Learning Experience 6

Turning Corn into Milk: Alchemy or Biochemistry?

Prologue

A cow stands over the grain bin contentedly chewing on corn. In a few hours, the dairy farmer will come in to milk her. What is the relationship, if any, between the corn that provides the cow with nutrients and energy and the milk that she produces both for feeding her offspring and for the farmer to sell?

In this learning experience, you apply the concepts from Learning Experience 5 to examine how organisms use food resources to synthesize new materials for their own use. You identify the chemical relationship between the food that a cow uses (corn) and one of the products a cow synthesizes (milk). You determine how one can be turned into the other.

Brainstorming

Discuss the following questions with your partner, and record your thinking in your notebook. Be prepared to share your ideas with the class.

1. Remember the phrase, "You are what you eat." Explain what that means to you.
2. What do you think the relationship is between what you ate at lunch and the cells, tissues, and organs that make up your body?
3. Why might this relationship be considered a form of recycling?

Corn and Milk: So Different Yet So Similar

ACTIVITY

How can a cow use a food resource like corn to produce milk (see Figure 1.19)—a very different substance? In this activity, you will analyze the biomolecular composition of corn and milk. You will use indicators to determine whether corn can provide any of the components found in milk. The indicators Biuret reagent, Benedict's solution, iodine, and Sudan III will help you test for proteins, sugar,

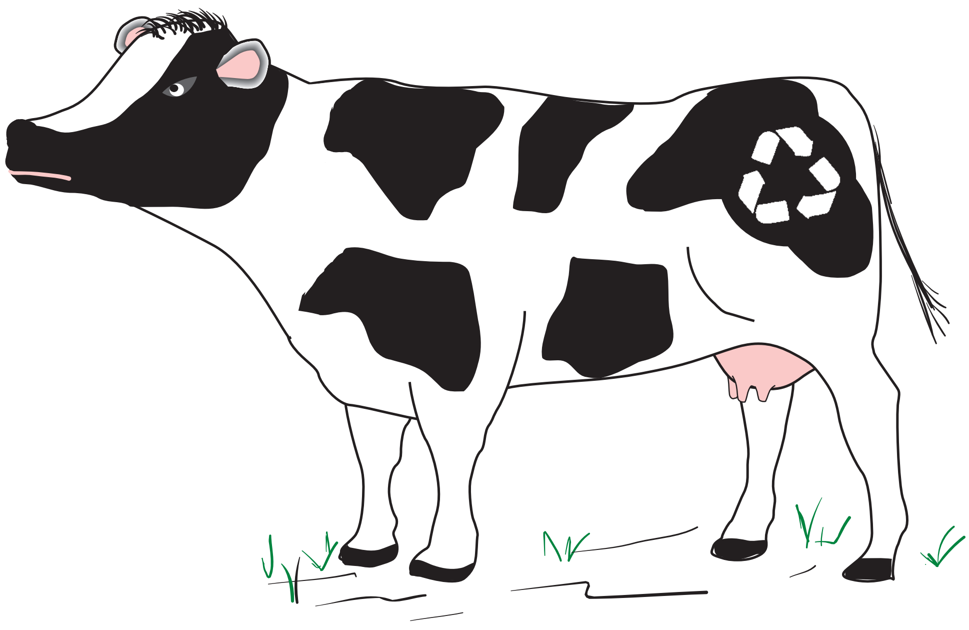

Figure 1.19

Cow, a natural recycling center: input corn—output milk.

starch, and lipids. Look at the experiment you conducted in Learning Experience 4, Feeding Frenzy. Review the use of indicators and the general procedure for conducting an experiment that uses indicators.

Materials

For each group of four students:

- nutrient label from a milk carton
- 4 safety goggles
- 4 pairs of disposable gloves (optional)
- 1 eyedropper or 10 disposable pipettes
- heat source
- 2 beakers (250-mL) or clean plastic margarine tubs or other containers
- 12 test tubes
- 1 test-tube clamp
- 1 test-tube rack
- 1 glass stirring rod
- 3 tsp canned whole-kernel corn
- 10 mL fresh, whole, pasteurized milk
- 1 small bottle Biuret reagent
- 1 small bottle Benedict's solution
- 1 small bottle iodine
- 1 small bottle Sudan III or IV reagent
- 1 fork or spoon (to mash corn)
- 1 wax marking pencil
- access to distilled water

For the class:

