location (98.6 °F/37 °C) for optimum fermentation. Remove the bags from the incubator and ask the students what they are observing. Allow the students to generate discussion with their observations. Do not confirm or deny ideas as you lead the conversation with your students.

Phenomena: Fermentation Bags					
A	1 tsp. yeast	50 ml water	1 tsp. glucose		
B	1 tsp. yeast	50 ml water	1 tsp. Corn flour	¼ tsp. amylase	
C	1 tsp. yeast	50 ml water	1 tsp. Corn flour	¼ tsp. glucoamylase	
D	1 tsp. yeast	50 ml water	1 tsp. Corn flour	¼ tsp. amylase	¼ tsp. glucoamylase

What is occurring in each of the four bags? Write the ingredients of each bag on the board and have students brainstorm observations or questions surrounding the function of each ingredient individually for 1 minute. Have them record both the bag contents and their observations on their charts for later use. Next, have the students share their observations in a small group for three minutes. Generate class discussion by asking groups to share their observations with the class.

Possible observations or questions about the Corn Fermentation in a Bag ingredients.

- *Glucose is a simple sugar (monosaccharide).*
- *Yeast are organisms/decomposers that eat sugars.*
- *Starch is a complex sugar (polysaccharide).*
- *Fermentation occurs when yeast consume sugar (glucose) and produce alcohol (ethanol) and carbon dioxide.*
- *Bag A produced the most CO_2 in 20 minutes (glucose).*
- *Bags B and C did produced very little CO_2 in 20 minutes.*
- *Bag D produced the second largest amount of CO_2 in 20 minutes.*
- *What do amylase and glucoamylase do? How do they function with sugars or yeast?*

The Problem: *Read the problem to the students and generate discussion with some of the following possible prompts:*

Human consumption of fuels is on the rise as both population and affluence steadily increase. **Renewable fuels**, such as ethanol, can help to decrease the need for **non-renewable fuel** sources such as crude oil. In addition, ethanol has replaced methyl tertiary-butyl ether (MTBE) as the major octane source in gasoline which has resulted in gasohol blends of up to 10% in almost every pump in the United States. Ethanol is a renewable fuel source that is both **energy positive**, which means it generates more potential energy than it consumes, and helps to reduce greenhouse gas emissions. More cars are on the road than ever before, so we need to be able to produce high quality ethanol quickly and efficiently to fuel the increase of active automobiles.

Fermentation is an anaerobic process where yeast consume sugars to produce alcohol and carbon dioxide. Ethanol is created when yeast consume **glucose** (simple sugar). Ethanol in the United States is produced by breaking down corn flour to create glucose, which is then consumed by yeast to produce CO_2, ethanol, and distillers grains. **Distillers grains** are the leftover corn fiber, protein and oil that result from the breakdown of starch in corn.

Here is the equation for the fermentation of glucose into ethanol and carbon dioxide.

$$C_6H_{12}O_6 \rightarrow 2CH_3CH_2OH + 2CO_2$$

Glucose -> 2 Ethanol + 2 Carbon Dioxide

Possible Student Prompts:

- *What is ethanol?*
- *How is ethanol used in gasoline to power cars?*
- *What is a gasohol blend?*
- *What is the feedstock for ethanol?*
- *How does ethanol help to decrease greenhouse gas emissions?*
- *Are there any co-products of ethanol production?*

The Challenge: *Read the challenge to the students.*
Create the greatest volume of ethanol (measured by the volume of CO_2 generated) in the fastest time possible.

Students should work in groups of 2-3 individuals for this challenge. Review the criteria and constraints for the challenge.

Criteria and Constraints

- Plan an (several) experiment(s) to produce ethanol in a small bag environment.
- You can only use the following materials/amounts provided by your teacher.
- You have 1 or more class period(s) to experiment on your initial design(s) based on your plan.
- Data must be collected and analyzed to provide evidence for your conclusion.
- Report back to the class and provide future experimental designs as a result of your current data/conclusion.

