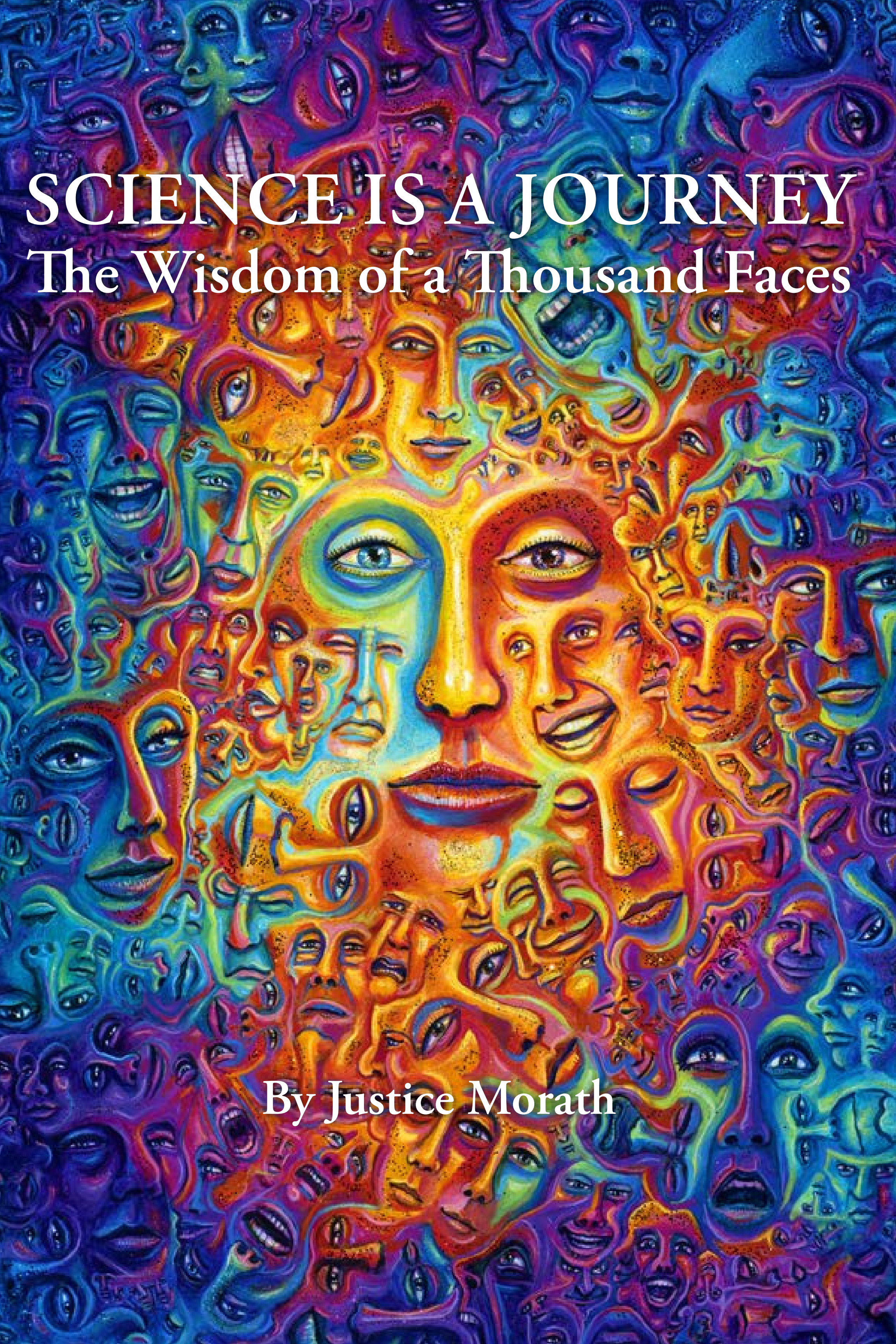
SCIENCE IS A JOURNEY
The Wisdom of a Thousand Faces



By Justice Morath

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Back cover Earth Rise from NASA.