- 1 set positive test control solutions, 1 tsp
- boiling water bath
- heat source
- blender (optional)

Procedure

1. **STOP & THINK** Identify the question being asked, and make a prediction about the outcome of this experiment. Record your response in your notebook.
2. **STOP & THINK** Read through the entire procedure and draw your experimental setup in your notebook. See Figure 1.15 in the Procedure section of Learning Experience 4 for an example.
3. **STOP & THINK** Why is it important to analyze milk even when you have access to information about milk from the nutrition label? Record your reasons.
4. Place 3 spoonfuls of corn with its juice in a 250-mL beaker (or clean plastic container). Mash up the kernels with the back of a fork (or you may use a blender).
5. Pour approximately 10 mL of fresh milk into a container.
6. Label a set of 4 test tubes: Water +, then label each with one of the following: "sugar," "starch," "protein," or "lipid." These are your negative controls. Place the test tubes in the test-tube rack. There will be a class set of positive controls.
7. Label a second set of 4 test tubes: Milk +, then label each with one of the following: "sugar," "starch," "protein," or "lipid."
8. Label 4 more test tubes: Corn +, then label each with one of the following: "sugar," "starch," "protein," or "lipid." Place the test tubes in the test-tube rack. These last two sets are your experimental unknowns.
9. Using a clean pipette or eyedropper, add 30 drops of water to each of the test tubes labeled "Water +."
10. Using a clean pipette or eyedropper, withdraw the corn mush from the beaker. Place 30 drops of the mush into each of the test tubes labeled "Corn +."
11. Using a clean pipette or eyedropper, place 30 drops of milk in each test tube labeled "Milk +." Wash the eyedropper.
12. Using a clean and separate pipette for each indicator (or a clean eyedropper), add 15 drops of the appropriate indicator to the appropriate test tubes (see Table 1.1, Learning Experience 4). You should have 3 test tubes for each indicator: 2 samples (corn and milk) and 1 negative control. Heat in boiling water those test tubes that contain Benedict's solution.
13. Examine all your test tubes for any color changes and record the results. You may need to hold the Biuret test tubes against white paper to see the color changes more clearly.
14. Record your results. Discuss them with your group.
15. Dispose of the contents of the test tubes and wash your glassware.

NOTE

If you are using an eyedropper, be sure to rinse the eyedropper well between each step. To rinse, draw water from one beaker into the dropper; then squirt the water into a second beaker. Repeat 2 or 3 times for thorough rinsing.

SAFETY NOTE

The hot plate and boiling water can cause burns. Biuret is caustic. If it comes in contact with skin, rinse thoroughly with water. If you should get any in your eyes, irrigate them immediately and inform your teacher.

Analysis

1. Prepare a laboratory report for this experiment in your notebook. Be sure to include the following:
   a. the question(s) being asked;
   b. your predictions about the outcome;
   c. the experimental design and how the investigation was set up (include a rationale for testing the milk again);
   d. the data or observations you made (in a chart or table);
   e. your analysis (include your responses to the Analysis questions that follow); and
   f. your conclusion (your answer to the question being asked).

2. What biomolecules are present in milk and in corn?
3. What chemical elements (atoms) make up these biomolecules? Would it be possible to make protein if you didn't take in protein? lipids? carbohydrates? Explain your answers.
4. How can two such different substances—corn and milk—be composed of many or possibly all (depending on your results) of the same biomolecules?
5. Create a diagram using words or drawings that illustrates the pathway by which a cow converts corn to milk. Base your diagram on the results of your experiment.

Reading

Haven't I Seen That Carbon Somewhere Before?

> Julie Lewis walks on a dream come true. Since she was a teenager, inspired by the rallies of the first Earth Day in 1970, she yearned to turn waste into something worthwhile. Now the 38-year-old is vice president of a company she founded called Deja. She calls her recycled invention the Deja Shoe.
>
> Its cotton-canvas fabric is rewoven from textile scraps. The foam padding was designed to cushion chairs. Factory-reject coffee filters and file folders go into the insole. Add recycled grocery bags, tire rubber, and plastic trimmings left over from the manufacture of disposable diapers.
>
> The shoes look handsome, durable, and ready for the outdoors. . . . Her Portland, Oregon firm ships 100,000 pairs annually [to] stores across the country. And when they wear out? Send them back to Deja to be recycled.
>
> —An excerpt from Noel Grove, "Recycling," *National Geographic*, July 1994, pp. 92–115

Julie Lewis's company takes trash and turns it into shoes. Cows take corn and use it to produce milk. Similarly, you eat pizza or salad and convert them into proteins, lipids, carbohydrates, nucleic acids, and energy. Your body uses these things to continue to grow and to maintain itself. Long before the first Earth Day, organisms were recycling materials.