Provide some, all, or additional material items to the students that are listed below.

Possible materials:

- snack sized bags
- 50 ml water
- 1 tsp. Yeast
- ¼ tsp. enzymes (amylase, glucoamylase)
- 1 tsp. sugars (simple & complex) as feedstocks: corn flour, corn starch, corn syrup, honey, and glucose
- Ruler to measure gas volume
- Index card or clipboard to measure gas volume

How will you investigate your challenge?

Discuss the engineering design process with your students. Encourage the student groups to create 2 or more experimental designs based upon their knowledge of what occurs in the phenomena bags. Why are they investigating their design? What is their reasoning for their materials? What patterns do they expect to see? They will also need to create a method for measuring their CO_2 gas. We suggest that they measure volume by height displacement using a clipboard and ruler to demonstrate their volume change in CO_2 gas.

Prediction

Students should be able to predict the outcome of some of their experimental designs based upon previous background knowledge and their observations of the anchoring phenomena.

Observations related to your investigation.

Encourage the students to create charts and graphs to show the volume change within their bags over time. Students should create their own experimental procedure to collect and record data.

Model:

Students should create a model of their fermentation ecosystem here. The students can draw what is happening in the anaerobic process of fermentation based on the data collected in their experimental models.

Create a discussion with your students to determine if they could improve upon their experimental design based upon the evidence presented. What could they improve upon? Materials used? Experimental conditions? What research could they do to make their design as efficient as possible?

- *Can you create a more efficient design using different materials?*
- *Can you predict the outcome of other experimental designs?*
- *How can you change you original design to become more efficient by changing the experimental conditions?*
- *Make predictions using all of the available feedstocks in separate designs to determine which one will make the most CO_2 over time.*

Differentiation

Other ways to connect with students with various needs:

- **Local community:** students may investigate the use of ethanol in their community. (i.e. Do any fuel stations offer gasohol blends? What gasohol blend %'s are available?)
- **Students with special needs (auditory/visual/language/reading):** See the extra support below.
- **Extra Support:** Video: How ethanol is made (https://youtu.be/59R-NqykoXs) This video helps demonstrate relationships between the components of the ethanol fermentation ecosystem.
- **Extensions:** Students can research the use of ethanol as a fuel alternative and current gasohol blends available to the public.

Assessment: Corn Fermentation in a Bag Rubric

	No Mastery	Partial Mastery	Mastery	Exceptional
Develop and refine models to explain, predict, and investigate the natural and designed world.	Compare models to identify common features and differences.	Develop and/or use models to describe and/or predict phenomena.	Develop and/or revise a model to show the relationships among variables, including those that are not observable but predict observable phenomena.	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.
Develop and/or use a model to generate data.	Develop a simple model based on evidence to represent a proposed system.	Use a model to test cause and effect relationships or interactions concerning the functioning of a natural or designed system.	Develop and/or use a model to generate data to test ideas about phenomena in natural or designed systems, including those representing inputs and outputs, and those at unobservable scales.	Develop and/or use a model to generate data to support explanations, predict phenomena, analyze systems, and/or solve problems.

Self-Assessment Rubric

	Yes	**No**	**Maybe/Unsure**
Did we develop a model that explains the fermentation ecosystem?			
Did we develop a model that demonstrates the relationships between components of the fermentation ecosystem?			
Did we develop a model that generates data that enables us to predict outcomes of the fermentation ecosystem?			

Lesson 1: Corn Fermentation in a Bag

Essential Questions: *What is fermentation? How do yeast consume sugars to make ethanol and carbon dioxide?*

Phenomena - What is in each bag? Describe the reaction. Fill in the boxes below.

Bag Ingredients						Reaction
A	yeast	water				
B	yeast	water				
C	yeast	water				
D	yeast	water				

The Challenge

Create the greatest volume of ethanol (measured by the volume of CO_2 generated) in the fastest time possible.

