Combatting Misinformation Using Foundational Biology

An Honors Thesis (HONR 499)

by

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Abstract

Following the onset of the Covid-19 pandemic, a new wave of scientific misinformation flooded the media. Conspiratorial ideas about the virus itself, vaccinations, and a myriad of other things spread through social media like wildfire. These, compounded with preexisting forms of pseudoscientific rhetoric, has led to a dramatic increase in public distrust of science. This type of distrust not only threatens scientific progress, but also holds broader threats to things like public health and policy decisions. Though there are several ways to combat scientific misinformation, this project aimed to cull misinformation by educating the public about the foundational biology underlying many of these conspiracies. Five videos were produced covering mRNA vaccines, alternative medicine, misuse of science to justify racism, and climate change denial. These videos will hopefully provide a more complete context for some conspiracies and aid the audience in developing skills to recognize and combat misinformation as they encounter it.

Acknowledgements

I would like to thank Dr. Eric (VJ) Rubenstein for his thoughtful feedback and guidance throughout this project. His help during this project is a miniscule part of the professional and personal guidance I have received from him over the last three years. I would also like to thank Todd McKinney for the same level of thoughtful feedback. His guidance through this project has pushed me to be a better and more accessible communicator.

I would also like to thank Rosalie Buckley for her artistic contributions to the project and patience with me as I worked on this daunting project.

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Process Analysis Statement

I was inspired to create my thesis following the onset of the Covid-19 pandemic. As a chemistry major, science education and communication had always been of particular interest to me, but it was not until I encountered the sheer volume of misinformation produced during that pandemic did it become a passion. Largely, this passion was sparked through conversations with family members and friends who began believing in and spouting off conspiracies about Covid-19 and other scientific misinformation. Initially, I felt very hopeless and frustrated during these conversations. Before encountering people close to me entangled in this type of misinformation, I found it easy to write off people falling for these ideas as unintelligent or crazy. The fact that my own family members were now buying into it forced me to reevaluate my personal biases and perceptions. Sometimes, I still walk away from these conversations feeling frustrated, but ultimately, these conversations have inspired me to attempt to tackle scientific misinformation through open conversation and communication. Therefore, I created a series of YouTube videos aimed at educating people without scientific backgrounds about basic biological concepts frequently associated with conspiratorial ideologies.

Narrowing down which topics to pursue proved to be one of the most challenging parts of my thesis because of the sheer volume of misinformation I have encountered, both in my personal life and on social media. Ultimately, I chose to cover five topics that I feel are commonly misunderstood: Covid-19 and mRNA vaccines, alternative medicines, evolution, race, and climate change. I chose a wide range of topics to appeal to a broad audience. This choice was also made to illustrate how diverse one single area of science like biology can be.

After choosing my topics, I began writing scripts for each video. To do this, I would begin researching different aspects of a topic and create an outline based around the key takeaways I wanted the audience to have for a particular video. Then, I would write each script and send it to my thesis co-advisors for several rounds of revisions. When selecting advisors, I chose to have one with a strong scientific background and one without a scientific background. This was useful in revisions because I was able to learn what types of tools are useful in communicating with nonscientists. This skill will be extremely useful as I pursue science communication further in my future career.

After writing and editing all of the scripts, I then moved on to recording and editing the videos. I chose to film them all in my bedroom. Initially, I thought that filming in a studio or in a lab room in the new Foundational Sciences Building would be best. After some consideration, I decided that filming in my room would give the videos a more authentic and down-to-earth tone that would be useful in communicating my message. Several of the videos also feature written whiteboard segments. I incorporated those segments as I saw fit to illustrate or better explain a particular biological phenomenon. To record them, I rented a camera and tripod from Bracken Library. The videos were edited using Adobe Premiere Pro. This portion of the thesis was also a big challenge for me because I had very limited experience recording and using that software before. Despite the initial challenges, I learned the basics of a new skill that may also be useful in the future.

Each video featured themed artwork in the background created by Rosalie Buckley, a Ball State student studying visual communication. Rosalie created all animated introductions for the videos, as well.

The videos were uploaded to YouTube after approval by my thesis advisors. I chose this platform because it is easily accessible and free for all people to use. There, I hope that people will be able to find them, click, and learn something new about science. Links to all videos are available immediately following this statement. Transcripts of each video are included in this document, as well. Because each video centered around a unique topic, the list of works cited for each video is available after each transcript.

Video Links

Vaccines and mRNA

https://youtu.be/NGQJlNyPrWM

Alternative Medicine

https://youtu.be/ACsoHZhRkGA

Evolution

https://youtu.be/hsLgssHwO9g

Race and Genetics

https://youtu.be/1b_nX0oPvvs

Climate Change

https://youtu.be/2h5vjq9dwZs

Vaccines and mRNA

Imagine not being able to breathe. Imagine getting up to walk across the room and having to stop because it is too exhausting for your body. Imagine it getting so bad that you have to go to the hospital, be put into a medically induced coma, and intubated so that a machine could breathe for you because your body is physically unable to. Even worse, imagine you can't get access to that lifesaving machine because the hospital is full of hundreds of patients like you who just happened to get there first.