Use It Again, Sam

How do living organisms recycle the resources they take in? How do they transform them into new materials that an organism can use? How can a cow use a food resource like corn to produce milk—a very different substance?

As you have been finding out, perhaps corn and milk are not totally different substances. At least they are not totally different in terms of the biomolecules and chemical elements they are composed of. The big differences are in how those elements are put together. For example, all biomolecules are composed of similar elements. But the biomolecules differ because each of their elements is put together into different subunit structures.

Because these subunits can also be varied, many possible kinds of carbohydrates, proteins, nucleic acids, and fats can be made. Single subunits can be different, and groups of subunits can be put together in lots of different ways. There are sometimes slight and sometimes more obvious differences in the way things are put together. These differences can produce materials with very different structures, chemical properties, and functions. The carbohydrate in milk, for instance, consists primarily of the disaccharide sugar lactose. The primary carbohydrate in corn, however, is the polysaccharide starch.

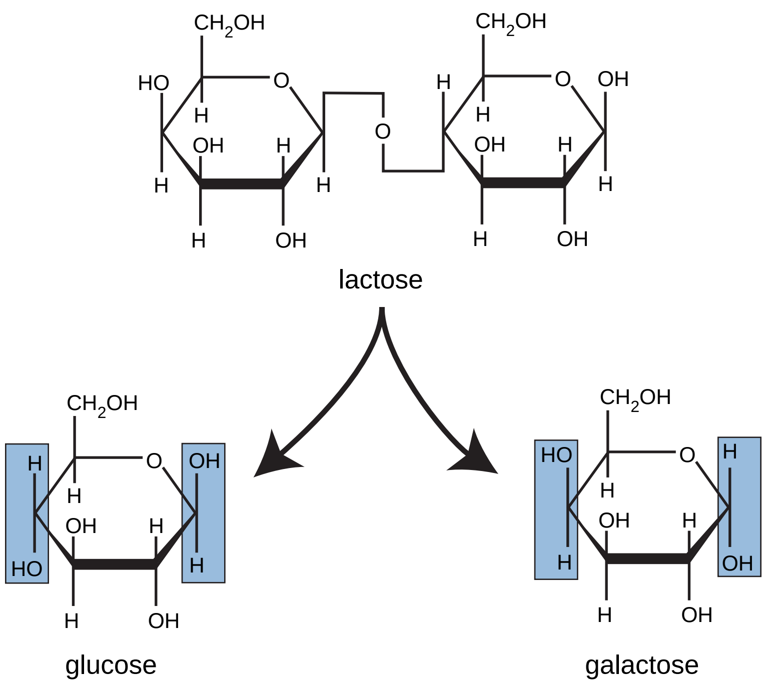

Figure 1.20
Lactose is a combination of glucose and galactose.

Grass, another food source for cows, has another polysaccharide, cellulose, as its major carbohydrate. Starch and cellulose are both composed of a long chain of linked glucose molecules. These two carbohydrates differ only in terms of how those glucose subunits are linked to one another. Lactose is a simpler carbohydrate. It is composed of a glucose molecule and a galactose molecule. Glucose and galactose are composed of exactly the same number of carbons (6), hydrogens (12), and oxygens (6)—($C_6H_{12}O_6$). But they differ in how these atoms are arranged (see Figure 1.20). This small difference in arrangement produces two sugars that are chemically different in nature. When these two sugars are joined by a chemical bond, yet a third and different sugar, lactose, is formed.

Imagine that you are an architect who has been hired to design a building constructed only of wood, ceramic, and glass. Using only these three materials, you have a tremendous variety of possibilities for how the final building might look. Just as carbon, hydrogen, and oxygen can be put together differently to make substances very different in nature from one another, you could design a variety of different buildings by changing the way building blocks are put together. All living organisms are made up of **organic** (carbon-containing) materials that have the same six elements. But life on Earth is diverse. This is due to the highly varied possibilities for design in how organic compounds can be put together. Think about the similarity in the elements that living things are made of and the variations in the structure of biomolecules. These characteristics suggest a start to responding to our questions, “How do living organisms recycle the resources they take in? How do they transform them into new materials that an organism can use?” If biomolecules differ in terms of how their elements are arranged, then perhaps one could be made into the other by reshuffling the chemical elements. If a cow could break down corn into smaller subunits, it could then rearrange them and build something new. This would be similar to Julie Lewis taking scrap pieces of textiles and weaving them together into a whole new shoe.

