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The Evolution of Genetic Engineering

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Introduction

What makes humans different than every other species on the planet? What elements of our genetic makeup are unique? Why would humans alter any species including our own? How would those alterations impact us as a society and as a planet? Genomic material tells an incredible story that can be manipulated and debated extensively.

I teach at McDade Elementary Classical School. We are a kindergarten through sixth grade gifted academy on Chicago's south side in the Chatham neighborhood. Students must pass a selective enrollment test (for giftedness) in order to enroll at McDade. With a population of about 200, our students are bused from all over the south side of Chicago to McDade and come with a variety of experiences and parental support.

I teach four 60-minute blocks of third through sixth grade Science. Each of my four classes has thirty-two students enrolled. We sit in cooperative learning groups of six to seven students per table. All learning in our classroom must have a cooperative element to it. Most students are able to choose their own learning community groups. Nearly all my students share an interest in science and the discovery of answers to questions past and present. Nothing delights both my students and myself more than the light bulb moments of new discoveries, further inquiry, and thought provoking analysis. Science allows students who struggle with reading and writing an opportunity for success. Hands-on manipulatives, experimentation, and kinesthetic learning evoke a positive response to scientific and mathematic principles. Science instruction in my classroom lights fires, both figuratively and literally. This passion, creativity, and willingness to explore are what I will tap into for this eight week unit. This unit is designed for my gifted fourth graders.

Rationale

This unit is an attempt to give a biographical overview of the genome, DNA, genetic engineering, genetic engineering's negatives and positives, and future applications. It encompasses a wide range of both history and present day application. The main focus and intent is on students having the following enduring

understandings.

First, students will be able to relay a basic understanding of any organism's genome. They should rationalize that their bodies are made up of trillions of cells that each have a nucleus that contains their genome. They should understand that chromosomes are packed with DNA which contains genes that encode the proteins that facilitate the chemical functioning of all of an organisms needs. They should understand that their genes are inherited. Most physical traits are an expression of their genetic makeup; however some things are strongly influenced by environment. This is an important standard as students begin to rationalize themselves both as a product of their own heredity and as an individual with unique characteristics.

Second, students will account for and recall the essential dogma of protein making. Students will be able to account for the mechanisms responsible and products made by DNA. This is especially important for their preparedness for further research and higher learning. The better they have solidified a simplistic version of these processes in their learning the more success they will likely achieve later. I want to insure that my students are prepared for both the genetics heavy seventh grade curriculum and a high school biology class that will push these ideas in further detail and impact.

Third, students will be able to recognize centuries of work that have gone into the field of genetic engineering. They will be familiar with the processes that have led to the evolution of genetic engineering. They will also be able to look at the impact the field has had on science, medicine, and the food industry. My students aren't always exposed to the field of applied sciences, nor do they comprehend exactly what an engineer does. This unit will harness a curiosity in the creation and application of engineering principles through knowledge of genetics. It will also address the controversies often present in scientific applications. They will then be able to apply this evolution to future professions, technologies, and advancements for the betterment of mankind.

Background

Genome

Science is the search for answers to mysteries not the validation or negation of proofs. One of the most fascinating scientific mysteries is the quest to understand the human genome, why each cell functions in certain capacities, and how to manipulate those capacitates for the betterment of mankind. There are about 50 trillion cells in each human body [1] . Inside each cell are multiple smaller functioning pieces called organelles. One organelle, the nucleus, contains two sets of the human genome (sex cells are the exception); one set came from the mother's egg, the other from the father's sperm. On each set there are between 20,000 and 25,000 genes [2] . The sets are not exactly identical physically or chemically. Physically, one arm of the pair is slightly larger, called the long arm to the short arm. Chemically, the exact gene encoding may vary as the father may pass on the gene for curly hair and the mother for straight. However these refined differences become one complete set of twenty-three pairs of chromosomes, and the genes within these chromosomes define (to a large extent) the individual.

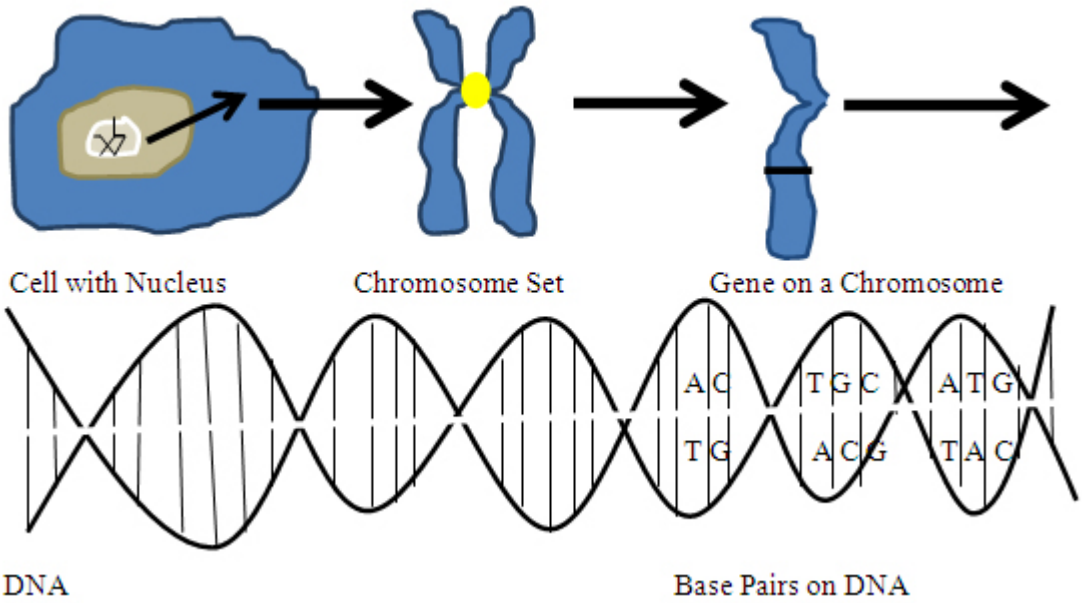
If you were to spread out models of all twenty-three pairs of chromosomes on a table you'd first notice that each pair is of different size. It is their size in fact, from largest to smallest that provides the organization for the numbering the chromosomes. Chromosome 1 is thereby the largest, carrying about 249 million base pairs

and eight percent the total DNA [3] . As being the largest it might also be considered the oldest. Not in that it is created first, but in that all species that have DNA have a Chromosome 1, and all Chromosome 1s are similar. On each chromosome are genes, genes are made up of DNA or long chains of coded instructions.