Layout designed by Sky Hatter of Clever Girl Visual A.I.D. Clever-Girl.art

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Preface

It is not possible to tell the entire story of science and how to do it in one book. I do not seek to do so. I am also not an historian or philosopher by training, but an experimental psychologist. I minored in philosophy because I saw the importance of understanding at a deeper level what I was most interested in (which was animal behavior and cognition.) I wanted to know the limitations of our methods in trying to answer seemingly impossible scientific questions.

Back to what this book is. This seeks to act as a guide, to have you ask questions and look at the world as a scientist. I fully acknowledge, and try to highlight, the pervasive problems with the current representations and practices of science. You may find more. I hope so! That is science working as it should; ask more questions, and create more knowledge. I also know that I am trapped in my human experience so cannot fully understand the world or other people. But in a way, isn't that pretty neat? Because we have a tool right here at our disposal to find out.

This is called Science is a Journey: The Wisdom of a Thousand Faces. But it is much larger than a thousand people. It is the collective wisdom of billions of humans over hundreds of thousands of rotations around a star. It is also not about singular faces, although many people will be seen. Science seeks to extend wisdom beyond the person, in both time and space. Yet science is an ultimately human endeavor bound by our experience, culture, and species.

We are here not to talk about the What of science, the facts and theories we currently hold or held over history. But instead to talk about the How of science, the ways we have come to ask the questions that we call the scientific method. There are many ways of knowing and many ways of asking. We are only asking in one way; what we now call science. Yet science is not a monolith. Across time and culture, humans have come to similar ways of testing how the physical world works, and have followed a myriad of paths to ask different questions, in an ever-splaying network of disciplines under the umbrella of systematic empiricism.

Alongside science, there are many stories we tell to understand our world. Story shapes our collective knowledge of ourselves and the world. One of the most common stories threaded through global society today is that of the Hero's Journey. It, like all things we know, is a limited reflection. But with that, this project uses the narrative of the Hero's Journey as a metaphor to discover the story of science. To quote David Bowie, "Then we could be heroes, just for one day." And hopefully longer.

A NOTE ABOUT SOURCES

In academia, it's common practice to rely on primary sources described by the originator of the knowledge, because secondary sources are simplified and interpreted by another person. In this project, instead I intentionally focused on quality secondary sources. The reasoning for this is that there are excellent materials that cover the concepts at this level and I wanted to point you to them to go further down the rabbit hole on topics that interest you. While I will mention historically important works, primary sources can be too vast and jargon-laden to be useful. For readability, I also chose not to use in-text citations or footnotes. Instead, you can find Further Reading at the end of the book separated by interest areas. I selected resources that I felt were of a high enough caliber and important to tell a part of the story. But that's not to say I endorse everything in a source. Everything is lacking or mistaken with something, giving us a chance to look back to discover more. To shine Carl Sagan's candle into the dark room as we move forward.

OPEN ACCESS

> *"If it's inaccessible to the poor, it's neither radical nor revolutionary."*
> *-Attributed to Jonathan Herrera*

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ACKNOWLEDGMENTS

Isaac Newton is often credited with the statement, "If I've seen further, it is because I stand upon the shoulders of giants." While this book intended to show us those giants, I have my own shoulders to credit.

I must first thank Diogenes, not just the Cynical philosopher whose stories inspired my skepticism and minimalism but my eponymous old, bored pit bull dog who stared at me this whole time. I owe him many more walks.

Second is my creative and life partner Sky Hatter who designed the book layout. I also want to thank all the great professors who led me to my love of science and knowledge-seeking. Scott Tuckfield granted me use of his work Sea of Faces II for the book cover and NASA gifted society Earth Rise which I used on the back cover. I'd also like to thank Paige Jarreau for her help in drafting earlier versions of some of these chapters for a previous project. This book being open access meant it relied on the altruism of so many more artists, writers, academics, scientists, and designers who gave me valuable feedback. Not to mention all the other random people who got more than they bargained for talking to me about it.