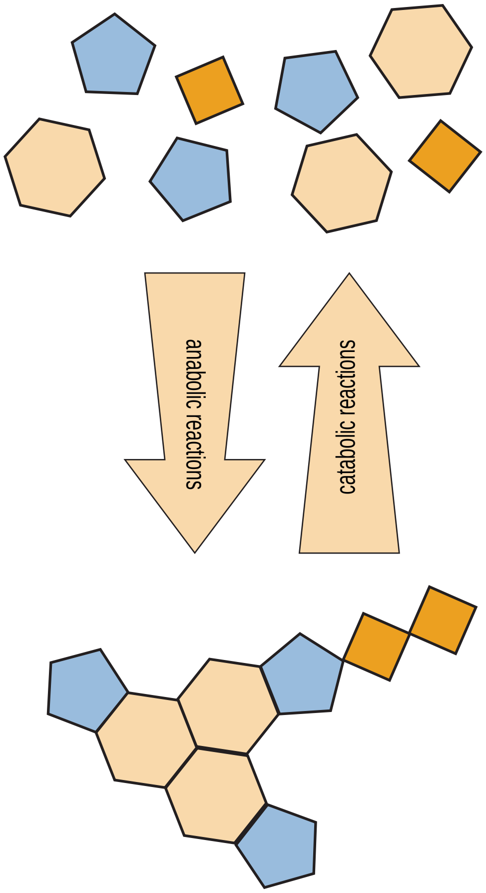

Figure 1.21
The cycle of catabolism and anabolism.

Break It Down, Building It Up

These chemical reactions of breakdown (**catabolism**) and synthesis (**anabolism**) are fundamental to how living organisms sustain life. One definition of a chemical reaction can be the transformation of molecules into other kinds of molecules. Anabolic reactions involve the building of biomolecules from other molecules. You have already seen an example of this in photosynthesis. Here carbon dioxide and water are transformed into sugar. The transformation of corn into milk actually involves many steps. The starch and other biomolecules are broken down (catabolized). Then the components are reassembled into the sugars and other biomolecules of milk. Figure 1.21 illustrates the relationship of anabolic reactions to catabolic reactions.

How do biomolecules get "broken down"? One of the major requirements is energy. If you have ever burned toast, you know that it turns black. The heat provided the energy that caused some of the bread to break down to carbon. This can also be seen when glucose is "burned." When heat energy is added in the presence of oxygen, the glucose molecule breaks. A great deal of energy in the form of heat is released. Chemically, electrons are transferred from the hydrogen atoms in the glucose molecule to oxygen. This results in the formation of water. When a molecule loses electrons, it is said to be **oxidized**. The chemical reaction for the burning of glucose can be written as the following equation:

$$C_6H_{12}O_6 + 6O_2 + \text{energy} \rightarrow 6CO_2 + 6H_2O + \text{energy}$$

In living organisms, a very similar reaction takes place. But this reaction happens in a much slower, controlled, series of small steps. The slower oxidation of glucose has several advantages for the organism. It (1) prevents the organism from burning up; (2) enables the energy in the bonds of the glucose molecule to be transferred to other molecules for use by the organism (rather than being released as heat); and (3) allows the products of the glucose molecule breakdown to be used by the organism to synthesize other biomolecules. In the next learning experience, you will be examining these energy transfers and the importance of oxygen in them.

Putting It All Together

Metabolism is the web of simultaneous and interrelated chemical reactions taking place at any given second of life. Within this web, complex chains of biomolecules are woven from simpler units or are dismantled piece by piece. Growth, movement, repair, and other life-sustaining activities depend on these collective chemical reactions.