To better understand the structure of the human genome. I offer Matt Ridley's analogy from *Genome: The Autobiography of a Species in 23 Chapters.*

> "Imagine the genome is a book. There are twenty three chapters called chromosomes. Each chapter contains several thousand stories called genes. Each story is made up of paragraphs called exons, which are interrupted by advertisements called introns. Each paragraph is made up of words called codons. Each word is written in letters called bases."

Thus, the genome is made up of pairs of chromosomes given from two parental sources. Each set of chromosomes stores a massive amount of genes. The genes are sectioned into exons and separated by introns. Each individual combination of bases is called codons. These bases are made up of four letters. Those letters form a very long chain. So long in fact, the genome is as tall as 80 stacked bibles and if read out loud continuously at a rate of two words per second would take approximately 47 ½ years [4] . The four letter alphabet of genomes is made up of A, C, G, and T or adenine, cytosine, guanine, and thymine. These bases are attached as rungs to long chains of sugar and phosphate molecules. This structure which looks like a long spiral ladder is called DNA. Both supporting sides of the ladder are made up of a sugar and phosphate chain. The rungs of the ladder are a base which is paired with the base's compliment to make the step part of the ladder. In DNA, A only pairs with T, and C only pairs with G. A pairs as the complement to T, as T pairs as the compliment to A and so on.



> Diagram i – Cell with Nucleus, Chromosome Pair, Gene, DNA, Base Pairs – Chromosomal material is located within the nucleus of the cell. A chromosome set is synched in by a centromere. Each gene is made up of thousands of genes. Genes are made of DNA. The thick curved outside lines represent the sugar and phosphate bods of the ladder's side structure. The straight vertical inner lines connected to the side represent the location a base which is connected to its compliment which in turn is connected to the opposite side.

DNA is fascinating in that it has the ability to both reproduce and read itself. Reproduction is as simple as copying a compliment and then rewriting the original. For example, the arrangement CGTAC becomes GCATG (compliment) then records back to CGTAC. The reading of DNA is a much more sophisticated process. First a copy must be made, but all thymine molecules are replaced with uracil (U). This "edited" copy is called messenger RNA or mRNA. The RNA travels outside the nucleus and forms a partnership with another cellular organelle called a ribosome. The ribosome reads triplicate combinations of bases called codons. These are then translated into amino acids which are put together to form protein chain. Proteins are used for various functions all over the human body. From digestion to hair growth, all possible from protein synthesis, every protein is a translated gene [5] . For example:

Original DNA	A	T	C	G	A	A	T	C	G
Compliment	T	A	G	C	T	T	A	G	C
mRNA	A	U	C	G	A	A	U	C	G
Triplicate combination	AUC			GAA			UCG		
Amino Acid Expressed	Isoleucine			Glutamatic acid			Serine[6]		

This same formula or reading is true for every living thing. The codon UCG isused to specify the amino acid serine in humans, rattle snakes, chickens, fruit flies, fern trees, and corn.

Put more simplistically, DNA is simply a database of information, coded upon genes using base pairs. These combinations of codons write the recipes for proteins. The gene's code, although quite long, is easily read by ribosomes which in turn create long chains of protein polymer chains that operate our bodies. Each gene creates one specific protein, although not all cells use every gene. For example the gene that expresses Aliases or insulin is located on chromosome 11 [6] . Every skin cell has a copy of chromosome 11 but doesn't utilize that gene as insulin isn't required in skin repair or replacement. This elaborate process of gene expression, and regulation of gene expression, happens in every living cell, every day.

Biological information must be expressed. DNA molecules store the instructions for building the proteins. So how does gene expression turned into protein define life? One correctly assembled protein can go to work. For example, the protein that makes red pigment, this protein is an enzyme catalyst that speeds up a chemical reaction that produces a red color [7] . This color could result in many things including red hair on a human, or the red petals of a rose. Red pigment is an observable trait or phenotype. Phenotypes are determined by genotypes or the codes written on genes inherited from parent cells. For example, in dogs a German Shepard's ears naturally stand straight up whereas a Labradors flop over and do not stand up. The uprightness is the phenotype, the genetic codes that cause the uprightness is the genotype. Interestingly, phenotype can be can also be effected by the environment. To illustrate, we often think of flamingos as pink, however their color is environmentally dependent. It has a gene that expresses a pink coloration; however that enzyme only acts in the presence of certain foods. Thus, the color of a flamingo is determined by its diet [8] . To summarize, the genotype codes for a specific trait or phenotype, however phenotype can also be impacted by environmental factors.

This process is seamless; it happens without the organism knowing unless cells are replicating to heal something the organism is finitely aware of (like the healing of a cut or bruise on skin), and can be ignored unless there is a change or error in the replication, reading, or protein production. Many errors, or mutations, in these processes are uneventful and harmless.

The human genome is 23 sets of chromosomes, thousands of genes, and millions of bases that code for the diverse proteins that operate our bodies. The same is true in dogs, except instead of twenty three chromosomes all dog breeds have 78 chromosomes. Mice have 40, chimpanzees have 48, fruit flies only have eight, and rice has 24 [9] . Some species have a varying number of chromosomes. Strawberry plants for instance, have anywhere from 14 to 70 chromosomes depending on the plant. While most species of strawberries are diploid, meaning they have 2 pieces in each pair of chromosomes, some are polyploid, meaning they have multiple copies of the same chromosome (many plants have this characteristic). Strawberry species and hybrids can be diploid, tetraploid, pentaploid, hexaploid, heptaploid, octoploid, or decaploid (having 2, 4, 5, 6, 7, 8, or 10 sets of the seven strawberry chromosomes, respectively).