You have probably heard of at least one similar scenario over the past two years in people who have contracted Covid-19. The novel coronavirus is an RNA virus originating in Wuhan, China. Though it typically produces flu-like symptoms in people, some cases, including those from newly emerging variants, have proven far more severe, leaving countless people on ventilators, dealing with long-term illness, or even dead. Life changed overnight for almost everyone, leaving people to deal with new family problems or mental health crises with little support. The world's response has been variable to say the least. As governments moved quickly or, in some cases, slowly in responding to Covid-19, the citizens of their countries were meeting them with mixed responses. Though some people immediately fell in line with what was understood to be best practice, others had some different ideas about what was actually going on. Almost immediately, conspiratorial ideas about the severity of the virus, the true origin of the virus, and the purpose of all the government mandates and lockdowns began to crop up and spread like wildfire through the internet. These ideas have delayed progress, but at the same time as these ideas were taking hold, good things were happening as well. Scientists united in an unprecedented way to develop new diagnostic tests. Almost immediately, full-

steam-ahead research efforts were started to develop a vaccine against the deadly virus, and they worked! The first ever mRNA vaccine was developed and approved for use by the public to fight Covid-19. This did not quiet the conspiracies, and as thousands flocked to get the new vaccine, others were less enthused. And, I mean, who can blame them for being skeptical? After all, what even is mRNA?

To begin understanding what mRNA is, we first must jump back in time to high school biology. Specifically, we have to understand how biological molecules like DNA, mRNA, and proteins function. Your body is made entirely of cells. Each of these cells contains its own unique genetic information called DNA. Cells care a lot about protecting DNA, so it is housed in the nucleus away from most other cellular components. DNA is what makes you unique from all other people. It contains the instructions to carry out life-sustaining processes. However, in order for these instructions to be carried out, a few other molecules are involved. Namely, mRNA and proteins. The proteins in the cell are a little different than what we usually think of when someone mentions protein. They are not a food group, but rather a type of biomolecule that carry out nearly every life-sustaining process occurring in our cells. The information encoded in DNA cannot be used to produce proteins directly. Instead, an important intermediate called mRNA is used. A certain molecule called RNA polymerase transcribes information stored in DNA into the transient messenger molecule mRNA. mRNA is produced in the nucleus where the DNA is, but unlike DNA, it is able to leave and interact with other components of the cell in the cytoplasm. Once mRNA enters the cytoplasm, it is translated into a protein by another cell machine called the ribosome. Through this process, cells are able to produce all of the items necessary for sustaining life. It may be helpful to think of this process in

terms of music. In this case, DNA would be the idea for a song in the composer's head. mRNA would be the song that gets written down, and proteins would be the song being performed.

Understanding this process is important in understanding how the new coronavirus vaccine works. Traditional vaccines rely on using dead, inactivated viruses, or protein subunits of viruses. These components cannot make you sick. They are introduced through injection into your body. Once there, the cells of the immune system recognize that they are foreign and launch a response to destroy them. This response involves producing antibody proteins that bind to some component of the virus and mark it for destruction. Recognizing the particles as foreign also forms a memory of the pathogen in your body. When you come into contact with a live virus, it usually cannot infect your cells because of your immune system's memory. This mechanism is much different than that used by the new mRNA-based Covid-19 vaccine.

To understand how the new vaccine works, it is important to first understand how the coronavirus hijacks your cells so that it can proliferate. Viruses like Covid-19 are enveloped in a lipid casing that protects its genetic material, which is RNA. Spike proteins on the surface of the virus help it gain entry to our cells. The spike proteins bind to receptors on the surface of our body's cells. Binding triggers a response that allows the virus to be brought inside of the cells. Once in the cell, the coronavirus essentially hijacks the protein synthesis machinery we talked about earlier. It uses those machines to produce more copies of itself. When these copies are fully formed, they are shipped out of the cell. The new copies of coronavirus are able to enter and infect surrounding cells, allowing the cycle to continue while spreading the virus throughout the body.

Now that we understand how the coronavirus enters our cells, we can talk about how mRNA-based vaccines prevent entry and ultimately prevent illness. The Pfizer and Moderna vaccines are both mRNA based. To refresh, mRNA is the transient messenger between DNA and proteins. mRNA in these vaccines is wrapped in a layer of lipid molecules that help the vaccine to be taken up by our body. Specifically, cells of the immune system called dendritic cells take up the mRNA. Once inside these cells, mRNA is translated by ribosomes. The mRNA encodes the spike protein, which is part of the virus that helps the coronavirus enter cells and produce illness. No other portion of the virus is encoded in the mRNA introduced through vaccination. On its own, the spike protein cannot cause illness. Once the mRNA is translated into the spike protein, the protein is moved to the surface of the dendritic cells. Other immune system cells recognize this protein as foreign and begin to form antibodies against it. Antibodies aid in preventing infection in two ways. First, they compete with the receptors on the surface of body cells to essentially neutralize the virus. Neutralization prevents entry of the virus into our cells. Second, they mark the virus particles as foreign and tell other immune cells to dispose of them so that they cannot produce illness. At no point in the vaccination process does the body interact with a dead or weakened coronavirus to illicit an immune response. Our DNA also remains untouched by the new mRNA introduced by the vaccine because the mRNA never even enters the nucleus where DNA is stored. So far, mRNA vaccines have proven safe and effective for every population monitored by the CDC.