Metabolic reactions are organized into pathways. Catabolic reactions are interconnected to anabolic pathways. The product or **intermediate** of a catabolic pathway may be the starting material for an anabolic pathway. The anabolic pathways consist of a number of individual steps. Through these steps, materials are progressively rearranged and built. These sets of reactions are called pathways. This is because they have a starting material (for example, starch), an end product (protein, nucleic acid, lipid, carbohydrate), and a series of reactions in between (steps along the path). At each step of a metabolic pathway, the

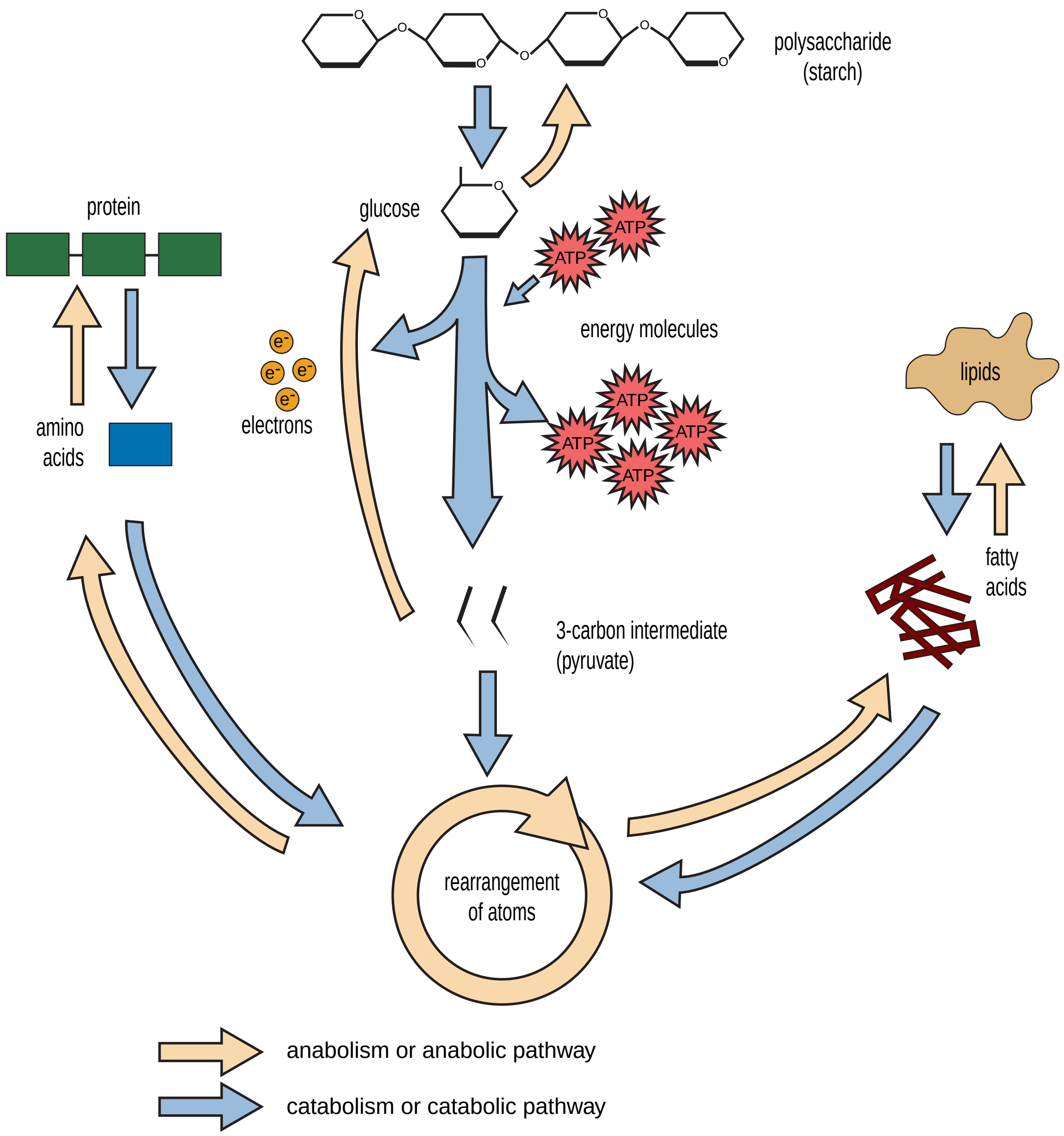

Figure 1.22
Metabolic pathways.

starting material is changed a little more (see Figure 1.22). Sometimes a new pathway can begin in the middle of an ongoing pathway.

In your experiment, you determined that milk and corn contain the same kind of biomolecules. The cow ingests corn; the corn is broken down further and further. It is broken down first by the digestive processes into its biomolecular components. It is then broken down by the catabolic pathways, into intermediates. This process releases energy. This energy is then captured in a chemical form that the cow can use. These intermediates are then used as building materials to synthesize new biomolecules using the energy from catabolism. These materials are also used for the other life processes the cow must carry out. Figure 1.23 represents these transformations.