All species have a varying number of genes written to their independent sets of chromosomes. Clearly there are both heaps of commonalities and differences in genetic material among different species. However, since most organisms have DNA one could easily identify it as the common thread and building blocks of life. What if we could edit the make-up of those threads to maximize performance? What would that look like? How far could we extend that process? Is it ethical? Contrary to popular belief, these ideas didn't start in a laboratory. The idea of transitioning or modifying the make-up of food sources has been in practice since humans started farming 11,000 years ago. It has evolved to the lab, and extended its practices across academic and medical fields.

Beginnings in Genetic Engineering

To understand how we have manipulated the genetic make-up of organisms we have to understand the evolution of food production and the hunter gatherer's background, as simplistic forms of genetic modification are directly linked to husbandry. Food production (especially on a massive level) is a recent development. Hunter-gathering societies have existed for four million years [10] . Producing food has been in existence .3% of that time (or about 11,000 years). This change was a subtle one. Similar to the time it takes for most social constructs to change, the process was gradual. Early farming was not a stable leisure life, nor was hunting-gathering a miserable meander of shiftless searching. In fact, comparisons of early farmers and concurrent hunter-gatherers show no disparity in nutritional equality [11] . Instead of viewing a differentiated society of either food producer or hunter-gatherer, many early food producing societies depended upon both producing and gathering [12] . No group would risk concentrating on a limited number of crops and/or herding because failure would only result in starvation.

Food availability and population are clearly proportional. With abundant supplies of food populations can increase and without they can potentially become extinct. Whether increased population inspired innovation or innovation inspired increased populations is unclear however it has been calculated that without any form of agriculture, the Earth's surface could only sustain a population of 20 to 30 million people [13] . Clearly with a growing population of over seven billion people [14] food production has played a pivotal role in the conception of the societies we see today.

How did we become a planet with over seven billion inhabitants? Lots of factors added to this, but food production was an especially significant contribution. Once inaugurated, food production spread rapidly. It took only 4,000 years to spread from South-west Asia to Western Europe [15] . Earliest settlements were along waterfronts and nutrient rich areas. Most primitive communities may have planted seeds that were found in other habitats, planted crops that tended to survive harsh weather, or planted for taste preferences. Once people began farming they could be choosy. They could select and plant seeds of only the best-tasting, most

nutritious plant foods. They could also breed two slightly different plants together to produce a third, called a hybrid. Primitive herd manipulation would not have required extensive tools. Animals that had previously migrated may have been restrained or confined. Although these simplistic changes do nothing to impact the organisms' genotype, these simple steps are the precursors to the earliest genetic modifications.

Initial domestication of any animal generally results in a decrease in size [16] . By limiting the movement you also limit the interactions of the animal and therefore its potential mating peers. This could also be a response to malnourishment from crowding. Early domesticators would have encouraged breeding amongst the strongest, biggest, fastest, or whichever other desired phenotype to increase their food supply or potential bartering commission. Thereby encouraging, limiting, or suppressing certain features breeders automatically impact the genotype of the organism.

Additionally, cultivation with the element of human selectivity, whether purposeful or not, naturally leads to genetic changes. These modifications are labeled domesticated. For example, today, there are no wild maize (corn) crops. The domestication of maize took over 3,500 years, as breeding and cultivation crisscrossed from wild genotypes to those specifically bred for phenotypes. Maize is wind pollinated so sustaining a pure breed raises significant difficulties. However after considerable effort these favorable genetic qualities stabilized in about 1500 BC. Modern maize Modern corn is completely dependent on man.

Early farmers thus housed animals, planted seeds with purpose, selecting for preferable phenotypes, and bred animals for size and use. Other prehistory examples of purposeful control of genetics include controlled breeding of humans through royal dynasties, which were kept pure by incest. Practical information derived from these breeding techniques was transmitted by word of mouth to families with similar interests in genetic purity [17] .

Fast-forward to the early 1400s in Western Europe where nothing at the time was more valuable than wool. The insignia of the Order of the Golden Fleece came to be known as an economic powerhouse. Of all of the domesticated animals, none were more purposefully and experimentally altered than sheep. Because of its connection and symbolism of wealth, who can blame breeders for attempting more efficiency? Over the next several hundred years, breeders acted on their own initiative, making decisions on an empirical basis. In the 18 th century Robert Bakewell of Dishley in Leicestershire, England became the benchmark sheep breeder. He targeted his attentions to maximum growth and maximum edible tissue. He encouraged and led a mini scientific revolution of the breeding community that had both designed experimental and abstract concepts. These sheep farmers ignored conventions and religious banter and followed an economic drive to create a more sellable sheep. Bakewell expressed his findings and best practices in a document called the 'Sheepish Doctrine [18] .' Part joke, part instructional manual his findings were labeled both ingenious and heresy. The document circulated eventually outside of England and was adapted for local needs.

Bakewell was inspired by his horses; built for strength and stamina. He knew that the public had a demand for cheap meat and envisioned providing that by breeding his sheep for specific purposes. By maximizing both the sheathing process for wool and the slaughter process for food production he could exploit profitability. He needed animals that would grow quickly on minimum food, whose meat was tender with sufficient fat content [19] . He began gaining his genetic knowledge though making environmental changes and careful observation. He found through experimentation that castrated rams ate more and bulked up quickly. He created controls and variables, collected data and analyzed the results choosing which animals to breed specifically for their worthy phenotypes and discarding the rest. He did all of this without any scientific training. This process is now known as selective breeding.

Despite the work of generations of farmers who purposely produced plants with desirable phenotypes, and some of the work of Bakewell and herders like him who tried to establish a dictionary of heredity, the actual scientific evidence of gene inheritance and potential manipulation is the life's work of a Central European monk named Gregor Mendel. Mendel's work although published in 1866, wasn't recognized until 1900 [20] . He systematically observed the breeding habits and inherited traits of pea plants. He recognized a regularity and specificity to how phenotypes are determined and related it back to the breeding process and the plant's genotype. From Mendel we learned that all genes are inherited from parents and that each parent provides an allele for each gene. Often times an offspring inherits two dominant alleles or one dominant and one recessive allele in this case the dominant phenotype will be observed. The only way for a recessive phenotype to be observed is through the inheritance of two recessive alleles. Mendel also noticed the possibility of a blending of phenotypes, called incomplete dominance, whereas a red and yellow flower may daughter an orange flower. And he noted a co-dominate feature where there was two dominant alleles as in AB blood type.

