Curriculum Units by Fellows of the Yale-New Haven Teachers Institute
2015 Volume IV: Big Molecules, Big Problems

Biochemistry and Baseball

Curriculum Unit 15.04.05
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Introduction

Hyde Health Sciences and Sports Medicine is a New Haven magnet school focused on providing hands-on, innovative learning experiences for its students. Located in North Haven, Hyde attracts a unique student population that is an 80/20 blend of New Haven students and surrounding suburban students, respectively. With a diverse student population in numerous respects—socioeconomically, racially, etc.—Hyde faces distinct challenges as it attempts to provide excellent science educations for its students.

As a chemistry teacher at Hyde, I am tasked with developing science experiences that engage my students in authentic and compelling challenges. As such, my unit strays from the typical chemistry curriculum and into biochemistry with analogies to baseball. The purpose behind this is to introduce students to concepts that reach into their lives using enzymes—those little machines in our bodies—and analogies to sports to capture their imaginations.

Throughout this unit, students will encounter a number of challenging concepts related to reactions—how they occur, the math behind them, and how they are mediated biologically. Students will learn about reaction collision theory through an analogy to baseball. They will engage mole ratios and grapple with the concept of the limiting reagent by making s'mores and mixing chemicals. Finally, they will discover the power of enzymes and their kinetics by exploring the Michaelis-Menten equation, enzyme saturation, and the importance of the K_m constant.

Exploring Enzymes

Catalysts: Chemistry's Facilitators

In organic and inorganic instances alike, a chemical reaction is defined as a process of breaking and/or making bonds that has two distinct sides, the reactant side and the product side. A catalyst is a substance that increases the rate of a reaction without being chemically changed. That is, a catalyst is not consumed. For

instance, in the Haber process, an iron catalyst is used to make ammonia from hydrogen and nitrogen and the iron is not used up. These inorganic catalysts are used to improve the yield of a product many-fold over. We also find catalysts in nature, called enzymes. Enzymes are catalysts made up of proteins. In a reaction, all reactants must overcome a barrier of energy, called the activation energy, to form products. [1] Enzymes are the biological molecules that lower this activation energy necessary for chemical reactions to begin and, in turn, increase the rate of these reactions. Figure 1 shows a reaction energy diagram with and without a catalyst and illustrates this phenomenon.