Criteria and Constraints

- Work together in groups of 2-3 students.
- Plan an (several) experiment(s) to produce ethanol in a small bag environment.
- You can only use the materials/amounts provided by your teacher.
- You have 1 or more class period(s) to experiment on your initial design(s) based on your plan.
- Data must be collected and analyzed to provide evidence for your conclusion.
- Report back to the class and provide future experimental designs as a result of your current data/conclusion.

How will you investigate your challenge? How could you plan an investigation to test the challenge? What two (or more) experiments can you design to create ethanol as quickly as possible? How are you going to measure which one of your experiments changes the most? Write your experimental groups below. Be sure to include your reasons for your investigative choices.

Prediction What do you think will happen to each experimental group and why?

Group	**Reactants in Fermentation Bag**	**Prediction/Why**
Group 1:		
Group 2:		
Group 3:		

Measurement of Data:

How will your group measure the carbon dioxide that is generated? Write your plan to measure CO_2 below.

Observations:

Collect data from the group's experimental designs below. Include charts here to show your results.

Include graphs here to show your results.

Model:

Draw and explain your group's model of fermentation below. Be sure to demonstrate the relationships between the components of the fermentation ecosystem that your group utilized in their design.

Self-Assessment Rubric

	Yes	No	Maybe/Unsure
Did we develop a model that explains the fermentation ecosystem?			
Did we develop a model that demonstrates the relationships between components of the fermentation ecosystem?			
Did we develop a model that generates data that enables us to predict outcomes of the fermentation ecosystem?			

Teacher: Lesson 2: Ticketase

DCI	
MS-LS1: From Molecules to Organisms: Structures and Processes	
Performance Expectations	
MS-LS1.7: Develop a model to describe how food is rearranged through chemical reactions forming new molecules that support growth and/or release energy as this matter moves through an organism. ● *Clarification Statement: Emphasis is on describing that molecules are broken apart and put back together and that in this process, energy is released.* ● *Assessment Boundary: Assessment does not include details of the chemical reactions for photosynthesis of respiration.*	
Science & Engineering Practices	
Developing and Using Models ● Develop a model to describe unobservable mechanisms.	Students use tickets to model how the enzyme *ticketase* interacts with starch.
Disciplinary Core Idea	
LS1.C: Organization for Matter and Energy Flow in Organisms ● Within individual organisms, food moves through a series of chemical reactions in which it is broken down and rearranged to form new molecules, to support growth, or to release energy.	Students examine enzyme and sugar reactions to determine how molecules are changed.
Crosscutting Concept	
Energy and Matter ● Matter is conserved because atoms are conserved in physical and chemical processes.	Students observe that matter is conserved as starch is cut into smaller molecules by enzymes.

This lesson builds upon Lesson 1, *Corn Fermentation in a Bag*, where students utilize different components (enzymes, yeast, feedstocks, and water) to produce ethanol and carbon dioxide through the process of fermentation. This lesson focuses on Developing and Using Models as a means to describe unobservable mechanisms in the interactions between the enzyme, ticketase (amylase), and starch. Students will use experimental models to examine enzyme and sugar reactions and determine how the complex sugar, starch, is changed into smaller molecules for yeast consumption. Students will also use the Ticketase model to generate data in order to determine both substrate and enzyme concentration.

Remind the students of the 4 fermentation bags used as the phenomena in lesson 1. What was occurring in each of the four bags? You can help guide the students' discussion by asking questions as you record their observations/questions.

- *How did the amylase and/or glucoamylase impact the fermentation reaction?*

- *What are the roles of amylase and glucoamylase?*
- *Did amylase/glucoamylase help the fermentation process occur more slowly, rapidly, or have no net effect?*

To begin investigating these questions/observations and learn more about enzymes, have the students work through the enzyme lab, Ticketase.