Mendel's findings were eloquent, extensive, and elaborately detailed. Although pushed under the rug for quite some time, once the information was accepted in the scientific community and penned for the common farmer, selective breeders had the scientific proof and mathematical back up to make specified decisions with predictably dependable results. Thus thousands of years of farming experiments were finally summed up into a concise definition of genotype combinations and phenotype expectations.

Modern Genetic Modifications

Mendel's principles are still effective and informatively used in selective breeding today. In 1900, three European botanists rediscovered Mendel's work. This was the beginning of genetics as a modern science and for the next 50 years many scientists focused on discovering exactly what the genetic material was. They assumed it was within the nucleus, and were especially interested in the structure. Then, in 1953, British scientist Francis Crick and U.S. scientist James Watson showed that the substance had a long, double spiral structure. They discovered the structure of DNA.

The following 60 years after the structure of DNA was defined by Crick and Watson involved a whirlwind of discoveries into finally the mapping of the human genome which was completed in 2003 [21] . However, a complete map was not necessary to consider laboratory exploration of genetic modification. The structure of DNA gave scientists the clues needed to show how DNA reproduced itself, and how genetic information in the DNA affected characteristics and traits of the organism. As soon as the structure was unharnessed, scientists could now envision the manipulation of genes without selective breeding.

The biggest disadvantage to selective breeding is the time involved. The heart of Mendel's work focused on pea plants. They are quick to reproduce, and quick to flower, two of the specific reasons he used them in his research. However, Bakewell's sheep may have taken two to three years before displaying a specific acquired trait. Additionally, breeding to achieve desired traits may have also bred in undesired traits. Historically royal families often interbreed to keep their blood purely royal. Queen Elizabeth of England (1837-1901) was a carrier of the gene for hemophilia (a mutation of the F8 gene that codes a protein that causes blood to clot, it mostly effects male offspring of female carriers). She had four sons, one of whom died as a young man of hemophilia. However, of her five daughters, two were also carriers who wed to royalty in Spain and Russia [22] . The hemophilia gene then infected their royal lineage. By not providing diversity in the gene pool these royal families kept their pedigree, but also inherited the same genetic problems.

As scientists gained an understanding of DNA structure and were gathering more information daily on specific

genes responsible for desired traits, industries demanded research into expedient methods of gene manipulation. In order for such to be possible a few genetic breakthroughs were necessary. First, scientists had to have a way to artificially replicate DNA to practice with and study it. Next, they needed methods to unravel and ravel it again. Third, they needed methods of splicing or cutting of the genome, and replacement of required sections. Finally they needed host cells to incubate the modified DNA.

Development of procedures and processes took time. Many methods of solving some of these needs involved identifying an appropriate enzyme. For example, one of the first enzymes that researchers managed to isolate was DNA polymerase. This is the essential tool to the DNA replication process. In nature, the two stands of the DNA double helix unzip or untwist. DNA polymerase then whips into action and makes a strand complementary to each side. Since the new DNA is complementary to the old each strand can reconnect with the newly written code. The end result is two independent copies of the exact same strands of DNA.

Once identified, scientists were able to utilize DNA polymerase to make multiple copies of any strand of DNA they wished to study. They simply heated the samples (this weakens the bonds of the DNA molecule) then added the DNA polymerase. An additionally useful enzyme find was the discovery of ligase. Ligase acts as a repairing agent to damaged DNA. It can repair the ends of two pieces of DNA that had been cut through [23] .

The effectiveness of polymerase was amplified when in 1983 a U.S. Scientist named Kary Mullis invented a process called polymerase chain reaction or PCR [24] . PCR allows for the infinite replication of a tiny amount of DNA. This process has become extremely important in forensic studies, and the tracking of pathogens, and modern genome sequencing.

With PCR and polymerase as effective replication techniques and ligase for repair, researchers needed methods for cutting DNA. Enter an additional family of enzymes called restriction enzymes. First located in bacteria as a defensive mechanism, restriction enzyme managed to attack the DNA of predator virus, leaving the virus indefensible by chopping its DNA to little bits. Much like a video game plot, restriction enzymes act as the weapon of use for the bacteria, cutting like scissors the virus' DNA molecule apart through several sections. However, unlike a video game, restriction enzymes don't make random wounds. They cut at specific coded locations. The cut isn't always made in a straight line either (please see picture below). If using identical strands of DNA, since restriction enzyme cuts in the same place, it produces pieces of DNA that are the exact same size.