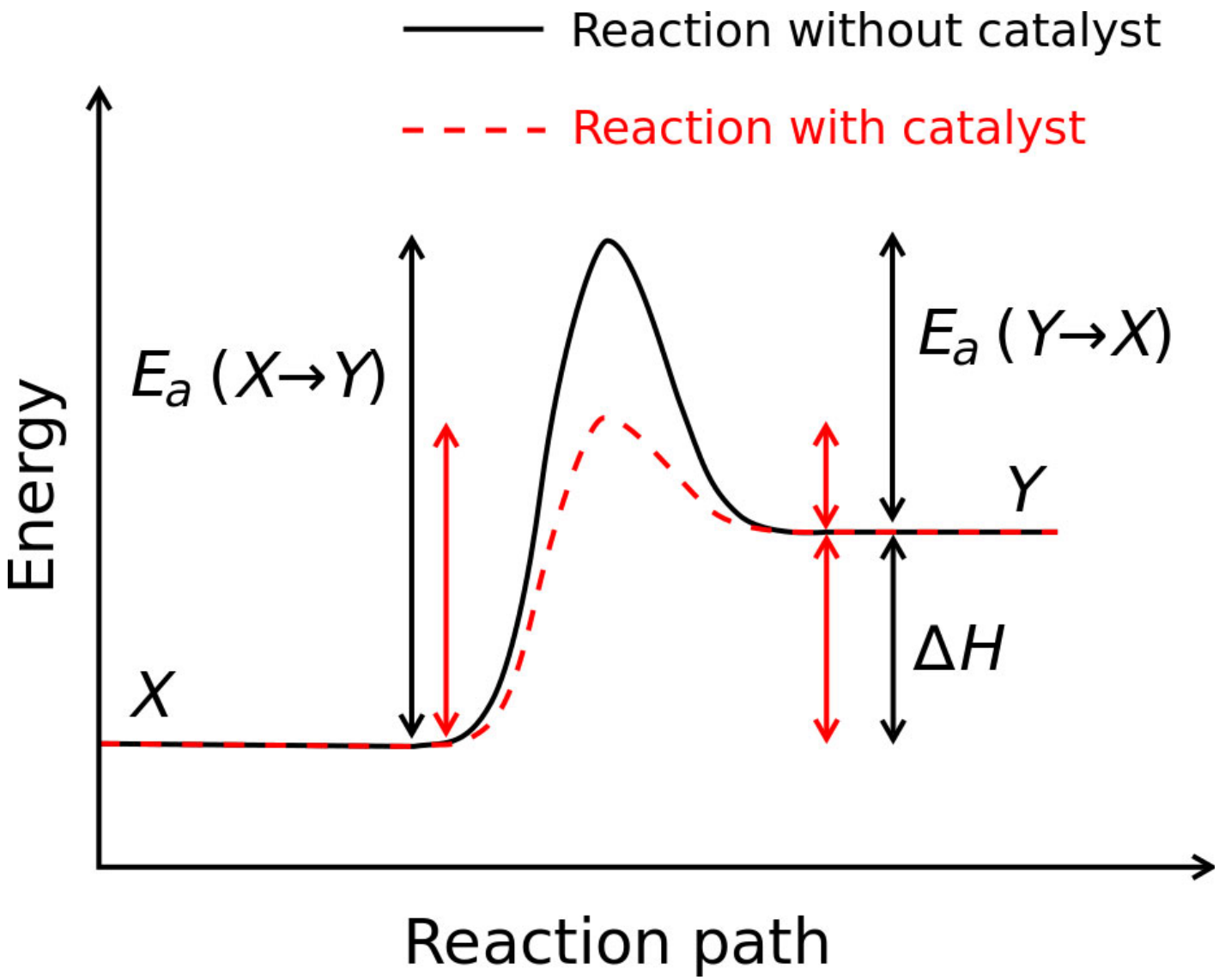

Figure 1: https://en.wikipedia.org/wiki/File:Activation_energy.svg

An Introduction to Enzymes

Though their activity had been studied during the 17 th and 18 th centuries, enzymes and their biochemical nature were relatively unknown up until the early 1900s. Some scientists believed proteins were simply carriers for the true enzymes, which performed catalysis. In fact, it was not until around 1930, that pure proteins were shown to be capable of catalysis through the work John Northrop and Wendell Stanley conducted on pepsin, trypsin and chymotrypsin. [2] In the years since, enzymology, the study of enzymes—their structure, function and kinetics—has become a cornerstone of biochemistry. This subject is particularly

important because enzymes serve as conduits for the accelerated reaction times needed to support life. [3] In particular, enzymes play an integral role in cellular function, catalyzing more than 5,000 known reaction types. [4] Let's explore one example. Proteases are a particular class of enzymes that cleave peptide bonds—the bonds that hold amino acids together. That is, proteases cut proteins. When we eat food our body uses a number of proteases to break down the proteins we ingest. One such example is trypsin, a protease that is secreted in the part of the stomach called the duodenum. Trypsin cuts proteins after particular amino acids, lysine and arginine. These peptide products are then broken down by other proteases until they are able to be absorbed into the blood stream. This example shows us that enzymes are not only biologically useful, but have specificity—only acting after certain amino acids—a topic we will explore more in the coming sections.

Moreover, this example allows us to gain insight into how enzymes provide a pathway for reactions to occur. To build a protein it takes energy. Amino acids must be connected one by one until the correct sequence is assembled. The final product—the protein itself—is therefore at a higher energy state than all the separate and individual amino acids it took to build it. And yet, these high-energy proteins do not spontaneously degrade into individual amino acids. To do that, they need a pathway to get to a lower energy level. Proteases provide that pathway and catalyze protein cleavage.

Enzymes operate essentially the same way inorganic catalysts operate. They both accelerate reaction rates by lowering the activation energy. For the Haber process, an inorganic process, and for protease cleavage, an enzyme-mediated process, the activation energies are lowered and the reaction rates are increased. For both the inorganic catalyst and the enzyme, the net effect is the same—dramatic increases in the rate of conversion of reactant to product, sometimes making the rate millions of times faster.

Yet, unlike inorganic catalysts, enzymes function in biological environments and have a number of special characteristics. In particular, enzymes allow for greater reaction specificity, greater capacity for regulation, and milder reaction conditions. Enzymes can also couple an energy releasing catalysis, such as the hydrolysis of ATP, with an energy consuming catalysis to move an unfavorable reaction forward. In this case, coupling a reaction allows enzymes to create products of a higher energy than the reactants. Each of these characteristics contributes to making enzymes unique and adaptable structures.

Enzyme Structure

Proteins are polymers of amino acids. To be biologically relevant, a string of amino acids forms a globular protein through numerous interactions. Although they range in size from tens to thousands of residues, proteins are usually between 1-100 nanometers large. [5] Protein structure is important because it creates enzyme specificity. A string of amino acids ends up forming highly defined enzymes with specific functions.

We will start with an example of a chemical polymer with no defined structure to understand how specificity arises. Chemical polymers have no sequence variation—the same monomer is added over and over. Low-density polyethylene (LDPE) is an example of a chemical polymer that we all encounter. Made from the monomer ethylene, flexible and chemically inert, LDPE is used in plastic bags, toys, flexible pipes, squeeze bottles and numerous other common household items. At its surface LDPE interacts the same way with everything it touches because its surface is identical at every point; there is no specificity inherent in its structure. The only way we impart function on LDPE is when we alter its global shape—not surface—and artificially mold it.

