explaining how the plant-based medicine your Team is focusing on works to address a specific condition or disease. Below is a list of key components of your communications strategy.

The Where and the What

1. What is your plant? Where is it found? How does it grow and reproduce?
   (from Lesson 6 preliminary background research)

2. What conditions or diseases does your plant treat?
   (from Lesson 6 preliminary background research)

The How

3. How does your plant compound specifically interact with human cells to treat the disease or condition?
   (in collaboration with the Molecular Modeling team, from their Day 1 and Day 2 research)

4. Who are the stakeholders involved in getting your plant compound from the plant or the lab to the patient?
   (in collaboration Finance team, from the *Benefits Sharing Agreement*)

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Communications Strategy Team Day 3:
Outline Communication Strategy Capture Sheet

Continued

The Why

5. Who are the patients that will benefit?
(from Day 1 of this lesson)

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Communications Strategy Team Day 4 and 5:
Create a Draft of the Communications Product Capture Sheet

Directions
It is time to create your communications product using your communication strategy outline! You will have two days to create an initial draft of this product.

1. If you are making a video or a podcast, write a quick script below or use any storyboard template (a quick internet search will yield many options).

   If you are making a slide deck, an article, or a brochure, outline any key points or strategies that you want to focus on as you create your product. Add links to images that you intend to use (cite image source).

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Communications Strategy Team Day 4 and 5:
Create a Draft of the Communications Product Capture Sheet

Continued

2. If you get stuck on any slides, video storyboard, or article outline steps, check in with your other Project Team Members or with your Project Team Lead (teacher) for additional support.

3. Seek feedback from the Molecular Modeling Team and Finance Team on communication product accuracy and scope.

4. Include a link to your draft product below (or a picture if the product is physical).

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Communications Strategy Team Day 4 and 5:
Create a Draft of the Communications Product Capture Sheet

Continued

5. Extension: If you have any additional time, complete this peer review activity to formally seek feedback from other Project Team Members.

My Peer Reviewer(s)

a. One celebration my reviewer provided was:

b. Two helpful suggestions my partner gave me were:

1.

2.

c. The specific changes I will make to my next draft or iteration are:

6. Use any remaining time to complete unfinished portions of your *Benefit Sharing Agreement* or drug production decision matrix, and make any edits based on peer feedback.

7. Homework option: Complete edits based on peer feedback if needed.

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Financial Analysis Scaling Team Day 1:
Values Discussion and Draft Benefit Sharing Plan
Capture Sheet

Directions
In order to develop a Benefit Sharing Plan for all stakeholders, it is important to have clear agreements about team values.

1. Reflect back on Lesson 2, Day 6 and review your Best Practices for Ethical Collaboration responses as a team.

   a. What Best Practices did you identify to ensure ethical and fair compensation among all stakeholder groups?

   b. Which do you feel has the greatest priority?

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Financial Analysis Scaling Team Day 1:
Values Discussion and Draft Benefit Sharing Plan
Capture Sheet

Continued

2. Complete the table below to form the scaffold for your *Benefit Sharing Agreement*.
   a. Choose three to five Best Practices that your team wants to use, and list them in the table below.
   b. Discuss and record how you implement each Best Practice in your *Benefits Sharing Agreement*.

	Best Practice Recommendation	Best Practice Implementation
Ex.	*Benefit sharing should include monetary and non-monetary compensation at all points during the relationship between all stakeholders.*	*Our medicinal plant has a long history of use with [Indigenous group] in [location] and uses their TEK. Non-monetary benefits will be explored and provided in the form requested by the community, such as recognition and ownership of IP, financial and infrastructure support to benefit their local economy, and conservation efforts in the region.*
1		
2		
3		
4		
5		

Continues next page >

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Financial Analysis Scaling Team Day 1:
Values Discussion and Draft Benefit Sharing Plan
Capture Sheet

Continued

3. Create your *Benefit Sharing Agreement* by compiling the table on the previous page into a 200–300 word document. Each point can be noted as a separate "article" in the agreement, and briefly described specific to your medicinal plant and Indigenous stakeholder community.

   Sample outline:

   Introduction (name stakeholder groups and provide summary of Best Practice recommendations).

   Article 1 (explain Best Practice 1).