Materials

- 3 strings of 50 connected tickets per student group
- *Optional: timer*
- *Optional: blindfold*

Procedure

Students should work in groups of 4. Provide each group with 3 strings of 50 connected tickets.

Reflection:

1. What happened to the **Reaction Rate** as the availability of **Active Sites** diminishes? Why did this happen?

Possible answers: The reaction rate decreases due to the decrease in active sites. This happens because the Ticketase does not readily connect with the substrate as the product (single tickets) increase in number

2. What happened to the reaction rate when the **Enzyme Concentration** increased? Why did this happen?

Possible answers: The reaction rate increased because there were 2 enzymes reacting with the starch molecules.

3. What happened to the reaction rate when the **Substrate Concentration** decreased? Why did this happen?

Possible answers: The reaction rate decreased due to a greater distance between available substrates.

4. What would happen to the reaction rate if the enzymes could separate the **products** and **reactants**? Why?

Possible answers: The reaction rate would increase because of the increase in substrate concentration.

5. How can Ticketase help to break starch into glucose molecules for fermentation (The string of tickets is the polysaccharide, starch, and the single tickets represent the monosaccharide, glucose)?

Possible answers: Ticketase separates the glucose molecules from the starch molecule. Glucose is the building block of starch.

6. How could the reaction rate increase if a second enzyme (one that tore 2 or 3 ticket segments off at a time) was introduced to work with Ticketase?

Possible answers: It would increase the reaction rate, it would decrease the reaction rate. It is important that the students provide evidence for their conclusions using data from their experiments.

Model:
Students create a model explain the unobservable relationship between the enzyme, ticketase, and the complex sugar, starch. Students should demonstrate how the enzyme cuts the starch molecule into smaller molecules. Students should label each component of the model and describe its function in the enzymatic reaction.

Differentiation:
Other ways to connect with students with various needs:

- **Local community:** Students may investigate the use of enzymes in digestion. How can the amylase found in human saliva help to break apart food molecules in preparation for digestion? Students can communicate with their findings with their local community.
Video: https://youtu.be/Lmma9Fwx7KY
- **Students with special needs (auditory/visual/language/reading):** See the extra support below.
- **Extra Support:** Video: How ethanol is made (https://youtu.be/59R-NqykoXs) This video helps demonstrate relationships between the components of the ethanol fermentation ecosystem. Infographic: http://vitalbypoet.com/infographics/ethanol-process-2 This infographic represents the process of corn flour breakdown into glucose for fermentation.
- **Extensions:** Students can research the current use of enzymes in corn ethanol production. Students can also research additional feedstocks for ethanol such as cellulosic switchgrass and the enzymes that would be necessary for carbohydrate breakdown.

Additional Resources for student research:

- http://vitalbypoet.com/infographics/ethanol-process-2
- Video: https://youtu.be/59R-NqykoXs

Self-Assessment Rubric Ticketase

	Yes	**No**	**Maybe/Unsure**
Did we utilize a model that demonstrates the function of the enzyme, *ticketase*?			
Did we generate data that enables us to predict the outcomes of the action of *ticketase* on starch?			
Did we develop a model that explains the function of *ticketase* in fermentation?			

Rubric: Ticketase

	No Mastery	Partial Mastery	Mastery	Exceptional
Develop and/or use a model to generate data.	Use a simple model based on evidence to represent a proposed system.	Use a model to test cause and effect relationships or interactions concerning the functioning of a natural or designed system.	Develop and/or use a model to generate data to test ideas about phenomena in natural or designed systems, including those representing inputs and outputs, and those at unobservable scales.	Develop and/or use a model to generate data to support explanations, predict phenomena, analyze systems, and/or solve problems.