Biological polymers, such as proteins, are very different. They are inherently defined and specific structures. From DNA we get a defined sequence of amino acids rather than a string of the exact same monomer. This defined sequence then makes defined folds and creates defined surfaces. Unlike LDPE, the surface of a protein is not identical everywhere. Rather, it is highly varied. Part of this surface will be the binding pocket where the reactant will fit. This is how enzymes are selective: discrete sequences create defined folds, which interact with specific molecules. Now that we have reviewed a framework for understanding the protein structure and specificity, we will engage structural details.

There are four separate levels of protein structure termed primary structure, secondary structure, tertiary structure, and quaternary structure. Primary structure refers to the amino acid sequence of the polypeptide chain. The primary structure is created during translation in which a specific sequence of mRNA nucleotides is read by the ribosome, which in turn, produces a protein. It is noteworthy that the primary structure is determined by the gene that coded the protein. That is, the protein's DNA is transcribed into RNA, which is then translated into protein.

Secondary structure refers to highly organized local structures. There are two main types of secondary structure, the alpha helix and the beta sheet, which Linus Pauling, a two-time Nobel Prize winner, proposed in 1951. [6] Alpha helices and beta sheets both have a regular pattern of hydrogen bonds between peptide chains. The alpha helix is a righthand-coiled structure while the beta sheet is a twisted, pleated sheet with either parallel or antiparallel stands of polypeptide hydrogen bonded together.

Tertiary structure refers to the interactions between the secondary structures, which give rise to the three dimensional structure of the protein. This folding is driven by hydrophobic interactions in which fatty amino acids collapse away from the surface of the protein—like how oil beads in water. In addition to this, tertiary structure is characterized by the presence of salt bridges, hydrogen bonds, and packing of disulfide bonds. Lastly, quaternary structure refers to the overall three-dimensional structure of a multi-subunit protein. Quaternary structures are stabilized by non-covalent interactions and disulfide bonds, which link subunits together.

These levels of protein structure will be generalized again for understanding. The amino acids that make up proteins are first chained together in a defined sequence that is determined by DNA. This defined sequence then has all the information necessary to make defined folds and defined binding pockets—the places where reactants settle for catalysis. These defined folds have limitless possible arrangements and limitless possible functions. This is how enzymes can do everything from helping digest food—remember trypsin—to packaging DNA. Enzymes carry out all of the functions necessary for life.

Enzyme Catalysis

Before a reaction can be catalyzed, enzymes have to bind their substrates. Several models to explain how this actually occurs have been proposed. Initially, Emil Fischer's 1894 lock and key model was widely accepted. It held that the enzyme and the substrate were like puzzle pieces with complementary shapes that fit together perfectly. The model explained how enzymes could distinguish substrates from other molecules, but overlooked how the stability of the transition state is achieved. [7] In 1958, Daniel Koshland proposed a new model known as the induced fit model, which accounted for the flexibility of enzymes. Under this new model, the active site, where the reactant binds, is viewed as dynamic. The amino acid side chains that make the active site are put into the positions necessary to perform catalysis, but are not necessarily rigid and can be shaped with the environment and the substrate. Moreover, according to this new model, the substrate can

change shape slightly to enter the active site. In this way, the substrate and active site of the enzyme undergo slight conformation changes until full binding occurs and an affinity maximum is reached.

Figure 2 shows a picture of the induced fit model. We see here that the unbound enzyme active site does not perfectly complement the two substrates. However, upon substrate binding, we see that the global structure of the enzyme shifts, which causes an induced fit in which the active sites now complement the substrates.