   Article 2 (explain Best Practice 2).

   Article 3 (explain Best Practice 3).

   Conclusion (if needed).

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Financial Analysis Scaling Team Day 2:
Question Selection and Research Capture Sheet

Directions
Examine the three ways you could produce your plant-based medicine summarized below.

1. Highlight the advantages and disadvantages that are most important based on your *Benefits Sharing Agreement*.

	Method	Advantages	Disadvantages
a	Sustainable Agriculture	Requires the fewest amount of resources, at minimum cultivated land and tools for upkeep. Sustainable agriculture can be adapted for both indoor and outdoor environments, which provides flexibility for production. Cultivating sustainable agriculture in an industrial setting requires more resources (i.e., warehouse, growing equipment, lighting, etc.) compared with an outdoor setting. Controlling environmental growing conditions can increase the yield and efficiency of production.	Sustainable agriculture is the least efficient method of production. Unless the chemical compound is produced at high enough concentrations naturally, this production method will require an excess of inputs to accumulate enough product to make a medicine. As a result, this production technique is better adapted to smaller scale production. This production technique is ultimately limited by the plant's developmental biology and growing conditions.
b	Biological Synthesis	Biological synthesis takes advantage of recombinant DNA technology and model organism systems, such as *E. coli*, yeast, or CHO cells. This production technique can more easily be scaled up to an industrial level compared to sustainable agriculture. This technique is often cheaper than total chemical synthesis (i.e., chemical synthesis of Taxol is too expensive for commercial production) and has greater versatility in terms of chemical compounds that can be engineered. *E. coli*, yeast, and CHO have a greater efficiency and shorter production time compared to sustainable agriculture. This production technique is limited by the model organism (i.e., which biosynthetic pathway is being used) as well as the purification method (i.e., chromatography, electrophoresis, ultracentrifugation).	Biological synthesis is the second most expensive production method. (Chemical synthesis and biological synthesis are more expensive than sustainable agriculture, but there is less of a difference in cost between chemical synthesis and biological synthesis.) This production method is also limited by the model organism biology and efficiency of the biosynthetic pathway.
c	Chemical Synthesis	Chemical synthesis is the most efficient production method. Similar to biological synthesis, chemical synthesis is versatile and can be used to synthesize many pharmacological agents. There are no biological limitations to this method in that the efficiency of this method is due to the chemistry itself. This production method can be optimized by manipulating the chemical synthesis pathway to improve yield and reaction dynamics.	This is the most expensive production and resource-costly method. Chemical synthesis, similar to biological synthesis, requires the greatest amount of inputs and resources to engineer pharmacological compounds. The limitations of chemical synthesis are from the chemistry itself, which can be more easily manipulated than biological organisms.

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Financial Analysis Scaling Team Day 2:
Question Selection and Research Capture Sheet

Continued

2. Extension: Explore all three options in more detail. Choose two to three questions per production method that are most important to you given your Team's *Benefits Sharing Agreement*.

Sustainable Agriculture

Question		Explanation
Developement		
How long does it take the plant to reach maturity?	Can you increase the time to maturity by controlling environmental conditions or supplementing growing conditions?	A plant with a shorter time to maturity will be able to be produced at a faster rate and will decrease the amount of resources needed during development (i.e., how much electricity if grown indoors or how much water and fertilizer is needed in an outdoor setting). Plants grown in an indoor facility will require more resources to initiate (more electricity, energy, industrial gardening equipment) compared to an outdoor setting (i.e., cultivated land).
Where does the plant grow?	Are there specific regions where the plant grows better? Is the plant endemic to a region?	Different environments are capable of growing plants better because of the environmental conditions alone, such as precipitation and temperature. Plants grown in remote regions are going to be more expensive to produce because of limited accessibility to the region. In turn, this will impact transportation costs depending on the region where this plant can be grown.
Is the plant domesticated or harvested from ecosystems?	Can it be produced on an industrial scale? Is the plant grown on farmland or pastures? Is it more or less difficult to harvest the plant from ecosystems? What are the differences in the abundance of domesticated plants versus plants grown in an ecosystem?	Plants grown on an industrial scale might cost more, but they will ultimately be more profitable because they produce a higher yield. Controlling the environmental conditions on an industrial scale allows scientists to optimize the growing conditions, which can increase the yield, or amount of product. In turn, this will impact the plants' time to maturity.

