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The magic of microbes may save our lives!

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Rationale

In the past I have treated chemistry as a separate science and did not try to incorporate any biological concepts. I am learning to see the value in combining content areas rather than segregating them. Since students in Pennsylvania now have to pass the Keystone Biology test in order to graduate from high school, it has become overwhelmingly clear that I need to use biological examples as much as possible in my chemistry classes. If students do not pass this standardized test in their 9th grade year, then they have to keep taking it twice a year until they do pass. If they did not comprehend biology content while enrolled in the course, then they need every bit of reinforcement that I can offer them. This unit will combine the mechanisms of chemical reactions with the interactions of microbes to see how the two work together to make us who we are. Students will be fascinated to learn about how many microbes are in us and around us without knowing it.

There is an idea called the hygiene hypothesis which seeks to explain why our overly clean modern living environments actually cause us to be less healthy. Essentially, this hypothesis states that the absence of certain infections during our childhood causes our immune systems to become confused, and to turn against us to produce autoimmune diseases. This idea is supported by scientific studies showing a correlation between clean living environments and increased rates of autoimmune diseases, such as asthma and other allergies. In an article written by Robin Anne Smith called "The Worms Within" she quotes Dr. William Parker and his research connecting modern living with our healthy immune systems. [1] This article suggests that our evolutionary history has played host to many wormy guests. These pathogens include hookworms, roundworms, and whipworms. [2] They have made their homes in our intestines and have always had a constant supply of food and nutrients. In the developed world these pathogens seem to be lacking but one third of the worlds' population is still infected with these intestinal worms. [3] Many intestinal parasites are passed from person to person when tiny amounts of feces get on our fingers or when we walk barefoot on contaminated soil. [4] Less than 100 years ago our grandparents were introduced to indoor plumbing, this and water treatment plants have played a major role in the reduction of our exposure to parasitic worms. The parasites that make our gut their home are also known as "helminthes" according to Parker. [5] Throughout our evolution we coexisted with our parasites. According to Dr. Janette Bradley these adaptations have left a mark on how our immune system is structured and controlled. Bradley also suggested that the reason our immune system overreacts is because when we live in an ultraclean environment without worms it doesn't have enough to do. [6] This shows that our immune system needs the chemicals that are produced by the helminthes naturally. Our

bodies have evolved to rely on these parasites just as they rely on us. This becomes a problem because they are able to evolve at a much faster rate than we can. [7]

Students always want to know why they have to take chemistry and why they need to know the content. By using examples that are relevant to them, I hope they will see the importance of understanding the science involved in making us who we are. Every single student at least knows someone who suffers from allergies and/or asthma even if it doesn't affect them personally. I would like to connect the chemistry and biology by analyzing the law of conservation of matter and how in every chemical reaction atoms are just rearranged, never created or destroyed. I would like students to look at the environment they live in and describe how it compares to the environment that was present thousands of years ago. They will look at the prevalence of asthma and allergies and determine what some of the causes of the changes could have been. According to Kathleen Barnes there are two sides of the immune system. The Th1 side deals with bacteria and viruses, and the Th2 side deals with worms. [8] Dr. Barnes believes that trying to figure out what the helminth-made proteins do inside of our bodies will be incredibly difficult to replicate as a drug. [9]

Classroom and school environment

This unit is specifically written for 10th grade academic or conceptual chemistry classes at an urban public high school. I currently teach at Carrick High School in Pittsburgh Public Schools where my students are 35% African American, 7 % Multi-racial, 57 % Caucasian, and 2 % Other. There also happens to be 79% of students who receive a free or reduced lunch. As with most city schools, students struggle to pass standardized tests (Keystone Exams): in the 2012-2013 school year 32.9% of students scored basic or below basic in reading, 46.9% scored basic or below basic in math, and a staggering 75.9% scored basic or below basic in Biology. Needless to say city school students are not always interested in the content presented to them, especially when it comes to science. Students are often forced to take academic chemistry even though many choose professions that do not pertain to the science field. In order to help close the Achievement Gap teachers do everything in our power to ensure that all students learn. Specifically in chemistry we are always trying to get students to think at the particle level; but, the world we live in is macroscopic and doesn't acknowledge the particle nature of matter.