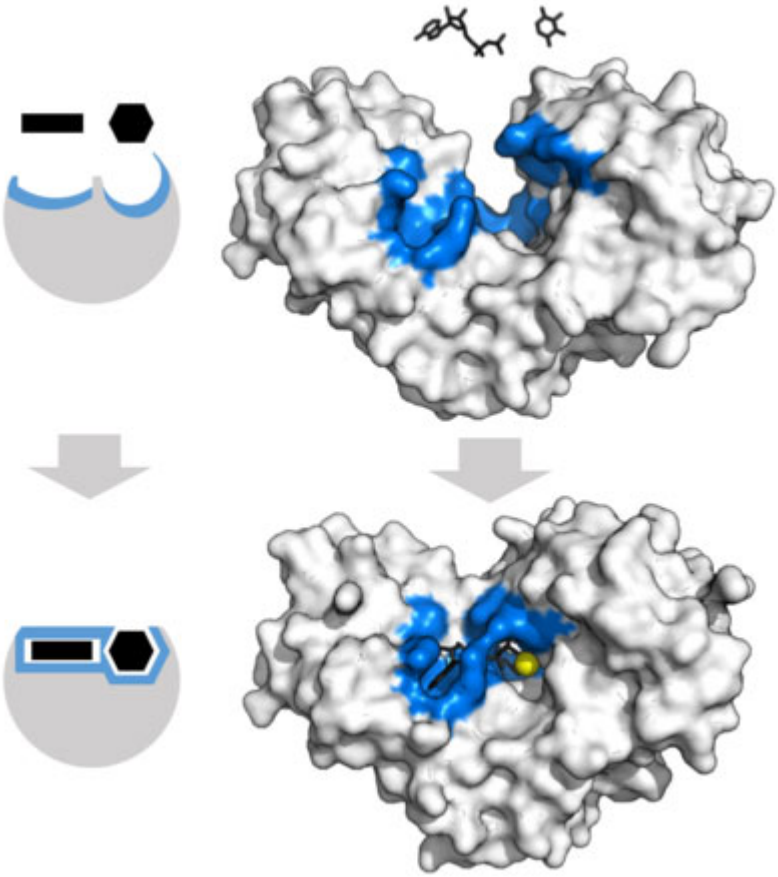

Figure 2: http://en.wikipedia.org/wiki/Enzyme#cite_note-Cooper_2000-34

These dynamic active sites not only complement the shape of the substrate, but its chemical nature as well. This allows enzymes to be highly selective between very similar molecules. [8] Take a simple example. Lactase, an enzyme needed to digest milk, cleaves lactose, a dissacharride, into glucose and galactose. Lactase can only cleave lactose, regardless of how similar other sugars may be to lactose. Sucrose happens to be one of those sugars. Also a disaccharide but made of fructose and glucose, sucrose is almost structurally identical to lactose. And yet, lactase cannot cleave sucrose; instead, the enzyme sucrase does this. The opposite is also true—sucrase cannot cleave lactose. The enzymes are specific for their substrates. While this may seem trivial, it explains how people become lactose intolerant. Insufficient lactase production results in an inability to process lactose resulting in lactose intolerance—other enzymes cannot perform lactase's job.

Now take a more complicated example. With DNA replication, where a single mistake is propagated with each subsequent replication, specificity is necessary to sustain life. DNA polymerase is one enzyme that proofreads the DNA. It checks that each specific DNA base is added correctly so that errors in the DNA occur less than 1 in 100 million base additions. [9] If this were not the case—if enzymes were not specific—mutations in the DNA would be rampant, mistakes would be propagated and death would result. Therefore, in the case of DNA

production the ability of enzymes to be selective and accurate is crucial.

Enzyme Kinetics

Enzyme kinetics is the study of the rate of chemical reactions. In this field, the reaction rate is investigated in relation to numerous variables, such as substrate concentration, to determine any number of things, including the mechanism of the reaction, how activity of the enzyme is controlled, and how the enzyme is inhibited or promoted.

The presence of enzymes specifically alters the kinetics of a reaction. Enzymes do not alter the equilibrium position—the point at which the rates of the forward and backward reactions are equal. The enzyme, however, alters the rate of the reaction and introduces saturating behavior. When small amounts of substrate are introduced to enzyme, the reaction is free to proceed linearly with substrate concentration; as one increases the amount of substrate, the amount of product formed increases by a proportional amount. However, at high substrate concentrations, the amount of product formed does not increase by a proportional amount. Instead, the reaction rate slows and reaches a maximum. In this case, most of the enzyme active sites are occupied by, or saturated with, substrate, which limits the reaction to how quickly each enzyme can turnover the substrate. In biology, this turnover is particularly important. Enzymes are often naturally found in very low proportion to their reactants and as such, reactions can only proceed as quickly as reactants can be turned over.

Michaelis-Menten Kinetics

The Michaelis-Menten kinetic model is an important introduction to the realm of reaction rates and the concept of enzyme saturation. Initially, at lower substrate concentrations, the reaction rate increases linearly with substrate concentration. However, at some point, saturation occurs and the rate of reaction reaches a maximum even upon the addition of more substrate.

To illustrate the concept of saturation, the schematized model for an enzyme-catalyzed reaction is shown in Figure 3. It shows that there is an initial bimolecular reaction between enzyme E and substrate S, which forms the enzyme substrate complex ES. Here, we can see how saturation occurs. As enzyme reacts with substrate to form ES, fewer and fewer enzyme molecules are left to react with substrate. Eventually, all enzymes will be bound to ES and saturation will have occurred. Once saturation occurs, the rate of the reaction becomes dependent on the concentration of ES and is essentially a unimolecular reaction.

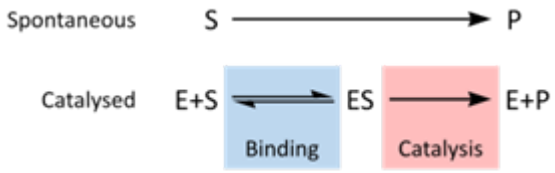

Figure 3: http://en.wikipedia.org/wiki/File:Enzyme_mechanism_2.svg

K_m in the Michaelis-Menten Equation

The Michaelis-Menten equation is displayed below and describes how the initial reaction rate (V_0) depends on the concentration of substrate ([S]):

$$v_0 = \frac{V_{max}[S]}{K_M + [S]}$$

The K_m in this equation is especially noteworthy. It is a useful index for affinity between the substrate and the enzyme. Specifically, K_m serves as a dissociation constant such that larger K_m values mean lower affinity between the substrate and enzyme and smaller K_m values mean the higher affinity between the substrate and the enzyme. In other words, K_m lets us know the affinity between the substrate and the enzyme. [10]