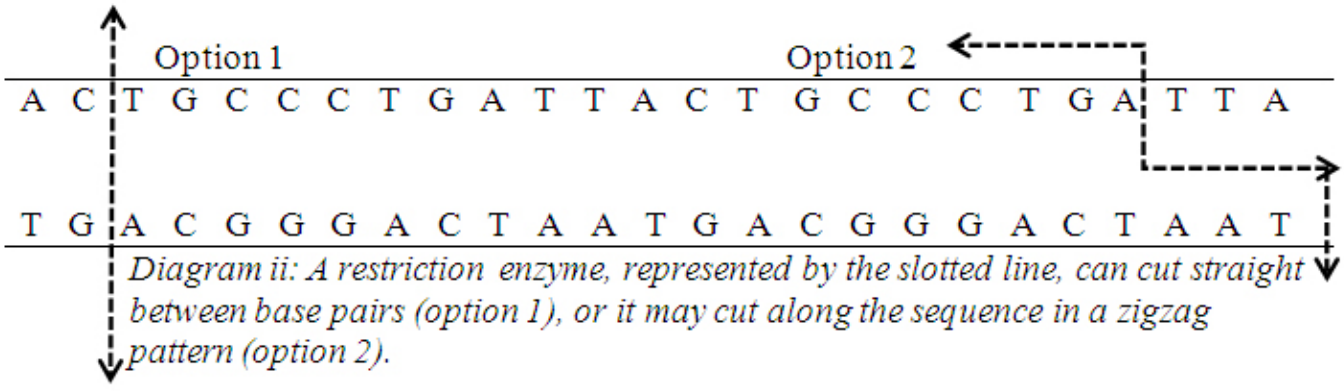
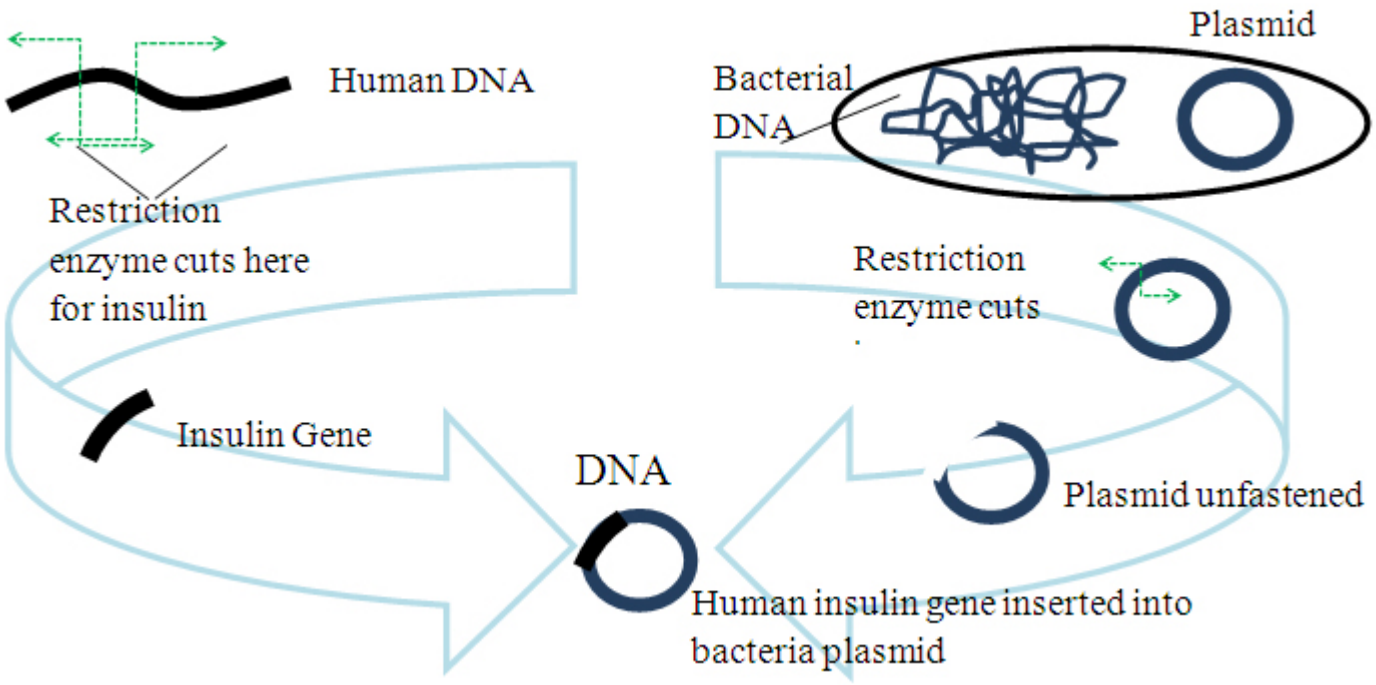


Diagram ii: A restriction enzyme, represented by the slotted line, can cut straight between base pairs (option 1), or it may cut along the sequence in a zigzag pattern (option 2).

With the ability to cut specific sections of DNA, researchers can eliminate what isn't needed and focus on single genes or single sections of genes. One the section needed is identified, scientists can use a restriction enzyme specific to that coding (or something nearby) to isolate the needed DNA. They then can replicate

millions of copies of this specific section using PCR. Now with many copies of that specific section or that specific codon, or protein building chain, they cannot simply inject those back into a cell and expect it to grow. Replication and expression of genes requires a scaffold with the appropriately placed signals to allow for control of replication and activation of transcription. As the first step, scientists use bacteria and a particular kind of gene scaffold, called a plasmid.

Many bacteria have a natural and distinct organelle called a plasmid. Plasmids are circular pieces of DNA that are independent of their chromosomes. They are additional pieces of DNA that help bacteria survive in certain conditions [25] . Bacteria will also take on additional plasmids from their environment if conditions are right. This is why they can be used in the manipulation process. First a plasmid is isolated outside the bacterial cell. Then a restriction enzyme is used to cut the plasmid open at a desired location. Then the human DNA is cut using the same restriction enzyme. This way the human gene can be replaced inside the bacterial plasmid because they have the same pattern of cut-ends. If this is done correctly the bacterial plasmid will re-enter the bacteria and start synthesizing for the human gene. With the correct conditions not only will the bacteria begin to make human proteins it will also begin to replicate itself including the replication of the inserted plasmid and will thereby have made multiple human protein producing bacterium.



This process is essential to the making of many modern medicines including human insulin. Many diabetes patients are insulin dependent as their pancreas cells have stopped or slowed the process of making insulin. By replacing the genetic code for insulin manufacturing into a plasmid and then reintroducing that plasmid to bacterium, the plasmid will begin to successfully fabricate human insulin in a bacteria cell. If then given further advantageous conditions, the bacteria making insulin can duplicate making many insulin producing bacterium. The insulin can then be removed from the bacteria and harnessed for inoculations for insulin dependent individuals. This same genetic manipulation technique is used to make human growth hormone, interferon, and tissue plasminogen activator, a drug given to stoke victims [26] .

Another use of genetic modification outside biomedical practices is the modification of food sources. Old agricultural traditions have been upgraded with this modern technology. Although, as discussed preciously,

farmers had been using genetic engineering principles for centuries, it was not until the twentieth century that farmers begin to understand that successes and failures had to do with genes. Genetically Modified Organisms or GMOs can be created using several technological advancements.