It has always been incredibly difficult to convince students why they should be interested in chemistry because they do not see how it is pertinent to them. In order to spark student interest we need to step back and show students the information is relevant. For example, how do tiny particles interact with each other in order for our bodies to elicit an allergic reaction for an asthma attack? There are multiple ways to think of particles. In the biological realm we think of all microbes as tiny particles; however, in chemistry we need to acknowledge that all microbes are made of the tiny particles we call atoms. This is part of why this is such an important concept, our world is based on the interactions of particles which are too small to be seen by the naked eye. It is incredibly difficult for high school students and even adults to wrap their heads around such an abstract concept. By using examples of how chemistry is important to our health we may get more students interested in making a difference and actually continuing their education in the sciences.

Background

There is a strong argument that the reason asthma and allergies are increasingly prevalent is due to our immune systems malfunctioning, because modern environments prevent the need to fight off as many infections when we are young in age. There are multiple factors working together to create these changes. Some of these reasons include the introduction of antibiotics, vaccinations, smaller family size, over-sanitization, and closing out fresh air from our homes. Keep in mind that these changes have been made for our benefit, but may have inadvertently been detrimental further down the road.

People have been getting sick since the beginning of time and, of course, then trying to figure out how to cure the illnesses they encountered in addition to preventing getting sick again. Our immune system does what it can to fight off disease, but is not always successful. If we take the average person off of the street and ask them what makes us sick they will likely come up with answers like viruses, bacteria, or even being dirty. When I think of being dirty, I think about people who do not bathe daily or throw out their garbage regularly. I imagine people who are referred to as being dirty would likely have insect infestations in their homes. It wasn't easy several hundred years ago to figure out what it was that made us sick. Even now, someone may recognize buzz words like viruses and other microbes, but most do not actually have a clue about what is happening inside of our cells. Viruses weren't discovered until the nineteenth century. As a species, we have been curious about what makes us sick, but had to wait for technology to catch up to our intuition.

There is no record of how hygiene originally came about; it seems as though it is just instinctive. Even thinking back to the cavemen, they would have defecated away from their homes and others, avoided bodily fluids, and stayed clear of people who appear sick. There is an innate inkling for grooming, just as we see our pets do. There are cave paintings showing how people used to use sea shells as tweezers to remove hair and men without beards, implying that they shaved their faces, presumably to remove facial parasites. [10] The luxuries we have available today make it seem like people who existed before the invention of soap and razors must have been barbaric. In reality, we use what we have available to us and make the best of the situation while trying not to go overboard by washing our hands 200 times a day or using hand sanitizer every single time we touch something in public. Oh wait, there are people who do that; but is it actually helping them stay healthy?

There is a very common misconception that all microbes are bad and are going to make us sick. The tendency is to only remember the ill effects of microbes, when in reality the microbes in our body tend to be innocuous and outnumber our cells 10:1. [11] Microbes can be bad, but there are also many beneficial microbes like those in our gut that aid in digestion, those that help with pollination, and those used in vaccinations. If they were all bad we would never feel well and would have a pretty rough time digesting our food. Microbes also take up a lot of space inside of us making it difficult for other potentially harmful microbes to have a chance to become established [12] . Our microbes also help us by removing toxins from our bodies. The point is that we need our microbes just as much as they need us. These symbiotic relationships help make us who we are.

In Carl Zimmer's book, *A Planet of Viruses,* he described how Felix d'Herelle discovered bacteriophages, which are viruses that can be used as a way of killing bacteria [13] . Bacteriophages and antibiotics are both effective ways of combating infections; however, both viruses and bacteria are able to evolve or adapt to their environment in order to survive. Carl Zimmer quoted Alexander Fleming in his book. Fleming, who discovered penicillin, warned about the resistance to antibiotics when he accepted his Nobel Prize in 1945. Microbes have been evolving to become resistant to antibiotics almost as long as they have been used. [14] Unfortunately since

bacteria are becoming resistant to the different types of antibiotics available, we may need to revert back to looking at bacteriophages to attack bacteria that will make us sick. As stated by Zimmer, "It may be hard to imagine a world before antibiotics, but now we must imagine a world where antibiotics are not the only weapon we use against bacteria" [15] . The idea of using live viruses as medicine didn't sit well with doctors; they were much more optimistic about the introduction of antibiotics in the 1930's. [16]