How can something that seemingly came out of nowhere already be touted as safe and effective? The answer is simple: this type of technology has been in development for decades. In fact, the first reported lipid-based mRNA delivery to cells happened in 1978. Using mRNA as a

therapeutic was just a dream then. There were a lot of problems to work out, but the reason that mRNA was never heard of until 2020 is because of a few main problems. One: mRNA is notoriously unstable. Cells do not try to keep mRNA around for very long. Rather, mRNA is supposed to serve as a transient intermediate between DNA and proteins. Figuring out how to get mRNA to stick around for long enough to be taken up and translated by cells was a huge challenge. This problem was addressed by wrapping the mRNA in lipids. Lipids also allowed for the mRNA to be more easily taken up by cells. Figuring out how to ensure that mRNA being introduced to the body did not cause a dangerous immune response was another hurdle. Fortunately, scientists were able to chemically modify one of the subunits of mRNA. This modification allowed the mRNA to hide from the body's immune system and be translated as any other native piece of mRNA. Finally, scientists have not always had the resources to produce mRNA in the laboratory-based way it is done now. Instead, they would isolate mRNA from animal sources. As you can imagine, this was very expensive and difficult, making it super impractical for large-scale production of things like mRNA vaccines. Developments in different biotechnologies in the past few decades have made large-scale production of mRNA without the use of animals a reality. So, even though it feels brand new, the precedent for mRNA-based therapeutics has existed for decades. In fact, clinical trials for mRNA vaccines for several different ailments, including cancer, have been ongoing for years without major safety issues being reported. Scientists have been running the marathon of mRNA vaccine development for decades. We have only just witnessed the sprint to the end.

If you are hearing me say all of this and still feeling skeptical, maybe it would ease concerns for you to hear that scientists were the biggest critics and skeptics of mRNA therapies

in the early days of their development. Very few people trusted the initial data suggesting that maybe one day mRNA could be used as a drug. They had valid reasons to doubt its safety. These doubts, coupled with the logistical issues of producing mRNA, were huge barriers to the scientists that dedicated their careers to studying these processes. Katalin Karikó and Drew Weissman, the scientists largely credited for developing mRNA vaccines, struggled to get funding for their labs because of how outrageous this idea seemed. Before the days of Pfizer and Moderna, Karikó owned a biotech company that eventually failed because no one would buy into her idea. One key aspect of scientific skepticism is that it is not a fixed barrier. Enough data supporting a new idea will eventually convince scientists that it is worth supporting. That is exactly what has happened with the mRNA vaccine. Enough people produced clear, reproducible results to support this new idea. Others read their results and decided that it was safe and worthwhile to pursue this new strategy. These pursuits resulted in even stronger evidence for the technology, and eventually mRNA vaccines made their way to clinical trials. By all metrics, the clinical trials for the mRNA coronavirus vaccines have been very successful. The vaccine is effective at preventing illness and the side effects are much more mild than severe cases of Covid-19.

I hope this video has instilled a new appreciation for foundational biology in all of you. These concepts underly the function of nearly all modern medicines that we use today. Understanding how they work is the way out of fear and distrust for science. I think you should get vaccinated, but I know that is not going to convince most people. You do not have to listen to me, but I hope that you can listen to evidence and reason. Studies about the efficacy and safety of the vaccine are free to access online. Tons of resources exist, including this video,

aimed at educating and dispelling misinformation. Skepticism is healthy, but only when it is flexible. Strong evidence in support of one idea is permission to believe in that idea. Standing in the way of therapeutic strategies that are consistently proven valid, safe, and effective by independent researchers only serves to delay scientific progress.

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Alternative Medicine

How many people do you know who would put something called (RS)-2-(4-(2-methylpropyl)phenyl)propanoic acid in their body? How many people do you know who have ever taken ibuprofen? Would you be surprised to learn that they are the same compound? Maybe, you know some people who don't take ibuprofen at all, and instead rely on natural anti-inflammatory substances to cure their headaches. After all, this does seem safer. Nature has produced that compound, not some guys in a lab. And, surely, our bodies can tell a difference. Right?

If you have spent any amount of time on social media, it is likely that you have come across medical or nutritional misinformation. As with anything, these myths range in severity from reported "dangers" of carbohydrates to outright denial of modern medicinal practice. Though some forms are less damaging than others, all types of misinformation are problematic for people trying to navigate their own health and diets. Some of this type of misinformation, like the keto diet, blood type diet, or several forms of alternative medicine, are rooted in an incomplete understanding of how medications or food is handled in the body. These myths, especially those focused on dieting, also often promote a sense of shame about body size or around the types of food we consume. This is clearly damaging for those who have struggled with issues like eating disorders or other mental health concerns. Myths are allowed perpetuate because they target people who are already anxious about their own health. And, honestly, who can blame these people for being anxious? When is the last time you met someone who could sit down and explain how ibuprofen, for example, is handled in your body? I don't have time to address and explain the principles underlying all of this misinformation in

one video, so instead, I am going to focus on one of the most prevalent types of misinformation in this category: complementary and alternative medicine. I hope that by focusing on this topic I can help redefine exactly what constitutes a chemical and provide some biological plausibility for some of these purported remedies.

Complementary and alternative medicines involve the use of non-mainstream medicinal approaches together with or in place of conventional medicine. This can take the form of several different things, including acupuncture, chiropractic medicine, herbal medicine, and different forms of "energy" healing. Some of these practices, including acupuncture and chiropractic medicine, have been demonstrated to be effective for a small subset of conditions, like headaches or pain management. Others, including those that claim to cure cancer, have limited to no support for their purported benefits.