To illustrate this, we will investigate reaction rates and their constants, indicated by K_1, K_2, and K_{-1}. The enzyme-catalyzed reaction equation below shows the formation of product from substrate, facilitated by an enzyme, where E_f corresponds to the free enzyme, ES corresponds to the enzyme-substrate complex, S corresponds to the substrate, and P corresponds to the product.

$$E_f + S \underset{k_{-1}}{\overset{k_1}{\rightleftharpoons}} ES \overset{k_2}{\rightarrow} E_f + P$$

From the equation above, we see that the rate of dissociation corresponds to the two arrows pointing away from ES—K_{-1} and K_2. Additionally, we see that the rate of creation of ES corresponds to the one arrow pointing towards ES—K_1. Dividing the rate of dissociation of ES by the rate of creation of ES, we get K_m, as shown below.

$K_m = (K_{-1} + K_2)/K_1$

In enzyme-catalyzed reactions, the rate-limiting step is generally the conversion of ES to free enzyme and product. Therefore, the arrow pointing from ES to E_f and P—K_2—represents a small value. In fact, the value of K_2 is so small in comparison to that of K_{-1} that the equation can be simplified to:

$$K_m \approx \frac{K_{-1}}{K_1} \approx \frac{[E_f][S]}{[ES]}$$

This shows that K_m is an approximation of the dissociation constant. It indicates the affinity between the enzyme and the substrate such that high K_m values indicate a low affinity and low K_m values indicate a high affinity.

Lets explore K_m further. The Michaelis-Menten equation shows that K_m must have units of substrate concentration since it appears in the denominator (shown below). Therefore, there must exist a point at which K_m equals the concentration of the substrate. To determine the point at which this occurs requires manipulation of the Michaelis-Menten equation. If you set [S] = K_m in the below equation and simplify, you get the subsequent equation, which shows that, indeed, K_m is the concentration of the substrate when V_0 is half of V_{max}.

$$v_0 = \frac{V_{max}[S]}{K_M + [S]}$$

$V_0 = V_{max}/2$

This finding—that K_m is the concentration of the substrate when V_0 is half of V_{max}—is particularly important because it allows us to determine K_m by analyzing a saturation curve, like the one shown below.

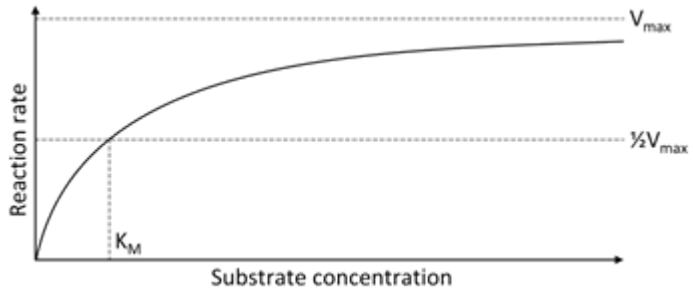

Figure 4: https://en.wikipedia.org/wiki/Michaelis%E2%80%93Menten_kinetics#/media/File:Michaelis_Menten_curve_2.svg

Using this graph, we can see how K_m is determined from the equation we derived. Knowing that K_m is the concentration at which V_0 is half of V_{max}, we can look at the graph above, find V_{max}, take half of it, and then determine the substrate concentration corresponding to it. That concentration is K_m or the dissociation constant.

Unit Workflow for the Classroom

I will provide a general trajectory for the unit, which has been tailored to meet student needs. The workflow follows this progression: anchored learning, core learning, expanded learning.

1. Anchored Learning—Learning about reactants and products through baseball: Students will be introduced to the story of the Oakland A's and Billy Beane. In this analogy, reactants will be baseballs and products will be homeruns. In this way, players are viewed as enzymes because they facilitate the conversion of reactants (baseballs) to products (homeruns).
    1. Collision Activity—Collision theory dictates that molecules must collide to react, but also that not all collisions result in a reaction. For a reaction to occur the interacting molecules must have enough kinetic energy to overcome the repulsive and bonding forces of the individual reactants and the molecules must be in the correct orientation. In this activity, students will be given soft tip darts to throw at balloons hanging from a wall. Those darts that end up popping the balloons will do so because of two factors that are integral to understanding collision theory: orientation and energy.
2. Core Learning—Formal introduction to mole ratios: With empirical knowledge, students will formally be introduced to the concept of the mole ratio and the limiting reagent, the reactant that limits the

reaction from continuing. This limiting reagent section will lead into Michaelis-Menten kinetics and students will learn how reaction rates are limited by enzyme concentration.