The introduction of vaccines in the 1930's saved lives by allowing us to not have to fight off life threatening diseases like polio and the measles. Our immune systems still have to fight off infections and diseases but are often aided by the use of antibiotics. This prevents our immune system the proper training to be able to identify particles as either friend or foe. [17] As a result, sometimes our immune system gets confused and tries fighting off particles that are identified as being foreign such as pollen, dust, and pet dander resulting in allergies. The increase in allergic diseases in the industrialized world has often been explained by the decreases in infections that our bodies have to fight off during childhood. It is estimated that there are over 130 million people suffering from asthma and allergies. [18] There are 50 million Americans alone who suffer from allergies and asthma. Allergy is the 5th leading chronic disease in the U.S. among all ages, and the 3rd most common chronic disease among children under 18 years old. [19]

There are three stages to an allergic reaction after a microbe is identified as a foreign substance that should be destroyed [20] . The first step is sensitization. This is where our immune system breaks down the allergen and creates antibodies that are ready to fight off the allergen the next time it is encountered. The second step is mast cell activation. This is when the allergen is encountered again later and the antibodies that have identified it bind to it and release chemicals like histamine so that mucus production is stimulated, the release of the histamine turns the area red from an increase in blood flow, becomes inflamed, and swells. The third stage in an allergic reaction is the late phase inflammatory response which occurs several hours after the reaction began and can last several days. This is when our immune cells mobilize to help fight off the invader and release chemicals to maintain inflammation and call for more support. There are various different types of cells in our immune system that work together to fight off the intruder until the job is completed. [21]

The prevalence of allergy and asthma in particular is increasing in economically advanced regions of the world. This is best explained by environmental factors. The four main environmental factors are the changes in exposure to infectious diseases in early childhood, environmental pollution, allergen levels, and dietary changes. As of right now the most reasonable explanation for the increases in allergies is the exposure to microbial pathogens. [22] Since there are over 130 million people suffering from asthma and allergies and the numbers are continuing to rise we need to look at the reasons for the increases. The numbers are much lower in developing countries when compared to those in the United States. There are also data to show that asthma is much more prevalent in urban areas compared to rural areas. [23] When suffering from an asthma attack there is a tightening of the muscles around the lungs, lung tissues become inflamed, and there are higher amounts of mucus. The combination of these symptoms makes it incredibly difficult to breathe because the airways are blocked by the collapse of the bronchioles. [24]

Changes in our homes and lifestyles have increased our exposure to allergens. By trying to make our homes air-tight to save on energy costs we have increased the buildup of allergens within our homes. We have better windows and air-tight doors allowing us to keep our homes nice and toasty during the winter. This is a great way to save money but also creates a concentrated area of indoor allergens. In the past, families tended to use wood-burning stoves which give off a heat higher than the surroundings to disseminate throughout the home. This was necessary to make up for the airflow that could be felt throughout the home. Consequently,

the constant flow prevented the buildup of allergens within the home. Since family members were continually exposed to these "allergens" their immune systems were able to fight off those which were attacking their immune system, and did not need to react to those which were harmless. The difference is the training that our immune systems have had. The act of fighting off infections at a young age helped our immune system identify which microbes were actually harmful and should be attacked rather than those that are harmless [25] .

Another factor identified with an increase in asthma and allergies is the difference in the family size of today compared to the families of the 18th and 19th centuries. Today it is common for couples to choose not to have children or to have only one or two children. According to U.S. Statistics, in 1790 only 11.5% of households had one or two people but 49.7% had 6 or more people. [26] One hundred years later 16.8% of households were one or two people and 34.6% had 6 or more persons [27] . These statistics have drastically changed, by 1990 56.8% of households contained only one or two people and only 3.7% had 6 or more people [28] . The data since then have continued the trend but changed only slightly from the 1990 values. In 2006 a staggering 57% of households had only one or two people, and only 3.0% had six or more persons. Earlier families tended to be large with many children who were often utilized to help around the farm exposing them to animals, natural environments, and the germs shared by siblings. Magdalena Pop wrote an article called "Germs Wanted?" which examined how having siblings helps us build our immune systems because we share the germs that are brought home. [29] Today parents keep their kids at home when they aren't feeling well, shielding others from their germs. The exposure to germs is beneficial to your health because it keeps our immune systems up-to date and in shape. This boils down to our need to be exposed to germs to keep ourselves healthy.