Lesson 2: Ticketase

Essential Questions: *How do enzymes act upon complex sugars like starch? Does enzyme concentration or substrate concentration affect the rate of enzyme activity?*

Background: Enzymes work to speed up biological reactions by lowering their activation energy. There are certain conditions that must be met for enzymes to work efficiently. One of these conditions is **substrate concentration**. The tickets represent the **substrate**. Your thumbs and index fingers represent the **active site** of the enzyme "Ticketase." To **catalyze** the reaction (tearing single tickets off of the string of tickets), you may only tear a single ticket off at a time, then drop the single ticket and the string of tickets back into the pile. Pick the string of tickets up again to tear off another ticket. Tickets must be torn off cleanly to count as **products**.

Procedure:

Part A

1. Students should work in groups of 4.
2. Choose one of the following parts:
    a. Ticketase (person who will tear the tickets)
    b. Timer (will tell ticketase when to start/stop)
    c. Counter (counts the # of individual tickets)
    d. Date Recorder (record all #s in the data tables)
3. Place a string of 50 tickets in front of Ticketase.
4. When told to do so by the Timer, Ticketase will begin by picking up the string of tickets and folding/tearing off one ticket at a time while **not looking at the desk** and pile of tickets at a constant pace (it is not a race). Ticketase must then drop both the single ticket and string of tickets into the pile before being allowed to pick up the string of tickets to tear off another ticket.
5. As Ticketase tears off the tickets, the Counter will count the number of single tickets and make sure that the single tickets are put back in the pile with the chain of tickets (because products and reactants mix during the reaction).
6. Put 10 seconds on the stopwatch. Count the number of tickets torn off in 10 seconds. Record the data in Table 1.
7. Then, keeping the same pile of single tickets and the remaining string of tickets, count the number of single tickets in 20 seconds. Record the data in Table 1.
8. Repeat #6, but for 30 seconds. Record the data in Table 1.
9. Repeat #6, but for 60 seconds. Record the data in Table 1. * If you run out of tickets, record the amount of time it took Ticketase to do so.

Part B

1. Repeat everything in Part A, but now spread out the tickets so that Ticketase has to reach for them (ticket concentration decreases). Record all data in Table 2.

Part C

1. Repeat everything in Part A, but now have 2 sets of 50 ticket strings and 2 students tear off single tickets (double enzyme concentration). Record all data in Table 3.

Table 1

Interval Time (sec)	Cumulative time (sec)	# Single tickets	Total Single Tickets
10	10		
20	30		
30	60		
60	120		

Table 2 (Decreased Enzyme Concentration)

Interval Time (sec)	Cumulative time (sec)	# Single tickets	Total Single Tickets
10	10		
20	30		
30	60		
60	120		

Table 3 (Increased Enzyme Concentration)

Interval Time (sec)	Cumulative time (sec)	# Single tickets	Total Single Tickets
10	10		
20	30		
30	60		
60	120		

Graph the number of single tickets (total) over time (cumulative). Put all 3 sets of data on the same graph and include a key to distinguish them.

Reflection:

1. What happened to the **Reaction Rate** as the availability of **Active Sites** diminishes? Why did this happen?

2. What happened to the reaction rate when the **Enzyme Concentration** increased? Why did this happen?

3. What happened to the reaction rate when the **Substrate Concentration** decreased? Why did this happen?

4. What would happen to the reaction rate if the enzymes could separate the **products** and **reactants**? Why?

5. How can Ticketase help to break starch into glucose molecules for fermentation (The string of tickets is the polysaccharide, starch, and the single tickets represent the monosaccharide, glucose)?

6. How could the reaction rate increase if a second enzyme (one that tore 2 or 3 ticket segments off at a time) was introduced to work with Ticketase?

Model:
Draw a model of ticketase and starch below. Label the model to explain how ticketase interacts with starch to create smaller sugar molecules.

Self-Assessment Rubric Ticketase

	Yes	**No**	**Maybe/Unsure**
Did we utilize a model that demonstrates the function of the enzyme, *ticketase*?			
Did we generate data that enables us to predict the outcomes of the action of *ticketase* on starch?			
Did we develop a model that explains the function of *ticketase* in fermentation?			