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Financial Analysis Scaling Team Day 2:
Question Selection and Research Capture Sheet

Continued

Sustainable Agriculture Continued

Question		Explanation
Purification		
What is the purification of the plant going to cost?	What purification technique is used to isolate the compound, or how is the compound isolated? What is the yield? Are there techniques that are more efficient or less efficient than others? How does the cost of different purification techniques compare?	Purification techniques will vary in cost. Purification techniques include sublimation, crystallization, distillation, and chromatography. Selecting a purification technique that is cheaper in cost may have a smaller yield, but a greater efficiency and require less resources. Once the compound is purified, how does it need to be prepared into a medicine?
Transportation		
What determines the shipping cost of the plant?	Is the product thermostable and does it have special transportation conditions (i.e., does it need to be shipped on dry ice)? What is the distribution of this product? Is it global or specific to a region?	Shipping costs will increase the further the product needs to be shipped. The shipping costs will also increase if special conditions are required to ship (i.e., if the product is not thermostable).
Production		
How much does it cost to produce a specific volume or mass of medicine?	What is the yield of the purification? Protein purification, for example, has different yields depending on the technique used. Is there a way to increase yield through manipulating environmental conditions (i.e., grown indoors, fertilizers, nutrients, etc.)? What is the dosage of the medicine?	To determine the overall cost, each of these factors must be considered. A higher dosage will require more resources and therefore be more costly.

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Financial Analysis Scaling Team Day 2:
Question Selection and Research Capture Sheet

Continued

Biological Synthesis

Question		Explanation
Developement		
Is a gene isolated that produces the plant compound?	How much does it cost to produce a specific volume or mass of medicine?	By upregulating the expression of a gene in a plant, you can produce a higher quantity of the gene target of interest. If there is no gene target in mind, what research needs to be done to investigate which genes can upregulate the gene target of interest?
Is there a plant species (tobacco, other) that can be used to scale the production of this compound?	Are there any special considerations for using certain plant species? Do some plant species have a greater environmental impact?	Plants are an efficient way to produce therapeutic compounds, but the yield must be strongly considered. Often plants do not produce enough yield natively. Engineering plants (i.e. soybeans) to overexpress a chemical compound is a viable approach to drug development, but some plants may not be easily engineered to express the target compound. Considering which plants to use to scale the production will have an impact on cost and efficiency.
Production		
Can this compound be produced in *E. coli* or CHO cells?	What are the requirements for cell culture? What type of training or personnel are required for maintaining cell culture?	Recombinant DNA technology has been used to engineer bacteria to produce pharmacologically important molecules, such as insulin. Terpenoids are a strong example of a biological synthesis that can be produced in *E. coli* and *S. cerevisiae* (yeast). Well-known examples are the anti-malarial drug artemisinin, anti-cancer agent paclitaxel (Taxol), and eleutherobin. The total chemical synthesis of Taxol has been achieved, but the production is too expensive to be commercially practical. By expressing Taxol biosynthesis genes in yeast cells, scientists are able to create a cost-efficient production of important natural pharmacological compounds.
How much does it cost to produce a specific volume or mass of medicine?	What is the difference in cost between biological and chemical synthesis?	Engineering *E. coli* and yeast to produce terpenoids requires the co-expression of the terpene synthases and modifying enzymes. Scientists have engineered *E. coli* to produce artemisinic acid, which can be chemically converted into artemisinin with a yield of more than 300 mg/L. The same group of researchers engineered yeast to produce artemisinic acid with a yield of 100 mg/L. Determining the cost to produce a volume of medicine will depend greatly based upon the biosynthetic technique used. A more efficient biosynthetic technique will require less resources and therefore may be less costly, but the most important consideration is the product yield.
How much energy does this use?	Are there some compounds that have a greater environmental impact?	This depends on the efficiency of the biosynthetic pathway. There are differences in energy required for cell culture (*E. coli*, yeast, CHO) compared to production using plant species. There are even differences between cell culture techniques. *E. coli* are able to produce three times the yield of artemisinic acid compared to yeast cells expressing the same genes (300 mg/L compared to 100 mg/L respectively). Considering the efficiency of the biosynthetic pathway and yield are crucial to determining the cost.
What other environmental impacts does this process have?	What is the waste generated from this process? Are there contaminants?	Whenever working with cell culture, the proper precautions must be taken. Cell culture in particular requires a sterile environment. This will ultimately cost more to upkeep a cell culture facility. Additionally, the risk of contamination is paramount in cell culture practices. Considering the risk of contamination will impact the lab resources required. Another consideration is waste generated. Does the waste need to be incinerated? Are there any contaminants or pollutants in the waste that may affect nearby environments?