Today we seem to have created a super clean environment. We tend to constantly use antibacterial soaps, hand sanitizers, and other products like bleach. This may become a problem down the road as microbes continue to evolve resistance to the antibiotics we use. These acquired allergies are affecting us in multiple ways. Many now suffer from hay fever and drug allergies which didn't exist previously. One of the major concerns is that we will run out of antibiotic options to help our immune systems to help fight off disease.

It is clear that doctors have been overprescribing antibiotics when we are sick which builds up bacterial resistance to antibiotics. According to C. P. Bradley there is a major thrust of government and professional efforts to reduce "irrational prescribing" by educating prescribers. Doctors are forced to weigh the appropriateness, safety, efficacy, and cost of prescribing antibiotics with the demand of the patient and a lack of time to manage using other options. [30] In addition to our overuse of antibiotics, 80% of the antibiotics used today are fed to the animals we consume. [31] Antibiotics are given to cattle and other animals prophylactically just in case they may get sick. There are too few studies conducted to understand the effects of the reactions of the antibiotics on these animals, and then being consumed by us. It seems likely that disease-causing bacteria will continue to become more and more resistant to the antibiotics available.

I am interested in seeing if students can think critically about the chemical reactions that happen inside of us and try to determine if there are alternative reactions that may be used to come up with a different product. Currently there is one set of antibiotics, carbapenems that are saved for the most extreme circumstances. Even rationing these powerful antibiotics like vancomycin, one of the carbapenems, there have already been microbes which have become resistant to these antibiotics rendering them useless [32] . According to Maryn McKenna, the rapid advancement of resistance to antibiotics and the need to use drugs sparingly has convinced pharmaceutical companies that antibiotics are not worth the investment. [33] This all seems to make sense especially if we acknowledge that there are now other ways that antibiotics are introduced to our bodies like through the foods we eat.

Objectives

The law of conservation of matter states that matter cannot be created or destroyed. Within this unit I plan to reinforce the law of conservation of matter focusing on how even though matter cannot be created or destroyed it can be changed into something else. It is important to acknowledge that existing bonds get broken, the atoms rearrange, and new more stable substances are formed. Students will be reintroduced to microbes which they should have encountered in their biology class, but will apply this knowledge to chemical situations. When thinking about microbes people tend to think of only the negative effects even though there are millions of microbes around us that are completely harmless. Some microbes are incredibly useful to us such as our gut bacteria. I think it is very important for students to identify the different types of microbes that are present, determine what they can do, and acknowledge how they cause both good and bad in our lives. The most important thing in this unit is the model of identifying a problem, determining a solution to the problem, and then recognizing that the solution can create another unexpected problem as a result. I want students to understand that there is more than one possible answer to questions. Even if different students come up with the same answer it is really important for them to see the multiple possible pathways to getting to that answer. After they have identified the model and come up with their own example we will be able to analyze multiple biological examples using microbes, specifically examples that are both positive and negative, as a common interface. Students will need to identify the problem and possible solutions then discuss with their small groups which solution is the best choice for a particular problem, and what are new possible problems that may result. One of the problems students have is taking knowledge that they have and using it in another situation. This skill is a true life skill and needs to be practiced in the classroom. In life, we tend to want a simple answer to every problem, but it just doesn't work out that way. Having a set of analytical skills is something they can take with them and use in their everyday lives.