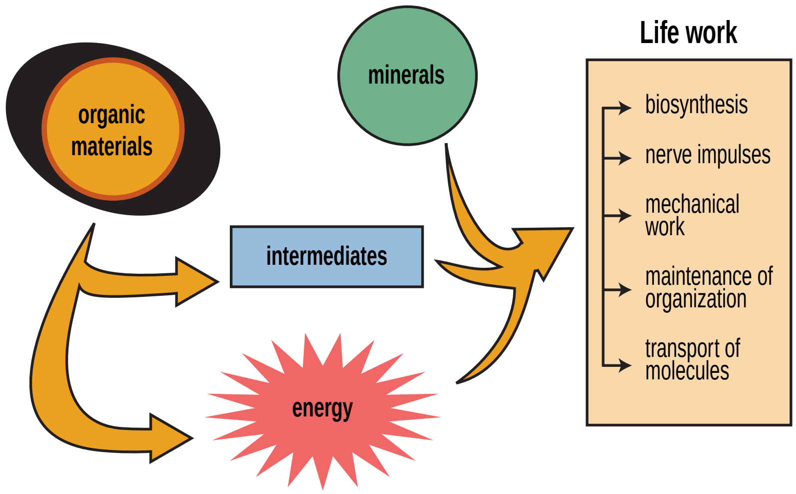

Figure 1.23
Metabolic processes provide intermediates and energy needed to carry out the activities of life.

ANALYSIS

Record your responses to the following in your notebook.

Create a concept map using *corn* as the starting idea. Include at least 10 words or ideas from the reading. Use the illustrations to guide you in developing your concept map.

EXTENDING *Ideas*

Recycling is popular today. Whether it is making shoes out of garbage or finding uses for the packaging materials that enclose many items that we purchase. Blue or green bins in many cities contain various items for recycling. These include glass, aluminum, polystyrene foam, and plastic. Write or draw an analogy of the recycling of food packaging material as it compares to the breakdown and synthesis of food. Describe what happens to the package during the recycling process. Explain how this compares to the recycling of biomolecules.

CAREER FOCUS

Teacher Tyrell is the kind of teacher we all wish for. He's enthusiastic about the science he teaches, and he cares about his students. To an outsider, Tyrell's classroom probably looks chaotic. Students are busy investigating plant samples, talking to each other, and trying to solve the problem at hand. The walls are covered with colorful posters and samples of students' work. As a high school biology teacher, Tyrell has carefully created a learning environment where students can explore science firsthand.

Tyrell teaches classes in introductory biology, honors biology, microbiology, and genetics. His job involves planning which topics to cover, deciding which activities or labs to use to illustrate the topic, preparing the necessary materials, working with students as they do the activities, and writing and grading quizzes and tests. Tyrell wants to help students explore science concepts in depth and examine science within social, historical, ethical, and political contexts. He feels that as a teacher he can really make a difference in his students' lives. He loves to see the expression on his students' faces when they accomplish something or gain a new understanding. But he spends a lot of extra hours at home planning lessons and correcting work.

Tyrell was always interested in biology. As a child, he begged his parents for a plastic anatomy mannequin with removable organs. He would study it for hours and continually take it apart and put it together again. Given his interest in human biology, Tyrell thought that he would definitely become a doctor. But after volunteering at a local hospital during high school, Tyrell decided that health care wasn't the right field for him. When he was a senior taking AP biology, one of the introductory biology teachers became ill. Tyrell's teacher asked him to fill in and teach the Biology 1 class. He reluctantly agreed and to his surprise loved teaching the class.

That experience, combined with his interest in biology, prompted Tyrell to pursue a career as a biology teacher. He completed a Bachelor of Science/Bachelor of Education degree. He then spent an extra year after getting his bachelor's working as a student teacher and completing master's degree courses to become a certified teacher.

Tyrell is fascinated with the fact that so much is still unknown in the world of science and that there is always something new to discover. He conveys this excitement to his students. Being a school teacher has given Tyrell the opportunity to combine a career with his interests—science, psychology, and children—and to pass his enthusiasm on to the next generation.

For Further Study

Metabolic Managers

Prologue

Through your study of metabolism, you have been exploring the interconnected chemical reactions that constitute some of the essential processes of life. You know that as some reactions are breaking down complex biomolecules piece by piece, other reactions are transforming and restructuring the simple units into new materials.