Act I

CHAPTER ONE
THE KNOWN WORLD

Imagine this. You're in a happy little village where everything seems to be clear-cut. You have your routines. You have your expectations of the world around you. You have the stories you've been told and things are good. It's blissful. But then something happens. You are forced to answer a call to some kind of adventure into an unknown world. This is the beginning of the Hero's Journey. A common story trope: Lord of the Rings, Star Wars, the Barbie movie, along with any number of other stories, films, and myths. Most popularized by Joseph Campbell's book The Hero with a Thousand Faces, it argued that all stories and myths fell into this same structure; that stories throughout cultures, throughout the millennia, fit into this hero's dream narrative. We know that's not true (his initial claim of its ubiquity was stretched) but we also know that many Western stories certainly do follow this path. And as a story arc it works, it's engaging. So we're gonna use it. You are the hero. You and I are going to go on a journey. The journey of science. But before we get to that, we gotta start back at that happy little village. Full of its traditions and norms and limited world views, where things are comfortable and certain. Shall we go?

We humans evolved numerous senses. In fact, more than just five. Something like 9-13, depending on which neuroscientist you ask and how they define it. We also evolved a very complex ability to do all sorts of cognitive tasks such as language, reasoning, and memory. Much of this we share with other animals. But a lot of it is special to us such as abstract reasoning which allows us to have a fuller understanding of the world beyond our immediate selves. Evolution shaped us to be able to make sense of this world by finding patterns and trying to figure out cause and effect, but only through what we could actually see and experience directly. Yet we rarely have a full understanding of what's going on. We have to fill in a lot of missing pieces and draw connections, hoping that they're there, even when they may not be. So while each one of us has a direct connection to the world through our senses and our experiences and our memories, it is not a completely accurate one. It's good enough to get by as an individual (usually.) But it can't be the whole story. This belief that you have a full understanding of the way the world works, and you know how the world works is what we call naive realism. We take what we think as real, a fixed value. This is that happy, blissful village.

Where do we get this information from? Where do you get this information from? Much is from places like culture and tradition. Norms and lore ground who we are. Some of those norms helped the happy village to exist successfully for quite some time. And so there's value in some of that tradition. But we also have to make sure that we don't fall trap to the logical fallacy of an appeal to tradition; just because it was doesn't mean it should be going forward. And just because a myth has worked does not mean it will forever. We as humans and you as an individual need to move beyond the blissful, limited understanding of the world to create a bigger and better understanding of our universe.

You can feel it. Sometimes things just don't seem to work anymore. There is an entire universe of unknowns, and we're drawn to that. We as humans seek to fill in those gaps. We create origin stories for which none of us could have seen. We create afterlife stories for which none of us have ever been. These myths serve their purpose, but what they are not is a knowable world. And what we're doing here is looking for the knowable.

What do you even mean when you say you know something, or that something is knowable? That sounds probably a little annoyingly academic, doesn't it? Well, there's a whole field of philosophy that goes into this called epistemology. This is the study where we try to understand what it means to know something. Because at first glance it might seem like, well, of course, I know what it means to know something. Until we peel back the layers a little bit and realize that, like I very much said before in the so-called known world, there is so much more to the story than appears at face value. This is due to a lot of things that we'll cover, one of which is what we call the egocentric predicament. This is the fact that we are, you are, always trapped inside our heads. You can see with your own eyes and hear with your ears. Think with your brain in your own body in this time and place. You cannot get out of that. We can come up with tools to know the world better. But the world is always slightly hidden from us.

Let's talk about vision. Sure, it seems like you can see pretty well. And humans do see well relative to many other animals. We have pretty good visual acuity, which means the level of detail we can see. We have a pretty good range of colors, more than many animals. And it's working out pretty well for us in general. But we don't actually sense or perceive all colors. The beautiful garden that you see out in your yard with all the pretty Reds, Greens, and Violets that you might see in the flowers is only a small range of the electromagnetic spectrum. What many insects and birds see is far more extravagant. Those flowers look very different to those other animals. And those animals are responding to those colors in kind for food and shelter. And what that means is that there's a whole world in that beautiful garden that you are not even privy to. What that means though is we do not have a direct line to a universal reality. Science and the philosophy that it comes from is the best thing we have available to us in our toolkit to discover what is real and what we can know. So do you want to see what the world that exists outside of your known life is? If so, then that is the next key point in a hero's journey- you answering the call to adventure. And this call to adventure sends us out into the unknown world. The hero, you, in this case, will tackle all sorts of trials, tribulations, and tricksters.