    1. S'mores Activity: This activity will allow students to get an on-hands grasp of stoichiometry—the quantitative analysis of reactants and products—and the concept of limiting reagents as they build s'mores. In this activity students will get to decide on the composition of their s'mores and eventually find that they run out of materials to make them. The first material that they run out of will represent the limiting reagent in their experiment. The composition of their s'more will dictate the mole ratios.
    2. Stoichiometry Lab: Students will encounter a chemistry stoichiometry lab. They will be given materials to investigate a classic reaction between sodium bicarbonate and acetic acid. Students will pour 10 mL of acetic acid into a small Erlenmeyer flask and various amount of sodium bicarbonate into a balloon. Then, students will place the balloon over the lip of the flask and place the balloon upright so the sodium bicarbonate reacts with the acetic acid. The balloon will then inflate and students will be given a series of calculations to estimate the volume of gas produced. Students will then alter the amounts of sodium bicarbonate to see that at some point, increasing the amount of sodium bicarbonate does not increase the amount of gas produced.
3. Expanded Learning—Enzyme kinetics: Students will be introduced to enzymes and enzyme kinetics and will explore concepts through a hands-on approach.

Anchor Learning: The Reactants and Products of Moneyball

For this portion of the unit, students will simply be introduced to the story of the Oakland A's and Billy Beane. The story can be summarized as follows. The Oakland A's need to think differently about their players. They cannot afford superstars. They have one of the most restricting budgets in baseball and they need to work around it. Billy Beane understands this. Relying on statistical analysis, he shirks conventional wisdom and develops new hiring statistics. Instead of hiring a superstar and paying lots of money, Beane hires two or three players who have the combined input to match that of any superstar. In this way, Beane creates a competitive team by piecing together stats and filling in the gaps.

This summary captures a few important ideas: 1) Mr. Beane had to think differently and rely on statistics; 2) superstars could be replaced by a combination of lesser players; and 3) this could all be done at a lower cost. In short, Mr. Beane recognized that statistics governed baseball. Star players yielded better averages, but lesser players, in combination, could replace them. Mr. Beane thought simple. He paid specific attention to interactions between the bat and ball—no matter how many players it took to get these interactions. For him, players were means to end and that end was runs and wins. This reduction allowed Mr. Beane to think differently about the game of baseball and it also allows us to understand collision theory and enzymes. In this vein, a key analogy will be introduced that will help students understand how enzymes operate, specifically in terms of the collision theory.

Collision theory dictates that molecules must collide to react, but also that not all collisions result in a reaction. For a reaction to occur: 1) The interacting molecules must have enough kinetic energy—energy of motion—to overcome the repulsive and bonding forces of the individual reactants and 2) The molecules must be in the correct orientation. Collision theory paints a dynamic picture of the molecular landscape—although molecules are constantly bouncing off each other all the time, they must have the correct orientation and the

right amount of energy to undergo a reaction and create products. Using baseball, we can view this same dynamic landscape at the human-scale.

In this analogy, reactants will be baseballs and products will be homeruns. In this way, players are viewed as enzymes because they facilitate the interaction between bat and ball, or the conversion of reactants (baseballs) to products (homeruns). What constitutes a reaction then, is the collision of the player's bat and a baseball to produce a homerun, which is a powerful analogy for collision theory. The majority of the time, when the bat makes contact with the ball it does not produce a homerun; rather balls are strewn in every direction all over the field. Thus, just as molecules require proper orientation and the right amount of energy to undergo a reaction, bats must make contact with baseballs with the correction orientation and energy in order to produce a homerun.

To explore collision theory further, a classroom activity will be conducted, which will be fully detailed in the labs section. All chairs will be cleared from the classroom. The class will then be split up into groups of five. Each student will be given a chance to throw a soft tip dart (darts with plastic tips) at large overinflated balloons taped to a wall. Students will find that as they throw darts some will hit balloon dead on, but not with enough energy. Other times, a student will throw a dart and it will have enough speed, but hit the balloon at an off-angle. Only those darts thrown with the correct orientation (towards the center of the balloon) and enough energy (speed of the dart) will result in a popping of the balloon or creation of the product. The activity will be done so that each student will rotate and get a chance to participate and then observe.

Core Learning: Formal Introduction to Mole Ratios

A mole ratio is simply a ratio of the number of moles of one molecule or atom to another. The purpose of mole ratios is to be able to compare either the amounts of a molecule needed to produce a product or the amount of a product produced with a given amount of molecule. The following is a lab intended to acclimate students to using moles ratios.

Utilizing the law of conservation of mass and principles of stoichiometry, students will build s'mores. A traditional camping snack, a s'more is normally made by putting a roasted marshmallow in between two graham crackers and adding a bar of chocolate at one end. This activity will allow students to get a hands-on grasp of stoichiometry and the concept of limiting reagents. In this activity students will get to decide the composition of their s'mores and eventually they will find that they run out of materials to make them. The first material that they run out of will be the limiting reagent in their experiment. The composition of their s'more will dictate the mole ratios.

Expanded Learning: Enzymes and Kinetics

For the enzymes and kinetics portion of the unit, I will extend student learning to biochemistry. Specifically, I will teach the principles of Michaelis-Menten kinetics using a classroom teaching technique adopted from William Moran. Firstly, enzyme kinetics is not a simple concept to grasp. Students are forced to tackle multiple

constants (K_m and V_{max}) and graphs while keeping in mind a temporal biochemical image of the actual enzyme and substrate. Unfortunately, for many of my students, the task of processing equations and graphs is daunting, meaning they might miss out on truly understanding enzyme kinetics. This exercise will help remedy that.