Today, I want to focus on things that people ingest to gain some sort of health benefit. Commonly, people eat things like herbs or the latest "superfood" in order to lose weight, improve some sort of health condition, or prevent serious diseases like cancer. I'm sure many of you have heard of people eating things like chia seeds or lavender to glean these purported benefits. As with other alternative remedies, some herbal supplements actually do help with a limited subset of conditions. For example, some evidence suggests that one of the most well-characterized medicinal plants, St. John's wort, actually is useful in treating mild and moderate depression. Despite the proven benefits of some of these plants, they will never be a cure-all or replace modern medicine. For example, despite its benefits, St. John's wort can also have severe interactions with prescription drugs like heart and cancer medications. Because of these interactions, taking St. John's wort at the same time as these prescription medications make

the prescriptions less effective and can worsen the associated health conditions. Taking St. John's wort in conjunction with other antidepressants can also lead to a condition known as serotonin sickness. This illness causes insomnia, confusion, and, in severe cases, seizures in people affected by it.

Similar interactions and side effects are common with other types of herbal supplements, as well. Because of these common side effects, depending on non-traditional medicines without doing further research on them can be detrimental to health. Herbal supplements are regulated by the FDA, but not to the same degree as prescription and over-the-counter drugs. This means that, although manufacturers are required to have some evidence supporting the claim of the supplement, the claim is not rigorously evaluated by the FDA before they are allowed to be sold. This is less of a health risk and more of a financial one. Herbal supplements are pricey, and they may not even be doing the thing they claim to be doing.

One fundamental problem with the belief in herbal supplements or "superfoods" is a misunderstanding about why some of them work and, by extension, why conventional medicines work in the body. Most drugs have a mechanism of action. This phrase refers to the way that a medicine interacts with your body to produce a desired outcome for your health. Some chemical component of the medicine interacts with another chemical component of your body to produce an effect. The reason why some herbal supplements work is because there is a specific chemical in that herb that interacts with your body. For example, in St. John's wort, a chemical called naphthodianthrone hypericin interacts with the body to help with the symptoms of depression. The mechanism of action of St. John's wort is thought to be fairly

similar to that of traditional antidepressants. St. John's wort targets specific receptors in the brain that lead to an overall increase in serotonin levels. It is the interaction between this chemical and our cells that helps symptoms, not any other special property of the plant. Even in medications with unclear mechanisms of action, all medications are well-characterized as effective and safe. As we discussed earlier, this is not always the case with alternative medicines.

Most common prescription and over the counter medicines available today have a well-studied and specific mechanism of action in our body. Some of these medicines, like aspirin, were even derived from plants! The important chemical from these plants is concentrated or synthesized in a lab for sale on the market. One important thing to note is that your body has no way to differentiate between chemicals that are synthesized in a lab and chemicals that are ingested alongside food or another supplement. So, choosing an alternative remedy over a pharmaceutical simply because it is "natural" is not really providing any type of benefit to your body. Critics of this point may argue that the long list of side effects for prescription medications are reason enough to make the switch to natural remedies. This point fails to acknowledge that alternative remedies, including St. John's wort, also frequently have side effects associated with their use as well.

Another thing that strong proponents of alternative medicines tend to gloss over is that not every herbal supplement or superfood is effective, and some actually carry intense health risks with them. For example, in 2016, apricot kernels, or the pit inside the apricot fruit, were being touted as the newest anti-cancer superfood that provided a myriad of benefits to the body. A man in Australia began taking apricot kernel-based supplements every day to prevent

his prostate cancer from recurring. When he went to the doctor, they found that he had twenty-five times the acceptable level of cyanide in his bloodstream. Cyanide is a molecule that prevents the body from properly delivering oxygen to your cells. Apricot kernels contain a compound called amygdalin. When amygdalin interacts with the body, it is converted to cyanide. When circulating through the body, cyanide can cause symptoms like vomiting, lightheadedness, or even death in severe cases. The Australian man believed that the amygdalin in the apricot kernels would kill off any new cancer cells if they grew in his body. The problem with this belief is that the cyanide produced when amygdalin interacts with the body cannot tell the difference between cancer and non-cancer cells, so it nonspecifically starves them of oxygen. Importantly, no clinical evidence shows that apricot kernels or amygdalin make effective anticancer medications. The risks associated with consuming them far outweigh any potential benefit.

Though this is just one example, it is indicative of a larger problem. The Australian man did not stop taking those supplements after having a conversation with his doctor. He still decided he needed apricot kernels to prevent his cancer even after being informed of the risks and lack of evidence for this belief. Why? Well, it's probably for a lot of reasons, but I think that illness-related anxiety is one major factor that has allowed for these beliefs to spread and stick in people's minds. Having a major illness like cancer is terrifying, and I understand why he would want to do everything in his power to prevent it. Common treatments for cancer can also have brutal consequences for the body, so seeing something as mundane as apricot kernels promised as a cure-all for that ailment would be an extremely appealing and simple solution. Unfortunately, science and medicine are very rarely simple.

As we have already discussed, the chemicals contained in the foods we eat and the medicines or supplements we take can have hidden interactions with our body that are harmful to overall health. Any product that claims to be a miracle drug that cures all ailments usually just has a good marketing team. Understanding how to find quality, reliable healthcare information is important to avoid falling into the trap of these marketing schemes. Though it can be difficult, it is not impossible, and several reputable sources, like the NIH or FDA, frequently publish fact sheets and studies outlining the risks and rewards of alternative medicines. Doctors and pharmacists are frequently happy to talk about how medicines work and interact with the body, and taking advantage of these resources is important and necessary to avoiding misinformation and living a healthy life.