We can't talk about what science is without talking about several other academic topics. We need to talk about history. We need to talk about philosophy. And we need to talk about statistics (but don't worry, I promise you won't have to do any math yourself.) One of the problems when we talk about history is that not all histories are preserved. For information

to be preserved, it needs to be passed down through some type of written or oral language. We also know that other bits of knowledge were forced out by colonizing civilizations. And so when we talk a lot about science coming from a Western tradition, it's important that you know it's not the whole story. This is not a history text any more than it needs to be, but much of our knowledge in our process of science did not come from ancient Greece or Western Europe in the Enlightenment but from places and times like the Islamic Golden Age. Science is ultimately a human endeavor. So independently across the globe, across millennia, humans were figuring out similar things, or they were figuring out how their science worked for them. And this is what makes science a journey. This is not a story where you get to say at the end, "I now know what science is and is not", because science is a process. It is not just a set of facts. It is the process by which we come to understand those facts and how we question them as needed. And how we come to learn new methods and borrow new ideas throughout this journey. And to do that well, we need certain tools in our packs. Now let's pack our bags. And head out over the horizon.

CHAPTER TWO
THE JOURNEY BEGINS

Empiricism is the philosophy that the only true knowledge about the physical world can be acquired through the direct sensory experience of the observer. And that anything that can't be seen or at least inferred from what is seen is not true knowledge because it cannot be confirmed nor denied. The origin of the term "empiricist" started in ancient Greece with philosophers such as Sextus Empiricus (yes, yes, get out the giggles now) as a response to the annoyance of their contemporaries thinking too much without verifying it through direct observation.

While modern empiricism and science have their own set of lineages, throughout written records we see plenty of examples of similar ways of trying to understand the world. We can only assume multitudes of examples exist outside of written language and the ancient works that were preserved. In fact, the first documented experiment with a control group is depicted in the Old Testament when Nebuchadnezzar was persuaded to test a vegetarian diet to a non-Kosher meat-based diet. So testing our ideas against reality in a controlled way certainly has been around for a very long time and likely before written history. While this is found in a religious text, it's important to think about how knowledge creation is not necessarily always split between the modern camps of religions versus science.

This idea was also around in earlier Greek philosophers like Anaximander. But it is not only tied to the Western world. We see examples of philosophy and worldviews arguing for this across the ancient world. And it's critical that we see how early technology was always a scientific endeavor. Early hominids could not have harnessed fire, tool use, hunting, and gathering without trial and error through direct observation. Multiple ancient human societies independently mastered astronomical calendars and maps across the globe in China, Mesopotamia, Africa, Polynesia, and North and South America. Our map of the history of science is incomplete without including these histories.

Cultures interacted and ultimately the Greek and Roman societies tapered off while the Islamic Caliphate arose. The ancient Islamic world took the great works of early medicine and philosophy from Greeks such as Aristotle and the Golden Age of Islam was born. While they valued such works, it was clear that for the blossoming early science and medicine to succeed, there needed to be more direct study. So while we see early evidence of attempts at experimentation like mentioned above, the medieval Islamic world is where the ideas of control groups and measurement advanced further Western European scholars started growing in the early modern period in what we call the Renaissance and so-called Enlightenment. Through interaction with Islamic scholars, these Europeans (typically monks) started to rediscover Greek philosophy and Islam's contributions. Thus modern science was born.

Descartes was an important figure in pushing forward an understanding of what we now consider science but with that said, he was also what we would call a dualist. This means that he believed that there was a physical world that would be ultimately studiable by natural philosophers (the early scientists) but then there's also a spiritual world. And this spiritual world does not subscribe to the same laws of physics and nature as the physical world.