The classroom exercise that I have chosen to implement is simple and allows students to view the turnover as an enzyme catalyzes a reaction. The full activity is detailed in the labs section. The activity involves students mimicking the enzyme with the students' hands representing the enzymes active site. Popsicle sticks are used as substrate molecules and the catalytic event is the breaking of the Popsicle stick into two pieces. In this way, students will be able to see that as Popsicle stick concentration increases the number of Popsicle sticks broken per unit time will also increase. Then, at saturating Popsicle stick concentrations, or when students are unable to break Popsicle sticks at a faster rate, the rate of turnover will be limited and students will see the initial rate (V_0) approach some maximum (V_{max}). With this short and simple experiment, students get a hands-on appreciation for multiple important ideas: 1) At relatively low substrate concentrations, the rate of the reaction varies linearly with substrate concentration. 2) As the enzymes' active sites are saturated, the rate of reaction reaches a maximum 3) Turnover rate is independent of the substrate concentration and dictates the maximum rate of reaction.

Additionally, students will generate a saturation curve (See Figure 4). Students will determine K_m by analyzing the graph and gain an understanding of its importance as a dissociation constant.

Teaching Strategies for Core Learning

S'mores Mole Ratios Lab

Materials

Electronic Balance, Paper Plates, Chocolate chips, Graham crackers, Marshmallows

Purpose

This activity is designed to allow students to understand the concept of limiting reagents in reactions.

Background

Imagine you are going on a camping trip with some of your friends. You are going to go hiking in the woods, swim in the lake and sing songs around the campfire. But that is not all the campfire is for. You and your friends planned ahead and brought supplies to make s'mores. One of your friends brought marshmallows, another brought graham crackers and yet another brought chocolate bars. Unfortunately, none of you planned out how much of each ingredient you would need to make the number of s'mores you wanted. So exactly how many s'mores can you make given the amount of ingredients you have? In this activity you answer that question and figure out which ingredient you need more of most, which will be termed the limiting reagent.

For this activity, each of the ingredients will represent a different element

- Marshmallow (M)
- Graham Cracker (G)
- Chocolate bar (Cb).

Since the Graham cracker is always used in pairs, it is a diatomic element and will be represented as G_2 in this activity.

Procedure:

1. Decide how you are going to make your s'more and how much of each ingredient you will use. You can shirk conventions here—customize the s'more recipe and make it your own.
2. Write down the empirical formula for your s'more using the element key above. Make sure you take into account what the chemical name of your product is.
3. Write and balance the number of ingredients of each side of the equation for your s'more.
4. Form as many s'mores as you can. How many s'mores were made?
5. What was the first ingredient that you ran out of in this experiment? This was the limiting reagent. What ingredients did you have left over? These were excess reagents.

Stoichiometry lab

Purpose

To determine, through experimentation, the stoichiometric ratio of reactants that generate a gas.

Materials

Acetic Acid, Sodium Bicarbonate, Balloons, Erlenmeyer Flasks, Graduated Cylinder, String, Metric Ruler

Procedure

1. Weigh out the following quantities of sodium bicarbonate, or baking soda. Use a funnel to add the baking soda to each balloon. Be sure to insert the funnel securely into the balloon so that the baking soda is deposited at the bottom of the balloon.
    - Balloon #1 - 0.18g
    - Balloon #2 - 0.35g
    - Balloon #3 - 0.52g
    - Balloon #4 - 0.70g
    - Balloon #5 - 1.00g
    - Balloon #6 – 3.00 g
2. Measure 10 mL of acetic acid in a graduated cylinder
3. Add 10mL of acetic acid to the beaker.
4. Attach a balloon containing the sodium bicarbonate to each beaker, being careful not to let the sodium bicarbonate mix with the acetic acid.
5. After the balloon is securely attached to the beaker, carefully and slowly lift the balloons to allow the sodium bicarbonate to mix with the acetic acid in the beaker. Repeat with all balloons.
6. Observe, paying special attention to the size of the balloons after the reactions. You can measure the diameter of each balloon. Hold a ruler horizontally and measure the largest diameter across each balloon, being careful not to change the shape of the balloon.

7. Record your observations for each trial in the table below.

Balloon #	**1**	**2**	**3**	**4**	**5**	**6**
Amount of sodium bicarbonate (g)	**0.18 g**	**0.35 g**	**0.52 g**	**0.7 g**	**1.0 g**	**3.0 g**
Diameter of balloon (mm)						

Calculations to determine volume:

- Determine radius first by solving for 'r': 2r=diameter
- Use 'r' to solve for volume of balloon: Volume=4/3πr ^{3}

Observations

1. Does each balloon inflate to some degree? Why?

   _____

2. Make a graph of the diameters vs. balloon number. Make balloon number the independent variable.
3. Use your observations and the graph to compare the degree to which each balloon inflated.

   _____

Teaching Strategies for Anchored Learning

Collision Theory Lab

Purpose

Students will explore the principles of the collision theory.