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Evolution and Antibiotic Resistance

When I say "evolution" what comes to mind? Maybe, like many others, you think of the common, and somewhat inflammatory, notion that humans came from monkeys. As I'm sure you can imagine, this is a dramatic oversimplification of the concept that provides the foundation for many biology classes.

Evolution is the complex process that describes how all organisms have changed since their first days on earth. Evidence for evolution exists in spades at the microscopic level. One great example of this is how similar the cells of all complex organisms, like animals, are. They all contain the same basic tools such as mitochondria and nuclei that are necessary to sustain life. Another piece of evidence supporting evolution is the genetic relatedness among different branches of life: Sequences of DNA are remarkably similar across species, even species that you would not expect to be related at all, like baker's yeast and humans.

At the end of the day, why should we care about this process? Evolution takes time to happen, and you might expect that any consequences of evolution happening now will be far removed from our lifetimes. If evolution only happened in multicellular living things like animals, you would be correct. The way in which populations of cows, for example, are changing would be mostly irrelevant to your life. Cows have several different cell types in their bodies. Cow evolution would involve the concerted action of changes in millions of cells, and these changes would have to be passed on to a new generation of cows. The problem is that smaller, simpler organisms can also evolve. Namely, disease-causing, or pathogenic, bacteria are evolving at a rate that is outpacing the development of new antibiotics. Unlike cows, bacteria are not multicellular, and they reproduce much more quickly. This allows any mutation

to spread through populations of bacteria very rapidly. This phenomenon is making it more difficult than ever to treat simple bacterial infections. Today, I am going to provide a deeper explanation of how genetic information can change, how these changes eventually lead to evolution, and how that has contributed to the development of antibiotic-resistant bacteria.

To begin understanding these complex processes, we must understand the fundamental molecules of our cells that change to allow evolution to happen. Those molecules are called DNA. The building blocks of DNA are called nucleotides. There are four nucleotides: adenine, guanine, cytosine, and thymine. Different combinations of these four building blocks form genes, which comprise the functional unit of DNA. Genes contain the instructions for a cell to carry out different tasks for the cell. If we think of nucleotides as words, then genes would be sentences giving instructions to the rest of the cell. Genes are the instruction manual that contain all instructions for sustaining life.

The information stored in DNA is remarkably stable. Despite this stability, accidents still happen all the time. DNA in cells can be damaged by different environmental factors, like exposure to UV radiation or cigarette smoke. DNA damage typically consists of some type of chemical alteration to individual nucleotides. More severe types of damage can cause breaks in the backbone of DNA. These are more difficult to repair than chemical damage. Though most damage done to a cell's DNA is ultimately repaired, some types evade the DNA repair machinery in the cell. Damage makes DNA more susceptible to mutations, or alterations in the sequence of nucleotides in DNA. Mutations can make it more difficult for the cell to interpret what the instructions encoded in DNA are, or they can change the meaning of those instructions altogether. Mutations do not always come from DNA damage, and instead can

come from errors during the process by which DNA copies itself to make more DNA for a new cell.

Mutations sound intimidating, but they are not always harmful. Just like how misprinted instruction manuals could simply omit one word or switch the order of important steps in the process, the effects of mutations vary, as well. Many mutations are neutral, meaning that they are neither advantageous nor harmful for an organism. Some mutations are even beneficial for an organism, and the accumulation of small beneficial mutations over long stretches of time is what causes living things to eventually evolve. For example, if a purple berry suddenly became toxic, but a one member of a colorblind species acquired a mutation that allowed it to see the color and therefore avoid the berry, that organism would be better able to survive in its environment than its peers. One key thing to understand about this process is that the effect that mutations will have on a cell is completely random. Though some types of mutations are more common than others, the gene that will be mutated is not specific. The purple-sighted organism we just talked about did not do anything special to gain the ability, it just happened to win the genetic lottery and become better suited for its environment.

So, how does an advantageous mutation get spread through a population? Simply put, organisms with advantageous mutations are better able to survive and produce offspring than those without the mutation. Through inheritance, their offspring are more likely than other offspring of the same species to have the advantageous mutation. There is a good chance that the organism with a new ability to see purple passed that trait on to its children. Like their parent, the offspring with the mutation are better able to survive and reproduce, effectively

spreading the advantage through an entire population. This is essentially how new species, or groups of living things that can reproduce in nature, develop and spread through the world.

This phenomenon is what has been observed with the growing number of antibiotic-resistant bacteria strains in the past few years. The pathogenic bacteria are forming new strains. A strain refers to a variant or subtype of a species. These strains are altered in some way that makes the bacteria resistant to traditional antibiotics used to kill them. There is an endless list of the ways in which this can happen, so to better understand the process, I want to talk about one of the most widely discussed antibiotic-resistant bacteria strains: Methicillin-resistant *Staphylococcus aureus*, or MRSA.

MRSA is a strain of *Staph. aureus* that has become resistant to the common antibiotic used to treat it, methicillin, over time. MRSA infections are spread through casual contact with other people. The spread typically occurs in healthcare settings. MRSA infections are very difficult to treat and have a mortality rate of roughly 36%. That rate is much higher than infections caused by strains of *Staph. aureus* that are still susceptible to antibiotics.