One of the keys to diversity in the living world is the variety of different materials that organisms build from the nutrients they take in. A wide array of protein, fat, nucleic acids, and carbohydrate products are constructed by living organisms in hundreds of different types of chemical reactions. Maintaining the web of chemical reactions must be a well-organized operation if the living organism is to survive. All reactions require starting materials and involve a transfer of energy. Reactions also require efficiency to meet the extraordinary and continuous material and energy demands that take place at every second of an organism's life.

Brainstorming

Discuss the following questions with your partner, and record your thinking in your notebook. Be prepared to share your ideas with the class.

1. What happens to a soda cracker when you place it in your mouth for a while without chewing?
2. Why do you think this happens?
3. Do you think this would happen faster in water or saliva? Explain your answer.
4. Do you think there is a difference in what happens to the biomolecules in the cracker in water versus saliva?

READING

Critical Players

Enzymes are critical players in this need for efficiency. Enzymes are protein molecules built by living organisms from nutrient materials they take in. Enzymes **catalyze** (speed up) chemical reactions. They facilitate the transformation process by helping to convert materials from one form to another. Metabolic reactions would take place too slowly to sustain life if it were not for these catalytic proteins. If an enzyme is unavailable, the reaction will still proceed. But it will proceed at about one-millionth the speed. In humans, one meal would take about 50 years to be digested without digestive enzymes.

You may already be familiar with digestive enzymes. These enzymes help to break down food into forms that your body can use. Saliva contains the digestive enzyme amylase, which initiates the breakdown of starch. In the stomach, pepsin begins protein digestion. Other enzymes assist in the further breakdown of sugars, proteins, and lipids. If an organism does not have a specific enzyme, it may be unable to break down certain kinds of food.

Other enzymes throughout the body work specifically at each step along metabolic pathways. One example is the chemical reaction that transforms carbon dioxide into carbonic acid. Without enzymes, 200 molecules of carbonic acid can be produced in 1 hour. With the aid of an enzyme in the blood called carbonic anhydrase, however, the reaction rate is increased to 600,000 molecules per second.

SCILINKS NSTA

Topic: Enzymes
Go to: www.scilinks.org
Code: INBIOH265

Enzymes function at their best in certain conditions, such as within a certain pH range or a certain temperature range. Enzymes can cease to function or be destroyed by exposure to high temperatures. This, in turn, disrupts metabolism. That is why humans, for instance, cannot live when the body temperature exceeds 44°C (112°F). Beyond that temperature, too many metabolic processes become disrupted because the enzymes cannot function.

Analysis

Record your responses to the following in your notebook.

1. What is the role of enzymes in the cell? What other roles can you think of that enzymes might play in addition to those mentioned in the reading?
2. What might happen if enzymes did not function correctly or were missing?
3. Describe how enzymes might play a role in the relationship between the corn a cow takes in and the milk she produces.

Crisis at the Creamery

Case Study

Before profits begin to fall at the esteemed milk producer, Sun Valley Creamery, you and your partner must determine whether Sun Valley or the complaining customers are at fault. In pairs, read through the following fictional scenario and answer the Analysis questions that follow.

SUN VALLEY CREAMERY FACES POTENTIAL FOR DECLINING PROFITS

Ms. Hatfield is the head of the Sun Valley Creamery. During the past several months, the company has received calls from customers who have repeatedly felt ill soon after drinking Sun Valley brand milk. They report suffering stomach cramps and bouts of diarrhea. Ms. Hatfield immediately runs a product check on all milk being shipped out from the company.

After scouring all facets of her operation and product testing the milk, Ms. Hatfield cannot find anything wrong with her production lines. Ms. Hatfield gathers data that compare her complaining customers with her noncomplaining customers (Table 1.2).

The complaining customers all drank from different batches. Thousands of other customers drank from all those same batches without suffering ill effects. Ms. Hatfield finds herself in a dilemma. The news of potential problems with Sun Valley products is spreading fast, and yet she cannot figure out where the problem lies. She needs to find out what is happening before any more people get sick and before Sun Valley's profits begin to disappear.