Advancement in the technologies of food included the creation of canola oil in 1974, which was developed by painstakingly examining the seed of thousands of varieties of the plant rape. These rape seeds were assessed individually for low erucic acid levels. Previously cultivated rape seed oil was especially high in erucic acid which was linked to heart disease. By examining a portion of the seed and testing for low erucic levels, scientists slowly weeded through until creating a finalized hybrid plant with seeds with very low erucic acid levels that created oil with low levels of saturated fats. This is the same canola oil we use today. Apples could be said to be far more unnatural than that. As apples are the product of one tree grafted onto the trunk and roots of a completely different tree. Apple growers proliferate this by cutting the branches into slips and grafting them onto root stocks. Thus by planting an apple seed found in your forbidden fruit you may not grow a plant identical to its parent. As seeds are a form of sexual reproduction, grafting is a low technology form of cloning [27] . But, these are hardly the genetic modifications in question today.

Many foods consumed today are either genetically modified whole foods, or contain ingredients derived from gene modification technology. This is a billion dollar business that is surrounded in controversy. Critics believe that applying genetic modifications to human food production could have several adverse consequences. For these critics the potential effects far outweigh increased food production and improved food quality. Specific issues raised include:

1. A consumer's right to know what is in their food.
2. Countries' rights to regulate agriculture.
3. Potential "food terrorism" and the security of genetically modified food crops.
4. The natural spread of modified plant seeds to non-modified farm land.
5. Coincidental rise of food related allergies.
6. The possible growth of insects resistant to modified plant toxins.

Supporters of genetic modification include many farmers and the industries and companies that financially benefit from the modification. Some farmers are especially supportive as genetic modification can lead to faster growing, disease resistant, weather resistant, and pest-resistant crops, crops that tolerate large amounts of pesticides and herbicides. Crops are also modified for taste, convenience, nutrition, and preservation. Additionally, because of poor dietary quality and malnutrition in developing countries, genetic modification of crops may assist in increasing the health and wellness of socioeconomically disadvantaged adults and children. As good access to affordable and safe food supply is linked to a productive workforce, genetic modification of crops could produce a plentiful crop and therefore increase that country's GDP. Additionally with an expected human population of over nine billion by 2050, something has to be done to sustain food production and nutritional needs for a dramatically increased worldwide population [28] .

These issues have been deliberated in government policy hearings, panel discussions, newspapers, and television programs. It is of the utmost importance that both the scientific community and those with limited understandings about GMOs disseminate information and communicate correctly. The information available needs to be clear and specific and written in an everyday language that is accessible to the general public. It needs to include the benefits and rationale for implementing GMO in biotechnology, its evolution, protocols, risks, and levels of predictability [29] . Additionally, risk assessment, management, and oversight of GMO practices and protocols should be publically available and openly discussed. Only then can a comprehensive

perspective emerge to fuel public understanding and independent family decision making.

Strategies

Using Inquiry

Our school's curriculum is based in inquiry based design (IBD). In IBD students often design and direct their own tasks. Students make observations, develop hypotheses about phenomena, and devise tests to investigate their hypotheses. They share responsibility within the group and with the facilitator for answering questions, and use a scientific approach to solving problems. Research indicates that students being taught in effective inquiry-based learning environments improve skills and exhibit more positive attitudes toward science. Improved skills, laboratory procedures, graphing interpreting data, oral communication, and evidence of critical thinking are all benefits of using an inquiry based design model.

The physical behaviors of scientists are demonstrated in IBD. Students simply learn more than science concepts and skills. They learn problem solving and question answering in a non-formulaic method. The inquiry process involves the following steps: observe a process or event, formulate questions based on observations, develop a workable hypothesis, devise a strategy for testing it, analyze and draw conclusions from collected data, and finally communicate findings to others.

Inquiry-based instruction requires a unique approach. As with all classroom activities, however, the use of sound instructional techniques is critical to maximizing student learning. It is not only appropriate but necessary to teach the process before beginning an IBD activity. Students must become aware of each phase of the process. Teach students how to focus on these elements purposefully, conduct guided and independent practice with each element individually.

Collaboration is an additional skill to model and set expectations before IBD can be successful. Help students learn to collaborate to solve problems. Working with and learning from others are integral parts of the scientific process. Students must work effectively with a group for inquiry-based instruction to be a success. Make your expectations for group work clear, and provide ongoing feedback based on your observations of student interactions.

In IBD all beginning of the year activities are a very Structured Inquiry. Here students follow precise teacher instructions to complete a hands-on activity. Partially through the year students begin Guided Inquiry in which they own parts of the procedures. Then students develop the procedure to investigate a teacher-selected question. Finally through Student-Initiated Inquiry, students generate questions about a teacher-selected topic and design their own investigations. Early in the year most activities are 90 percent structured inquiry, but midway through the year structured inquiry should be limited to no more than ten percent of activity time. Students should be the facilitators of their own learning and own designs.

As always monitor your responses. Most students are familiar with traditional instructional models; they are accustomed to asking a question and being told an answer. IBD instruction requires a different approach. Supply what students need to move forward with the investigative process, but don't ruin the ending. Science instruction should reflect the way that science is practiced in the real world.

Gaming

Children learn best when what they are learning is able to be connected to their past learning and is relevant to their daily lives. It also doesn't hurt if they consider the activity fun! Engaging students in relevant materials that connect to their prior knowledge isn't an easy job, but it makes learning material solidify when done correctly. Most adults can still recite songs and games they learned as children. Gaming isn't just for the preschool classroom; it can make concrete connections for students of all ages. Games in the classroom also increase student efficacy. Students are motivated to participate successfully. Games can also increase the level of rigor as they are usually easily scaffolded for higher and lower learners. Finally, games in the classroom improve student to student relationships as most games are collaborative. Teacher to student relationships are also affected in that learners can see the teacher in an engaging environment that promotes learning with fun.

Reading in the Science Content Area

Science and reading and writing are natural partners for today's elementary classroom. Reading instruction is easily taught through science texts and vice versa. The writing about scientific observations is also a process easily transferable to expository writing and vice versa. There is also a fine array of children's literature available today that teachers can use to introduce their students to the world in which they live and to teach reading skills in a meaningful context. This meaningfulness and real-world approach has been shown to significantly enhance students' comprehension of what they read [30] . To increase their self-esteem and sense of self-worth, all students need to see themselves reflected in what they read and study in school. The wide variety of high quality literature available today helps to accommodate this need; careful selection of what is to be read helps to assure that students can relate to what they are reading and, therefore, make it meaningful to their own reality.