To understand how MRSA became resistant to methicillin, we must first understand how methicillin was able to kill MRSA to begin with. *Staph aureus,* like many bacteria, has a cell wall that protects it from its surroundings. One type of molecule that makes up the cell wall is called peptidoglycan. These molecules form a mesh-like structure that protects bacteria from their environment and helps maintain their shape. Methicillin functions by interrupting the synthesis of this outer mesh. Without the mesh layer, bacteria are not able to survive. Enough methicillin eventually kills off the population because it inhibits the synthesis of this outer layer.

Now that we understand how methicillin kills *Staph aureus*, we can begin to understand how bacteria evolve to become resistant to antibiotics. As we have already discussed, mutations happen to DNA all the time. Some of these mutations in bacteria gave them a survival advantage against methicillin by producing a new molecule that binds to and neutralizes the antibiotic so that it could not inhibit peptidoglycan synthesis. This allows the bacteria to survive in the presence of an antibiotic. Because those bacteria were able to evade death by the antibiotic, they are the ones that reproduce. Other bacteria that lack this new mutation are killed off by methicillin, essentially selecting for this new population of bacteria that has the mutation. When the new bacteria reproduce, their offspring inherit the genetic information from their parent cell, including the new mutation that causes methicillin resistance. Enough rounds of this replication eventually gave rise to the new strain known as MRSA. This new type of bacteria is extremely dangerous because it is still able to cause disease, but now, doctors are unable to use methicillin and several other antibiotics that work similarly to methicillin to treat it.

This type of evolution happens all the time in nature, but antibiotic-resistance has been on the rise due to human actions, as well. Particularly, the over-prescription, inappropriate prescription, incorrect usage, and agricultural use of antibiotics have accelerated this process. All of these actions have selected for antibiotic-resistant bacteria through similar paths as outlined above. The scary thing about this process of evolving antibiotic resistance is that it never ceases. Already, new MRSA variants that are resistant to multiple types of antibiotics are emerging. These variants are much more rare than single-drug resistant strains of MRSA. This new emergence is due, in part, to the actions of scientists and healthcare workers. Since the

discovery of MRSA, there has been a popular movement in healthcare to decrease the prescription of antibiotics. Now, if a patient does not have a diagnosed bacterial infection, it is very rare that a doctor will prescribe antibiotics. I know this can be frustrating if you are sick, but by limiting the use of antibiotics, doctors reduce the likelihood that multi-drug resistant bacteria develop and inhibit the spread of bacteria that are already antibiotic resistant.

I hope that learning about this topic has demystified the broad concept of evolution and given some real-life context to how evolution works. Understanding evolution can help combat the fear and confusion that the word frequently elicits. All living things are constantly changing, and a small subset of these changes are a threat to human survival. By engaging with this foundational concept, scientists have discovered strategies to cope with the fast-evolving bacteria we see today. When the public fully understands and embraces these strategies, we are able to unite against these threats to survival to benefit everyone.

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Race and Genetics

Headlines boasting a gay gene, an intelligence gene, or an aggression gene have made their way through the news cycle more times than many of us can recall. These stories are very exciting – if we had a hard and fast way to explain the source of aggression, for example, maybe we could use genetic measures to help people with the gene better cope with their alleged innate aggression. However, as with everything in science, genetics is much more complex than that. Human behavior is extremely complex, making it difficult to nail down one source of any aspect of someone's identity. So, why do these stories keep getting published? How much of us – how much of our personhood and identity – is determined by our genetics? And, what happens when these "discoveries" are misused to justify bigotry?

Genetics is the study of how traits are inherited and how they vary among people. Behavioral genetics is one branch of genetics that focuses on how behaviors or personality traits are inherited. Though some legitimate scientific progress has been made in this field, it has a dubious past, and much of the work done in the field has been used to justify bigoted ideology. The field has been co-opted, frequently by non-scientists, to push specific ideologies that serve to further the political divide that can be seen in the United States and beyond. In this video, I want to discuss a few of these common myths and how they are misused to further political ideologies. I hope that through watching this video, you will gain the skills to recognize when science is being misused and correct these ideas when they crop up in your life. I also want to provide a clearer context on the things that can actually be used to determine behavioral traits and illustrate that they are much, much more complex than one single gene.

The “warrior gene” is a common gene that people cite as being problematic, claiming that it causes people with defective copies of it to be more violent, especially when they grow up in abusive households. Before we talk about the behavioral genetics application of this gene, it will be useful to discuss the actual known function of it. The proper name for the gene is the monoamine oxidase A, or MAOA, gene. The MAOA gene codes for the monoamine oxidase A enzyme. This enzyme breaks down monoamine chemicals in your body. Among these chemicals are neurotransmitters like serotonin, epinephrine, norepinephrine, and dopamine. Neurotransmitters are responsible for sending signals between the cells in your brain. When a signal is done being sent, the neurotransmitters need to be broken down or put away in the cell so that the signal is not continuously sent. The monoamine oxidase A enzyme is one path through which neurotransmitters can be broken down.

Now that we understand what the MAOA gene encodes, we can discuss how it gained its reputation as the “warrior gene.” Some studies have found that variations in the gene that reduce the function of the MAOA enzyme cause people with that variation to be more aggressive than those with normal gene function. These studies are controversial to say the least. One such study supporting the claim that low-functioning forms of MAOA make people aggressive did not even have reproducible results between the multiple trials included in the study. This means that for one of the experiments, people with low-functioning MAOA were more aggressive than their high-functioning copy counterparts, but for the other three, there was no significant difference between the two groups. If this was a random, relatively unknown study, it might be easy to write off the results. However, this specific study was published in the Proceedings of the National Academy of Science, well-known journal. The article was also highly

cited and reported on by the media at the time of its publication. The "warrior gene" even gained national attention on *Dr. Phil* around this time. Despite the media craze, the hard evidence supporting the claims around the MAOA gene is still lacking. Though some connection to violence has been demonstrated, simply possessing the low-functioning copy does not automatically predispose someone to violence. If any association with violence is observed, it is not solely due to the MAOA gene and is likely due to a combination of both environmental and genetic factors.