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Financial Analysis Scaling Team Day 2:
Question Selection and Research Capture Sheet

Continued

Chemical Synthesis

Question		Explanation
Development		
What inputs are necessary for the chemical synthesis process?	What equipment is required for chemical synthesis? What training is required for organic chemistry? Will you need an organic chemistry lab?	Chemical synthesis requires a technical knowledge of organic chemistry. The chemical synthesis of aspirin requires salicylic acid as a chemical input as well as organic chemistry lab equipment and reagents, such as glassware and acid/base reagents. If the chemical synthesis of a product requires a greater amount of energy or resources, it will have a greater environmental impact and therefore be more costly. The chemical inputs for aspirin synthesis are phenol, sodium hydroxide, carbon dioxide, acetic anhydride, and hydrogen.
Are there any environmental or transport costs that should be considered for source materials?	How abundant is the chemical input? Is it endemic to a region? How many chemical inputs are required? Multiple chemical inputs will be more costly.	Chemical inputs that require more transportation and are not as easily acquired will be more costly. The chemical inputs for aspirin are found in the bark of willow trees, *Salix alba*. The bark contains high levels of salicin, a glycoside of salicylic acid. A glycoside is a molecule in which a sugar is bound to another functional group via a glycosidic bond. Many drugs derived from plants are glycosides. Because willow trees are common throughout the Northern Hemisphere, the cost of salicin is low.
How much energy is required to produce the chemical	What are the chemical characteristics of the compound? Does the chemical compound need to be heated for an extended period of time to solubilize? How complicated is the chemical reaction? What type of chemical reactions are involved?	The chemical reaction for aspirin can be broken down into four chemical reactions. In order to synthesize aspirin, the chemical inputs need to be heated in one of the first reactions on a hot plate. The amount of energy needed to synthesize aspirin is relatively low considering that the reaction only needs to be heated for around 10 minutes. Synthesizing chemical compounds that require more chemical reactions will use a greater amount of energy.
Production		
How much does it cost to produce a specific volume or mass of medicine?	How is it prepared into a medicine? What type of medicine will you prepare: capsules, tablets, suppositories, or elixir? What dosage will you prepare? Another major consideration is what is the percent yield from the chemical reaction? What is the theoretical yield?	Higher dosages will require more chemical inputs and therefore may be more costly. Using infrared spectroscopy, you can confirm the chemical properties of the chemical synthesis. The product can also be analyzed for melting point and titration to confirm its identity.

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Financial Analysis Scaling Team Day 3:
Financial Analysis Introduction Capture Sheet

Directions
When making decisions about models with different measurable factors that are difficult to quantify precisely, financial professionals and engineers often use a tool called a decision matrix to make evidenced-based decisions.

Analyze a completed Decision Matrix used to decide the best method to scale the production of aspirin.

1. Familiarize yourself with the analysis scale for this activity, shown below. Note that a higher score is more favorable and a lower score or negative score is less favorable.

2	Possible, favorable
1	Possible, challenging
0	Unknown
–1	Possible, extremely challenging or not feasible/possible
–2	Possible, but with unintended or undesirable consequences or is impossible

2. Explore this completed *Decision Matrix for Aspirin Production.* There are three analyses: Sustainable Agriculture, Biological Synthesis, and Clinical Synthesis. Each of these analyses is given an overall score based on the scale above. There are a possible 22 points.

19	Sustainable Agriculture
7	Biological Synthesis
–3	Clinical Synthesis

3. Do you agree with the author's analysis? Why or why not?

4. What mode of production does this analysis recommend?

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Financial Analysis Scaling Team Day 3:
Financial Analysis Introduction Capture Sheet

Continued

5. With this analysis example in mind, work with your partner team member to find information specific to your drug to fill out a similar matrix for your plant-based medicine. Record your findings in your science notebook or below.