Teaching Strategies

Students will be asked to start out by identifying a problem in their own lives then create a list of possible solutions they think could solve their problem. They will then analyze their list and determine which solution they think is the best option for them. Rather than this being the end of the exercise, they will then need to extend their thinking to identify what new problems can arise from the solution they chose. I expect a common example to be that they do not have enough pocket money. I anticipate that they will come up with solutions like asking their parents for money, getting a job, or selling some of their belongings. In the event that they would choose to get a job their new problem would be that they now have less time to spend with their friends. This is just one simple example that may be used. After working through multiple microbe problems I will introduce another problem using the same model where there is an oil spill and students need to determine how to clean it up. The trick is that you can't just clean it up and pretend the oil has disappeared. As stated in the law of conservation of matter it can be turned into something else, but it cannot just disappear.

Classroom Activities

Activity 1: (1 day) Identify a problem in your everyday life that is important to you. Next come up with a possible list of solutions that you think can solve your problem. Then identify one solution that you choose to use in order to solve your problem. Most importantly then brain storm what new problems will result from the solution you originally chose. You cannot go back and change your mind, you only get one chance to solve this problem this time. For an example template see Appendix 2.

Activity 2: (2 days) First brainstorm what you know about microbes and how we encounter them in our lives. Then your will break up into small groups where each group will be assigned one type of microbe to gather information on and then present to the rest of the class. You will be given three possible websites to use as resources. Discuss as a class how the lives of our ancestors has changed so that there is now a difference in the microbes that we interact with, and the effects of those microbes. For an example outline see Appendix 3.

Activity 3: (2 days) Read the articles provided about microbes, what they are, how they impact our lives etc. As a class we will discuss what the problem was, what possible solutions were available to solve the problem, and then what new problems arose as a result of the solution chosen. (Bacterial infection and Virus) Then you will be given a third problem to identify on your own, brainstorm the possible solutions, and new problems that may arise. There is space on Appendix 2 for this information.

Activity 4: (1 day) Connecting to chemistry – identify the parts or steps in a chemical reaction. Think about what happens during a chemical reaction; are there multiple possible solutions? What determines which products will be formed if more than one chemical could be produced? Describe how this works at the particle level, what has to happen? How is this similar to the interactions that happen within our bodies resulting in asthma and allergies? For an example connections sheet see Appendix 4.

Student and Teacher Resources

Websites for background information on Microbes

http://archives.microbeworld.org/microbes/types.aspx

http://resources.schoolscience.co.uk/SGM/sgmmicrobes1.html

https://www.boundless.com/microbiology/introduction-to-microbiology/microbes-and-the-world/types-of-microorganisms/

Allergic Reaction video:
http://health.howstuffworks.com/human-body/14063-body-invaders-allergies-and-dust-mites-video.htm

Articles for Students to Read

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Materials

Articles to read

Internet Access to the suggested websites

Appendix 2

Appendix 3

Appendix 4

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Appendix 1

Standards

The Next Generation Science Standards and the Common Core standards encourage teachers to embed rigor into their curricula: this unit is specifically designed to meet the following Next Generation Science Standards: ETS1.B and HS-ESS3 [34] . The intention is for students to be given nonfiction text where they will need to identify the problem given in the text. Then they will need to decipher what information from the text can be used to create possible solutions. They will then need to analyze which of the given possible solutions is the most appropriate, then extend their thinking by determining what other problems may arise as a result of the solution they chose. Students will need to acknowledge both the positive and negative effects of the microbes around us and associate these interactions with the steps in a chemical reaction. One major difference is that in chemistry we can usually write a balanced chemical reaction with only one specific pathway and set of products. When using this parallel with microbes students are also forced to think about how microbes can evolve in order to survive changing the effects of a given situation. This process will help them model the behaviors of scientists and develop their skills at backing up their opinions using data.

Appendix 2

Problems Problems everybody's got em!

Describe a problem that you have in your life, be sure to be specific and give as much detail as you can about this situation:

Brainstorm all of the possible solutions to this problem, how can you possibly get the solution you want?

Analyze: Specifically look at all possible solutions for this problem, which solution provides the best outcomes for you?

Extend: Looking only at the solution you chose what new problems can arise from using this solution compared to one of the other possible solutions you came up with?Fitting the model. This unit is going to use the Problem – Solution – New Problem model multiple times. Fill in the following form which will be updated with each situation we analyze. NOTE: No two papers should be exactly alike for any reason. We are beginning with your personal problem.