Additionally more and more content is being packed into the school day. Teachers are expected to integrate safety, creative movement, social emotional needs, drug abuse prevention, and conflict resolution into elementary curriculum. To address this compacted day, it is necessary to teach more in the same amount of time. The only effective method to achieving this is to implement an integrated curriculum where more than one subject is taught at the same time. This enactment makes content areas more applicable because they are connected to one another, and more can be taught in a given period of time than if subjects are taught separately. If two subjects are taught at the same time, not only can more be taught in a given period of time, but instruction in one area reinforces and enhances learning in the other. This is especially important in reading, because reading involves many skills; but these skills need a meaningful context, they need to be applied to a content area and science instruction is an easy fit.

Activities

We will begin with a study DNA from a cellular level. Students will review the general structure of cells, the general function of major organelles, and the location of genetic material in the cell. Students will study chromosomes, watch simplistic videos of mitosis, and understand that the origin of life is debatably genetic. After reviewing Ridley's book analogy (see paragraph 10 above), students will be asked to create an advertisement poster for the "book" of DNA. Then, to further prove their ability to express the progression

from chromosome to base pair, students will create their own analogies and make an artistic representation of their analogy to be displayed at the end of our unit in a gallery walk. We will then move into base pairings, restriction enzymes, polymerase, and ligase.

In an inquiry activity designed to demonstrate an understanding of restriction enzymes students will be given a long strand of double stranded DNA base pairs. Then they will be given three restriction enzyme codes. Students will cut their DNA strands at the coded restriction enzyme locations. Once their DNA has been cut into pieces they will trade with a designated partner who received different restriction enzymes. With their partner's pieces they are to reconstruct the original DNA strand. Then they will have to justify their recreation. Why are the pieces where they are? How do you know you've reconstructed it correctly? Are there any other possible arrangements? Why or why not?

We will then look at the uniqueness (or non-uniqueness) of human DNA. Comparing human DNA to DNA of different species will allow for the discovery of a common platform for all biotic factors on Earth. We will extract DNA from strawberries, green split peas, and chicken liver. All are plentiful in DNA and easy to extract and visualize (see Appendix A). We will compare our findings and make generalizations about the three samples. Then students will be given a research project to find the base pair sequence of first chromosome of humans and compare it to the first chromosome of different animals (chicken, mouse, dog, and chimpanzees). Again the focus will be the comparison of two different species' DNA sequences; students should find that they are actually quite similar. Students will then find the percentage of similarity and make some generalizations about all species.

After we've discovered that most organisms derive from a similar DNA platform we will begin to focus on the idea of genetic manipulation and building the perfect pet. We will study pedigrees of the current Westminster Dog champions and track histories of hip dysplasia and other common diseases. We will discuss and contemplate the ability to pinpoint single (and multiple) gene causing diseases and derive an understanding of the trade-offs and philosophical arguments made about pinpointing disease causing genes. We will have several activities related to selective breeding. Students will have the opportunity to selectively breed their own animal in an online game, choosing specific traits and characteristics to build the "perfect" pet. Through these discussions and activities students will be able to articulate how selective breeding works and the advantages and disadvantages of using this method to breed favored traits. With both an understanding of genetic inheritance and selective breeding students will then really begin to unravel the science behind genetic engineering.

Next we will look at the history of crop cultivation and its recent technological evolution. We will be visiting a genetic engineering lab where students will have the opportunity to view and participate in hands on activities related to genetic modification including PCR. Students will participate in a teacher designed game (see instructions in Appendix A) where they are farm owners, some organic non-GMO, some organic GMO, and some nonorganic GMO. Similar to the game of Monopoly, students in small groups will have to strategize for their farms' success despite natural and human created obstacles. The game can easily be modified to fit higher or lower students by changing the math calculations, initial money allocations and acreage.

Finally, we will look at the controversy of genetically modifying our food supply. We will research commonly modified food then go on an ingredient hunt in our own homes making a mess of the kitchen but separating all the food in the pantry into modified and non-modified quarters. We will study California's proposition 37 which would have demanded a labeling of all genetically modified foods. Afterwards we'll perform some simple taste tests of modified foods. Then students will research the processes, potential dangers, and inconsistencies to

genetically modified foods. Although pertinent articles will be included throughout the unit, the bulk of the reading standards will be accomplished here. As the unit's finale students will write their congressional leaders to convince them to continue research into genetic modification or stop production. Students will need to include a complete explanation of the DNA molecule and the history of cultivation as well as their opinions supported by evidence and research.

Appendix A – Activity's Instructions

DNA Extraction Lab [31]

*Students copy/answer all questions in their interactive science notebooks.

1. Beginning Ideas and Testable Questions	Background: DNA is made of four nitrogenous base pairs: _____, _____, _____, and _ _____. DNA is found in every single cell of your body. Specifically, the cell organelle that DNA is kept in is called the _____. All living things have DNA, including animals (like dogs and spiders) and plants (like trees and strawberries). Question: If you extract (meaning "take out") DNA from a strawberry, split peas, and chicken liver what will the DNA look like? Hypothesis: *(Write a complete sentence!)*
2. Procedure **What is the purpose of…** a) Mashing the strawberry? b) Soap? c) Salt? d) Cheesecloth? e) ethanol?	1.Place one strawberry in a ziplock bag. 2. Smash strawberry with fingers for 2-3 minutes (do this gently and maturely—do not break the zip lock bag!) 3. Add 10 ml of DNA extraction buffer (contains salt, soap, and water) to the bag. 4. Mush again for one minute. 5. Place a double layer of cheesecloth in a funnel 6. Place the funnel into a test tube 7. Slowly pour some of the strawberry juice into the cheesecloth, and let it filter into the test tube 8. Slowly pour the cold ethanol into the test tube until the tube is half-full 9. Where the strawberry juice meets the ethanol, you will see the DNA precipitate (come out) of solution. Spool the DNA onto your paperclip and place it onto the microscope slide 10. Clean up: -throw away ziplock bag and cheesecloth -pour liquid from test tube into collection bin -put goggles back in bin, clean table with paper towel -wash your hands 11. Repeat the same process using the marinated and blended split peas, and then the chicken liver.
3. Observations	What did the liquid in the test tube look like after you added the ethanol in step 9? What did the DNA look like? (Explain in complete sentences, including what color it was, what texture, what size, etc).
4. Claims and	1. Do strawberries have DNA? Give evidence for your answer to