Now, in modern times we as scientists reject trying to study a non-physical world and instead are materialists. Materialism is the belief that only the physical world exists and all the things that Descartes would ascribe to being a construct of the soul are simply physical too. Your self-awareness and emotions are simply physical actions in the material plane of your brain.

But this Cartesian delineation lingered into modern science and medicine outside of questions of religion and reality. Our structures have been built around this dualism. Insurance companies treat mental and physical health differently while social and behavioral sciences are often incorrectly thought not to be empirical since those are the place of the mind, which Descartes thought not to be physical in nature.

The discussion of materialism begs the question of other issues such as what does this mean for religious thought? Remember the early scientific thinkers were often religious themselves and whatever culture and religion that was around them at the time the science reflected that. Questions that religion and theology might ponder such as, is there an afterlife? Or, what is the nature of a god? These are simply not empirical questions; those aren't questions for science. As science only deals with things that we can immediately observe in the physical world and by definition many things religious in nature are not directly observable or independently verifiable. The great paleontologist and science communicator Steven J. Gould deemed these realms to be non-overlapping magisteria. He discusses how religion and science can be compatible because they're simply asking separate questions. That is not to say that there is never conflict between religious dogmas and discovery through science. This conflict has always been there, from Galileo being deemed a heretic for providing evidence the Earth revolves around the sun, to Darwin struggling with how to blend his discoveries of evolution by natural selection with his Methodist upbringing, to the science of sexual orientation and gender identity showing that humans are far more complex then mainstream modern Christianities believe.

Part of our journey is about trying to understand to vast complexities of reality. What orbits each star in the sky? But we also seek to marvel at the commonplace. What is behind each mundane human interaction? We also seek to find applicable solutions by using discoveries to invent new technology. And technology has always been a driving force of science. It both grants us new tools of discovery and creates new questions. Science also betters society and the environment through our discovery. From speaking and painting to written language,

shaping sticks and rocks into tools to satellites and spaceships, controlling fire to combustion engines and electricity. All of these advances in technology were in tandem with early scientific ways of thinking. They have also served as metaphors to help us understand reality. Like Rene Descartes' use of early machinery as a metaphor for anatomy, and our use of the Hero's Journey here, science often borrows metaphor from technology, and vice versa. Quantum computing, artificial intelligence, and neural networks are all simply metaphors we use to understand what we are creating. But they are only that; a metaphor.

CHAPTER THREE
THE WIZARD'S MINDSET

You are wrong most of the time. Most ideas we have about the world, whether in our daily lives or in the science lab, are wrong. We can not just make a mental connection or find a pattern and then proclaim we now know the ways of the world. We must test this idea before it can be considered a theory. The most common way this is done in science is through hypothesis testing. Think of it as hypo is below or before, -thesis is a theory. So we take our idea or question about the world and frame it into a testable prediction- the hypothesis. Then we go test it in hopes of building our theories.

As we go through the world trying to figure out the patterns that we see in the phenomenon that we come across our first impulse is to explain it. How did it happen? And science seeks to do this too. But a simple explanation is not enough, even if some aspect of the explanation is in fact accurate or close to the truth. What science seeks to do beyond having explanatory power is to have predictive power; if your explanation is accurate it should also be able to predict how that will happen again in the future. The question of why it happens, outside of the how it's not a question for science. It is what we would call an essentialist question. This is a question better left to the philosophers, humanities, and theologians.

In empiricism, we are always seeking to understand how the complexity of the world interacts with itself. How all the variables create cause and effect and relate to one another. We do this through reasoning that is somehow connected to systematic observation. This is unlike the rationalist philosophers who thought that you could deduce the way the world worked through armchair theorizing. But we're never blank slates that just simply absorb the world around us. Scientists still use deductive reasoning in our creation of the understanding of our world. Deductive reasoning is creating an understanding of the world based on previous ideas. Inductive reasoning on the other hand is creating ideas based on observations of the world. We are always bringing to the table previous experiences, expectations, and theories.