Materials

Soft-tipped darts, Balloons, Tape

Preparation

The classroom will be cleared of all chairs. Inflated balloons will be taped to an appropriate wall or backing. A line ten feet behind the wall of balloons will be marked with tape.

Procedure

1. Five students at a time will be asked to step up to the line and throw plastic darts at the balloons.
2. Students will find that as they throw darts some will hit the balloons dead on, but not with enough energy. Other times, a student will throw a dart and it will have enough speed, but hit the balloon off-angle. Only those darts thrown with the correct orientation (towards the center of the balloon) and enough energy (enough speed of the dart) will result in a popping of the balloon or creation of the

product, in this case.

3. Students that are not throwing darts will take notes on the collisions and fill in the following table. In addition, students will be asked to track three collisions that result in a popped balloon and three collisions that do not end up in a popped balloon and make notes as to why each instance resulted the way it did.

   Relative Speed of Dart Relatively slow speed Medium speed Relatively fast speed
   Resulting Interaction

4. Students will rotate from being observers to participants and get a chance to throw darts at the balloons.

Questions

1. In this particular simulation, what do you think was more important in getting the balloon to pop, orientation or energy? Explain with evidence.

   _____

2. How do you think this actually relates to the way in which reactions occur?

   _____

Michaelis-Menten Lab

Purpose

To understand how saturation occurs according to Michaelis-Menten kinetics and why K_m is important.

Materials and Methods

Two containers, Popsicle sticks, Blindfold, Timer

Explanation

The student volunteer is the enzyme. The hand of the student grasps the Popsicle stick and represents the enzyme's active site. The catalytic event is the breaking of the Popsicle stick, which will follow a transfer from the left container (containing the reactants, or Popsicle sticks) to the right container (containing the products, or broken sticks).

Procedure

1. Popsicle sticks will be put in the left container and randomized for each trial with the number of Popsicle sticks from 5 – 40 to simulate different "concentrations."
2. Then, a student is blindfolded and is asked to break Popsicle sticks for ten seconds, placing the pieces into the right container. This is done to get the initial rate of the reaction.
3. Then the number of Popsicle sticks is varied and the exercise is repeated.
4. Students will create a graph depicting V_0 as a function of substrate concentration to get the saturation curve.

Results

Once the data and necessary information is collected a graph similar to Figure 4 will be created.

This graph will show that the rate of Popsicle stick breaking (V_0) depends on the Popsicle stick concentration. Additionally, it will show that as Popsicle stick concentration is increased, saturation occurs and the rate of the reaction reaches some maximum (V_{max}).

Exploring K_m

To determine the point at which this occurs requires manipulation of the Michaelis-Menten equation. If you set, [S] = K_m in the below equation and simplify, you get the equation just below that one, which shows that, indeed, K_m is the concentration of the substrate when V_0 is half of V_{max}.

$$v_0 = \frac{V_{max}[S]}{K_M + [S]}$$

$V_0 = V_{max}/2$

Using the saturation curve, students will determine the K_m for the reaction.

Why is K_m *important?*

K_m serves as a dissociation constant such that larger K_m values mean lower affinity between the substrate and enzyme and smaller K_m values mean the higher affinity between the substrate and the enzyme.

Questions

1. Why does the reaction reach a saturation point?

_____

2. Repeat this activity with other people acting as enzymes and breaking Popsicle sticks. Generate saturations curves for each enzyme and determine the respective K_m values. Which enzyme had the highest affinity for the substrate? Which enzyme had the lowest affinity for the substrate?

_____

3. How did low or high K_m values correlate to what you saw when people were breaking Popsicle sticks?

_____

Standards

DINQ.1 Identify questions that can be answered through scientific investigation.

DINQ.2 Read, interpret and examine the credibility and validity of scientific claimsin different sources of information.

DINQ.3 Formulate a testable hypothesis and demonstrate logical connection between the scientific concepts guiding the hypothesis and the design of the experiment

DINQ.4 Design and conduct appropriate types of scientific investigations to answer different questions

DINQ.5 Identify independent and dependent variables, including those that are kept constant and those used as controls

DINQ.6 Use appropriate tools and techniques to make observations and gather data.

DINQ.7 Assess the reliability that was generated in the investigation

DINQ.8 Uses mathematical operations to analyze and interpret data, and present relationships between variables in the appropriate forms.

Materials for Students

Miller, Kenneth R., and Levin, Joseph S. *Biology: Foundation Edition.* New Jersey: Person Education, Inc., 2010.

A great introductory biology resource for students to learn the basics.

http://www.bbc.co.uk/schools/gcsebitesize/science/ocr_gateway_pre_2011/rocks_metals/7_faster_slower1.shtml

An easy to follow walkthrough of the basics of collision theory.

http://www.learningliftoff.com/high-school-science-learning-activity-collision-theory/#.VZN1tRNViko

An interactive collision theory web application.

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Cooper GM (2000). "Chapter 2.2: The Central Role of Enzymes as Biological Catalysts". The Cell: a Molecular Approach (2nd ed.). Washington (DC): ASM Press.

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