As discourse continued around this gene, eventually, discussions about race came up, as well. People of color carry low-functioning copies of this gene at higher rates than their white counterparts. As we have already discussed, work linking MAOA to violent behaviors has been discredited, and simply carrying the gene does not make someone innately violent. However, some fringe theorists have chosen to ignore the nuance surrounding MAOA research and use it as an example to demonstrate some difference between people of color, especially African Americans, and white people. In a now-deleted episode of *The Joe Rogan Experience*, Charles C. Johnson, famous alt-right activist and journalist, cites research surrounding the MAOA gene in support of his claim that African Americans are innately more violent than whites. Though he experienced pushback, both on the show and online, he was still able to spread this harmful piece of misinformation on a massive platform. Johnson also met with two US representatives in 2019 to discuss "DNA" and "genetics." Though it is unclear whether or not these topics were discussed, it is concerning that someone as misinformed as Johnson has been one of the loudest voices in the public eye about these topics.

Johnson and his supporters are incorrect that the MAOA gene makes black people more violent. The underlying principle of this claim is incorrect, as well. There are not significant genetic differences between people of any race, and all people are estimated to share 99.9% of their genetic makeup. The observable differences in skin color, hair texture, and eye color that are associated with race make up a miniscule portion of our genome and are associated with variation in the genes that determine them. Furthermore, if race did have an underlying genetic component, we would expect that any specific variation in genes would be found in only one type of racial group living in a given region. However, this is not the case, and research has demonstrated that 92% of the variations determining these features are found in two or more geographic regions. Of the 8% of variation that was specific to a region, only about 1% of the people in that region had the specific variation. This is clearly not enough evidence to support that possessing the variation could indicate a person belongs to that specific race. The concept of race as we know it has been socially constructed. People in power have defined what race is, and frequently, it is used as justification to oppress people of color.

MAOA is not the only gene that is cited as being different between the races. Genetics are often given too much credit in discussions of intellectual differences between individuals. People have used this idea to claim that black people are less intelligent than white people because of their genetic differences, such as *The Bell Curve,* an infamous book by Richard Hernstein and Charles Murray. As we have already discussed, the genetic differences between people are miniscule, and no reproducible data has shown that black people are innately less intelligent than white people. Though genetics is a crucial component in who we are, it is insufficient to explain complex emotions or other behavioral traits like intelligence. The

environmental conditions in which we are raised plays another major role in determining these traits. How intelligent you are could be influenced by who your parents are, but much more frequently, it is influenced by the quality and quantity of educational resources you have access to. Groups of people facing systemic barriers to these resources, like people of color, are going to perform worse on assessments used to measure intelligence, especially if these assessments are not culturally competent. This fact says nothing about marginalized groups' innate abilities or intelligence, but instead, reveals a social problem that we can work to change.

Bigots have been coopting the language of science for decades and using it to defend their unfounded beliefs. People unfamiliar with scientific language are particularly vulnerable to these ideas. However, as we have discussed, they are wrong. I hope this video has given you a more complete context for these ideas and the language to refute some of these claims. Bigots have always existed, but if they want to keep justifying their claims among themselves, they are going to have to look elsewhere. Their science does not hold up.

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Climate Change

At this point, most of us have heard about the reported dangers of climate change or global warming. Though climate scientists have reached a consensus about human impacts on climate change – an estimated 97% agree that human actions are accelerating this process – guidelines that could slow or reverse this process have been slow to be implemented. Alongside the calls to action from scientists, a movement of people that outright deny the existence of human-accelerated climate change has also sprung up. Because they deny the very existence of climate change, this movement opposes any action that could be taken to stop or slow down this process. We could spend hours debunking these claims from several different branches of science, but, today, I want to focus on the agricultural, biological, and health-related consequences of unincumbered climate change.

To begin, we should discuss exactly what is meant by climate change. This phrase describes the long-term shift in temperatures and weather patterns across the globe. Sometimes, this change is natural, but, since the Industrial Revolution, climate change has been greatly accelerated by human actions. The introduction of fossil fuels, like coal, oil, and gas, have generated greenhouse gases that coat the earth like a blanket and trap heat. Temperatures have risen approximately 1 degree Celsius in the past 200 years, and the past decade had the warmest temperatures on record. Though 1 degree does not seem like it would make a big difference, the important thing to note is that 1 degree is an average rise. Regions at the poles of the earth, like the Arctic, are heating up twice as quickly as places at the equator. This is accelerating the ice caps melting and leading to an increase in global sea levels. Weather patterns have also been affected by this process. For example, by the year 2100, high altitude

regions are expected to see a dramatic increase in precipitation, but regions near the equator are expected to experience droughts. Hurricanes are also anticipated to become more destructive as climate change goes unchecked. The fact that climate change is occurring and is being accelerated by human actions is not up for serious debate, and it poses a major risk to life as we know it. Climate change is not the only serious threat humans are posing to the environment, and other human actions, such as excessive use of pesticides and other pollutants have had detrimental impacts on the environment.