Problem	Possible Solutions	Chosen Solution	New Problems
The problem I am having is that…	I could solve this by…	I chose to do..because..	Doing this could…
Case #1			
Case #2			
You already know the pattern…this one is on your own. We have used the model three times, can you get the information you need from the article and come up with your own solutions?			
Case #3			

Appendix 3

Brainstorm: What is a microbe???

http://archives.microbeworld.org/microbes/types.aspx

http://resources.schoolscience.co.uk/SGM/sgmmicrobes1.html

https://www.boundless.com/microbiology/introduction-to-microbiology/microbes-and-the-world/types-of-microorganisms/

Type of Microbe	What it Does	Where you find it	Special because…
Bacteria			
Viruses			
Fungi			
Algae			
Protozoa			
Archaea			

Appendix 4

Connecting to Chemistry:

Word bank: activation energy, atoms, broken, collision, endothermic, exothermic, products, reactants, releases

In a chemical reaction _____ just rearrange.

At the beginning of a chemical reaction we call the chemicals we start with _____. There must be a _____ in order for a chemical reaction to take place. The bonds of the reactant molecules must be _____ which requires energy. The atoms are rearranged and then form new bonds which _____ energy. The new chemicals that are produced are called the _____.

Sometimes extra energy must be added to make a chemical reaction happen, this is called the _____.

At the end of a chemical reaction if you end up absorbing energy it is considered an _____ chemical reaction.

At the end of a chemical reaction if you get extra energy being given off, usually in the form of heat or light it is considered an _____ chemical reaction.

The Law of Conservation of matter reminds us that _____.

There are multiple types of chemical reactions that can be identified. Match each type of reaction with the appropriate partner, then determine if they exemplify the law of conservation of matter or not. If not place the appropriate coefficients on the provided lines to satisfy the law.

____ 1. Combination (Synthesis)	A. ___ $Al_2(CO_3)_3$ → ___Al_2O_3 + ___CO_2
____ 2. Decomposition	B. ___$C_6H_{12}O_6$ + ___O_2 → ___CO_2 + ___H_2O
____ 3. Single Replacement	C. __NaOH + __$FeBr_2$ → __NaBr + __$Fe(OH)_2$
____ 4. Double Replacement	D. ___Zn + ___HCl → ___H_2 + ___$ZnCl_2$
____ 5. Combustion	E. ___H_2 + ___O_2 → ___H_2O

**Bonus: Reaction B is incredibly important to human life, what process does this reaction represent?

Using the following reaction show at the particle level how it exemplifies the law of conservation of matter.

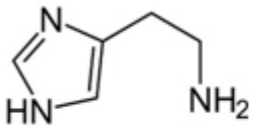
What happens when you have an allergic reaction?

Allergic Reaction video:

http://health.howstuffworks.com/human-body/14063-body-invaders-allergies-and-dust-mites-video.htm

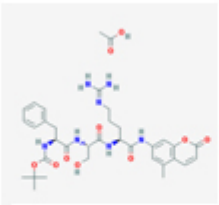
How can you relate what happens during an allergic reaction to a chemical reaction?

The chemical reactions we have looked at in class usually have less than 10 atoms in each reaction. Why do you think we did not use the chemical reactions that happen during an allergic reaction?



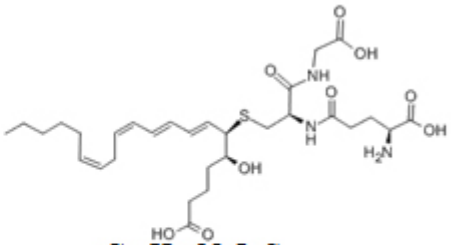
$C_5H_9N_3$

Histamine



$C_{35}H_{47}N_7O_{10}$

Tryptase



$C_{30}H_{47}N_3O_9S$

Leukotriene C4

Even though we use the most basic chemicals there are during class, the process of a chemical reaction still remains the same. In your own words describe the process of a chemical reaction and how this is similar to how microbes interact with our bodies and our environment.

Notes

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