Evidence	back up your claim. 2. Was your hypothesis about what the DNA would look like supported by the results from the lab? Explain 3. What is the purpose of the soap in this activity? (HINT: what is protecting the DNA from the outside environment of the cell?) 4. A person cannot see a single cotton thread 100 feet away, but if you wound thousands of threads together into a rope, it would be visible at some distance. How is this statement an analogy to our DNA extraction? 5. In order to study our genes, scientists must first extract the DNA from human tissue. Would you expect the method of DNA extraction to be the same for Human DNA? Why or why not?
5. Reflection	If you were going to do a follow up experiment, what would you do?

Maize Day Game Teacher Instructions

1. Separate students into teams of 6. Have students create a name for their farm. Then randomly assign a size for their farm. I like to write several different acre sizes on index cards then have students pick one randomly without looking. Then do the same thing for a starting bank account amount. You can either hand each team fake money, or I suggest a mini white board and white board marker which could be used to easily add and deduct.

2. Display the game board on an overhead or smart board. Use a different colored game piece for each team. Every team begins on Go. As teams buy property use a corresponding marker color to show ownership of that space. All fines are to be added to the center of the board. This can be done using fake money or by just calculating the amounts and updating a sum as necessary.

3. With each roll of the dice teams will have the opportunity to grow or harm their farm in different ways. Chance cards (which you will need to create ahead of time) have an opportunity to help or harm the farm owners. This is where most of the real learning will happen as the chance cards should illustrate the advantages non-organic farming has over organic. Write your chance cards strategically to illustrate the defects. A list of recommendations is included.

4. Landing on a "SO SUE ME" space means that the farm that landed there and the nearest farm (in proximity to the left) are in legal litigation. To solve this each team must roll the dice 3x the team with the highest quantity of the three rolls wins the law suit and takes the bank.

5. Each time a team passes go that represents surviving another planting year.

6. The game ends at the end of the period where each team adds up their total acreage and is bought out by a giant corporation. The corporation pays the farms .40 per acre which is added to their bank account. The team with the largest total bank account balance wins the game. The following day students should reflect on the games challenges and their teams successes. They should strategize how they would have a better advantage and reflect upon the differences in farming techniques.

Example Game Board

So Sue Me!	180 Acres available $900	30 Acres available $400	Chance	90 Acres available $1700	Jail
40 Acres available $400	BANK				140 Acres available $2,000
80 Acres available $200					Chance
Chance					60 Acres available $750
140 Acres available $1400					250 Acres available $1400
GO!	1,000 acres available $75,000	4,300 Acres available $105,000	Chance	250 Acres available $16,000	So Sue Me!

Chance Card Ideas:

A. Consumer Reports Magazine reports that consumers prefer the taste of organic corn. A major news story about this is reported and read by millions. As a result sales for organic farmers increase while non-organic decrease. If you are an organic farmer add $50,000 to your bank account. If non-organic deduct $50,000

B. E. Coli outbreak traced back to corn. Consumers are outraged! Everyone deduct $100,000 in product sales from bank accounts.

C. Protestors are seen outside your farm disputing use of GMOs. They block your entrance and exit for 3 days. If organic non-GMO, you are not impacted, all other farmers deduct $3,500 for 3 days profits.

D. GM seeds from a nearby farm have infiltrated your land. If organic non-GMO you spend a week digging up these plants and ensuring the safety and non-cross pollination of your product. Deduct $8,000.

E. A drastic weed outbreak has occurred! It eats 30% of your crop. If organic, you lose $55,000 worth of product.

F. A drastic bacteria outbreak has occurred. If organic it ruins 80% of your crop. You lose $130,000 in product.

G. You are caught purposely spreading seeds to another farm. Go to Jail for 2 turns.

H. You are unable to pay your taxes. Go to Jail for 2 turns.

I. A major maker of corn syrup says your plants are not producing fast enough. They decide to not contract for

work with your farm anymore. If organic deduct $200,000 from future profits.

Appendix B – State Standards

Standard	Description of Standard	How Standard is being addressed
Next Generation Science Standard (NGSS) 4-ESS3-2	Generate and compare multiple solutions to reduce the impacts of natural Earth processes on humans.	Students will compare selective breeding techniques to genetic engineering and natural pollination. They will create lists of pros and cons for each to both the environment and humans. Then deduce where each has a place in current agricultural practices.
NGSS 3-5-ETS1-1	Define a simple design problem reflecting a need or a want that includes specified criteria for success and constraints on materials, time, or cost.	Students will address and show mastery of this standard through the designing of their perfect pet. They will analyze genetic problems in the species of their choice and then decipher which breeding techniques could be used to create a pet without these problems.
NGSS 3-5-ETS1-2	Generate and compare multiple possible solutions to a problem based on how well each is likely to meet the criteria and constraints of the problem.	This standard will be addressed in the perfect pet activity as students compare and contrast the results and possible solutions others have created.
Common Core States Standard (CCSS) RI.4.7	Interpret information presented visually, orally, or quantitatively (e.g., in charts, graphs, diagrams, time lines, animations, or interactive elements on Web pages) and explain how the information contributes to an understanding of the text in which it appears.	Students will have to interpret DNA structure puzzles, pedigrees, multiple data charts, and graphs throughout the process of this unit.
CCSS RI.4.9	Integrate information from two texts on the same topic in order to write or speak about the subject knowledgeably.	Students will be given multiple sources both for and against GMO to compare and contrast. Then students will be asked to synthesize this information into their own persuasive writing.

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32. Lab Sheet designed by Madeline Keleher, adapted and used with her permission, no copyright necessary.