Now that we understand what climate change is, we can talk about some of the biological impacts of this process. One major impact that we have already begun to see is the loss of biodiversity across the globe. You may be aware of the ongoing "Save the bees" campaign. This movement is aimed at increasing the number of bees worldwide. Roughly 80 percent of all pollination worldwide is carried out by honeybees. Food consumed by humans – including several types of fruits, nuts, and vegetables – rely on honeybees to be pollinated and grow more plants. In fact, bees pollinate 70% of the top 100 food crops. These crops supply 90 percent of the world's nutrition. As you can imagine, it was a big deal when US National Agricultural Statistics revealed that the bee population in the US had declined by 60% between 1947 and 2008. This decline in bee population is largely attributed to the overuse of pesticides and the loss of natural grassland habitats in favor of monoculture farmland. Climate change is also contributing to the decline in bee population. Changes in weather patterns and warming have changed the flowering time of some bee food sources, causing bees to be malnourished. Basically, the time that the bee's food source is available and the time that the bees are in a particular location are starting to drift apart. "Save the bees" has been gaining a lot of attention

recently because the continuing decline in bee populations poses a threat to natural biodiversity. If bees become extinct, not only will we have lost them, but we could also lose several different food sources like apples and squash that are dependent on bee pollination. This makes it critical to advocate for programs and policies that prioritize the safety and health of bee populations.

Agriculture is also projected to be negatively impacted by the changing climate. Rising temperatures, shifts in weather patterns, and unforeseen major weather events all threaten to impact food availability. As temperatures climb beyond a crop's optimal temperature, the yield of that crop will decrease. Extreme weather could potentially destroy some of these crops, further reducing their yield. Extreme weather events also have the potential to interrupt food delivery, making it more likely that food prices spike in the aftermath of those events. Heat waves will also negatively impact livestock, making them more prone to disease, decreasing their fertility, or decreasing the production of animal byproducts like eggs or milk. All of these effects have the potential to disrupt food availability and decrease food quality.

Of course, bees, livestock, and crops are not the only living things that will be harmed by pollution and climate change. Outside some of the agricultural impacts I have already discussed, pollution and climate change are projected to have more direct and severe impacts on human health. Particularly, air pollution is projected to get worse as climate change progresses. This type of pollution is caused by an increase in ground-level ozone, a key component of smog. It is associated with poor lung function, increased hospitalizations for asthma, and increased rates of premature deaths. Unlike stratospheric ozone, which forms naturally in the upper atmosphere and protects the earth from the sun's rays, ground-level

ozone forms from chemical reactions involving volatile organic compounds, which are produced from human-made products like cars or power plants.

Air pollution is not the only threat to human health posed by climate change, however. Temperature extremes like heat waves have also been exacerbated by climate change. Heat waves lead to preventable deaths from heat stroke, cardiovascular disease, and cerebrovascular disease. Because urban areas sometimes form heat islands due to the lack of natural land cover like trees or shrubs, they are particularly susceptible to heat waves.

Finally, another major threat to human health posed by climate change is disease carried by insects like mosquitoes, fleas, or ticks. Climate is one factor impacting the seasonal and geographic distribution of these insects. As climate continues to change, the changes can impact the geographic range of some of these disease carriers. These shifts coupled with changes in how the insect interacts with its new environment can alter the frequency of insect-borne diseases. It can also introduce new diseases to a particular geographic area depending on how far the insect spread as climate changes. All of these consequences of global climate change will have dramatic impacts on human health. Coordinated global efforts aimed at slowing climate change and minimizing these effects are necessary to preserve life and protect vulnerable populations.

Despite the dangers posed by this process, the worst of them could be minimized or avoided entirely if we began taking decisive action against climate change. Damage done to the planet by climate change is irreversible. However, if policies were put in place to slow climate change, further damage would not be done to the environment. Global temperatures would likely begin to plateau, and after many centuries, temperatures could begin to decrease.

Stopping climate change now also has the potential to prevent major losses in ice caps and prevent further increases in sea levels. Biological impacts will also be mitigated as slowing temperature increases can also slow the agricultural and biodiversity impacts of that process. Additionally, impacts on human health would also be minimized if action were taken against climate change. By reducing carbon emissions through actions like taking public transit or policies like carbon pricing and hopefully slowing the increase in temperatures, problems like heat islands in urban areas could be mitigated and the number of heat-related deaths could be reduced. Stabilizing the global climate would also prevent disease vectors from moving into new areas, slowing the spread of the diseases carried by them. Finally, reducing pollution levels in major areas will help those with impaired lung function because the air will be cleaner.

Despite all of the benefits of action to stop climate change and pollution, very little has been done to stop these processes. I think this is due in part to the effects of climate change and pollution feeling very far-removed from most people's lives. The people currently living are likely not going to experience the most dramatic effects of these processes, and they likely will not be able to see the most significant benefits, like the lowering of global temperatures, of decisive action against this problem, either. Because of this, it becomes easy to put climate change on the back burner and spend time trying to solve more imminent problems. However, this ignores the people alive today that are already dealing with the consequences of pollution, like people living in urban areas that deal with smog or those that do not have access to clean water. Taking action to prevent further pollution would greatly benefit these groups. Action against climate change would also have short term drawbacks for the average person, like increasing the price of fuel or other goods. Though this would impact many average people's

day to day lives and would provide challenges for these groups, avoiding the worst effects of climate change and protecting future generations from this process would be well worth the day-to-day inconveniences.

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