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Financial Analysis Scaling Team Day 4:
Complete Draft Quantitative Analysis Capture Sheet

Directions
Use the Decision Matrix to determine the best method of production for your plant-based medicine.

Use a 0 to indicate that you do not have enough information or did not choose to make a recommendation on that factor.

Use the table to provide a rationale for any non-zero answers based on your research from Days 2 and 3.

You do not need to analyze all factors. Use your Benefits Sharing Agreement to prioritize.

1. What does your analysis indicate about the production method that is ideal for your plant medicine, given your *Benefits Sharing Agreement* and team values?

2. Write a proposal to share with your Project Team and the Project Team Lead (your teacher) about how you will produce your medicine.

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Financial Analysis Scaling Team Day 5:
Check In and Seek Feedback Capture Sheet

Directions
Seek feedback from your Project Team and/or Project Team Lead (teacher). Use any remaining time to complete unfinished portions of your Benefit Sharing Agreement or drug production decision matrix, and make any edits based on peer feedback.

1. Answer the questions below with the feedback you are given.

My Peer Reviewer(s)

a. One celebration my reviewer provided was:

b. Two helpful suggestions my partner gave me were:

1.

2.

c. The specific changes I will make to my next draft or iteration are:

2. Homework option: Complete edits based on peer feedback if needed.

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Rubric for Biotech Unit Challenge

Constructing Explanations and Designing Solutions

Directions

The Medicinal Plant Products (Financial Plan, Communication Plan, and Medicinal Plant Model) should be assessed after presentations during this lesson.

Note: This rubric should not be used for a final grade until Lesson 9.

Observable Features of Medicinal Plant Model, Financial Plan, and Communications Plan	**Meets Expectations** 8–10 points	**Progressing** 5–7 points	**No attempt** 0 points
Constructing explanations			
a. Students explain if and/or how a disruption in cellular processes allows a plant-based compound to treat a described disease or condition in a particular patient population, making a claim about a *cause and effect relationship.*			
b. Students use *quantitative* reasoning to explain how a particular production method is appropriate for their plant compound based on evidence from research and the unit as they plan to *scale production from the lab to the public consumer.*			
c. Students use *patterns* to identify the connections among the target audience, financial plan, molecular model, and target patient population in a format that meets the needs of the identified target audience.			

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Rubric for Biotech Unit Challenge

Constructing Explanations and Designing Solutions

Continued

Observable Features of Medicinal Plant Model, Financial Plan, and Communications Plan	**Meets Expectations** 8–10 points	**Progressing** 5–7 points	**No attempt** 0 points
Designing Solutions			
a. Creation of a detailed *system model* including: — prototype sketch — 2-D or 3-D engineering prototype model Students can explain how the model illustrates the mechanism of action of their plant-based medicine.			
b. Creation of a detailed financial analysis that uses *scale, proportion, and quantity.* Students utilize a spreadsheet to illustrate: — environmental impacts — stakeholder benefits sharing — production efficiency — cost of their plant-medicine compound			
c. Presentation product illustrates a *system model* of the plant-based medicine and its production scaling plan for a specific target audience. With teacher approval, format choices may include: — video — slide deck — newspaper article — brochure The communications product is: — professional — targeted to a specific audience — accurate — representative of the science described by other team members			

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Rubric for Biotech Unit Challenge

Constructing Explanations and Designing Solutions

Continued

Observable Features of Medicinal Plant Model, Financial Plan, and Communications Plan	**Meets Expectations** 8–10 points	**Progressing** 5–7 points	**No attempt** 0 points
Peer Feedback and Iteration			
a. Students give and receive kind, specific and helpful feedback throughout the project to refine their understanding of: — *patterns* used to identify a patient population — *system models* to describe the cellular process of a particular plant medicine — *scale, proportion, and quantity* to analyze which production method best suits their particular plant medicine			
b. Students integrate peer feedback into all project iterations.			
c. Students document their revision process and the choices they make about what feedback to consider.			
Final Score			
Grade			