Ms. Hatfield starts to wonder what might tie all these cases together. Is there anything all these complaining customers have in common? Ms. Hatfield has a thought: Perhaps these complaining customers are having trouble with dairy foods in general. She recalls that many people lack the enzyme lactase, which converts lactose to glucose and galactose. Following the ingestion of certain dairy foods, people lacking lactase will experience stomach cramps and bouts of diarrhea. She decides to run an experiment. She asks several complaining and noncomplaining customers to participate. In this experiment, each participant is asked to consume (on separate occasions) a container of Sun Valley yogurt, a portion of Sun Valley cottage cheese, a portion of Sun Valley cheddar cheese, and a glass of Sun Valley milk.

HOW ARE DAIRY PRODUCTS MADE?

Ms. Hatfield chose the foods based on her experience with how dairy products are made. All dairy products begin with one basic ingredient: milk. Each of the cheese and yogurt products produced by Sun Valley, and tested by Ms. Hatfield, started out as milk. The transformation of milk into yogurt or cheese involves a transformation of the nutrients found in milk. These changes produce unique tastes, textures, and appearances.

The typical cheese-making process first involves separating fluid milk into curds (a white gel) and whey (a murky, watery liquid). Most of the nutrients are concentrated in the curd. (The nutrients are a high percentage of proteins and fats, and a smaller amount of sugar.) The Sun Valley Creamery makes cheese by adding bacteria to milk. As the bacteria grow in the milk, they produce acid (lactic acid). This causes the milk to curdle, or separate into curds and whey. The lactic acid is a product of the breakdown of the sugar lactose. Lactose is broken down by the enzyme lactase, which is produced by the bacteria. The lactic acid produced by the bacteria, as well as other changes in the nutrients caused by the bacteria, produces cheese with distinct tastes and textures.

Both cheddar and cottage cheeses are made from curds that have been acid-separated. However, cheddar cheese goes through an additional stage of preparation called ripening, or curing; cottage cheese does not. Ripening and curing describe the process in which the curd is exposed to another round of bacterial culturing. The bacteria, and more specifically the work of their enzymes, further transform the nutrients in the fresh curd. For instance, in this final stage of ripening, any remaining lactose in the curd is converted into lactic acid. Thus, ripened cheeses generally have no measurable amounts of lactose, whereas unripened cheeses may contain a small amount.

Unlike cheese, the yogurt products we eat contain live cultures. A spoonful of yogurt contains lots of bacteria. These bacteria work to metabolize the nutrients that you are also spooning into your mouth. Similar to the curd and whey separation in making cheese, yogurt cultures primarily consist of lactic acid–producing bacteria. These bacteria are converting the lactose in the milk into lactic acid. But because yogurt contains live cultures, these harmless bacteria can enter your stomach in a spoonful of yogurt. Here they continue to metabolize the lactose with the lactase enzymes they are producing.

The bacterial cultures in yogurt also build enzymes that break down proteins and lipids. As a result, the proteins and lipids clot. This "clotting" and the effect of the increasing concentration of lactic acid change the physical properties and chemical structure of milk into what we commonly recognize as yogurt.

Table 1.2 Ms. Hatfield's Test Results

Dairy Product	Complaining Customers	Noncomplaining Customers
milk	felt ill	felt fine
yogurt	felt fine	felt fine
cottage cheese	felt ill	felt fine
cheddar cheese	felt fine	felt fine

ANALYSIS

Record your responses to the following in your notebook.

1. Describe the similarities and the differences among yogurt, cottage cheese, and cheddar cheese.
2. Are the symptoms being experienced by some customers the result of a problem in the products being produced by Sun Valley? Explain your answer.
3. Explain why milk and cottage cheese cause some customers to feel ill, whereas yogurt and cheddar cheese do not.
4. Why do you think some customers have experienced these symptoms, whereas most of them do not?
5. Suggest ways that Sun Valley Creamery might help its customers.
6. How is the following scenario similar to Ms. Hatfield's dilemma? Describe the similarities and differences.
   A ruminant is an animal that "chews its cud." Animals such as cows, goats, and giraffes like to dine on grass and other vegetation that is made primarily of cellulose. Cellulose is a tough, fibrous substance; it is a long-chain polysaccharide. Animals cannot break down cellulose because they lack the necessary enzyme, cellulase. Cellulase breaks down cellulose to glucose. However, bacteria that inhabit the stomach of ruminants do produce cellulase. In exchange for room and board, these bacteria help cows and other ruminants break down the cellulose in grass to glucose. The glucose can then be used for energy and building blocks by the cow.
7. Why can ruminants eat grass, whereas humans cannot?