It may be surprising but the concept of scientific laws is not used across all sciences. This does not mean that certain fields do not have the same rigor or certainty as others. Instead, this comes from the fuzzy nature of understanding reality, and how different norms exist. So what is a Law in science? It's a description of a cause-and-effect principle that has been independently observed so often it's considered a certainty it will always be observed. It is only a description; not an explanation or prediction. For that, we must go on to something all science uses; the scientific theory.

There is no Theory of Everything, but there are an awful lot of theories of somethings. In science, a theory is an explanation and prediction of the relationship between things you're seeing out in the physical universe. A good theory is based on mountains of tested hypotheses and data collection that has weathered the test of peer review and further research. A theory stands strong on all of this evidence that has been gathered about the question at hand.

A theory is a predictive model of how the world works. It's merely a representation of the truth. This does not make it weak or flimsy. The strength of scientific theories comes from the fact that 1) they are based on empirical evidence, and 2) they leave themselves open to change. This does not mean that they are certain to change nor does this mean that they are certain to be proven wrong. What this means is while all the best available evidence at this time the theory stands to explain and predict sufficiently, there is an ability for the theory to change if new research comes forward. But the likelihood of a well-substantiated theory being outright thrown out is next to none. The power is in not being dogmatic, and letting any potential future evidence come forward.

If further evidence comes forward it must again be empirical and if it's an extraordinary claim it requires extraordinary evidence. It must also account not only for the new evidence it brings to the table but also all the previous evidence that needs to also be explained by the new competing theory. For a new theory to be plausible it must fit within currently accepted theories, or account for all the other data. This is called the connectivity principle. Belief in astrology and horoscopes requires one to ignore everything we know about astronomy, physics, and psychology! A theory is also confined to the discipline and the methods of that specific topic. This is why there will never be a full overarching theory of all of physics or all of psychology.

There is an old Jain monk parable about the five blind men and an elephant. Upon discovery of the strange animal they have not yet experienced more, they approach to learn what they can about it. One grabs the tail and says this beast is very much like a snake. Another grabs the ear and says it's more like a large leaf. Another touches a leg and proclaims it's like a tree. The elephant is like, who are these annoying people? But the point is that every one of these men has partial knowledge of the animal but none are completely correct. To be more correct, they must combine their discoveries to paint a more complete picture of the elephant.

This is how many disciplines and different levels of analysis within disciplines can paint an understanding of reality. One can not fully understand Substance Use Disorder (addiction) by just looking at the microscopic world of neurons and neurotransmitters in lab rats, although that info is incredibly important. We also can't fully understand it at the level of social and political issues by looking at the global drug trade. We must combine all this information to build a more complete picture of whatever topic you are trying to discover.

While all these different disciplines have their own theories and norms by which they are studied ultimately they should fit within what we call this principle of convergence. Looking

at societies versus individual behavior or planets versus atoms is going to be different but they're going to piece themselves together in a layered complex jigsaw. That's not to say it's always perfectly clean cut but if a theory does not mesh well with other theories from the same discipline or related disciplines at different levels then it's also violating the principle of connectivity.

One way that we try to find the simple answers is by simplifying the incredibly complex problem. We refer to this as reductionism. A big complex issue must be broken down into smaller parts so that we can fully understand them and then build them back up.

As you break problems down and look at things on a smaller and smaller scale the rules change sometimes. And by rules I mean the best research methods and the ways you measure your variables. Whether you're looking at something at the molecular level or at the planetary level is going to change your tools of analysis and measurement and then also it can change the fundamental rules of cause and effect. Whether you are looking at the level of the society or the group or the individual or the individual's specific neurons is going to change your tools and rules.

Much like entire theories, no single study is the be-all-end-all. It takes many different studies building upon one another to tell the whole story, like the annoyed elephant above. Even in the rare cases where a major breakthrough occurred in a study, it was still built upon a foundation of previous research and it requires replication by independent researchers to ensure it wasn't a fluke or the result of a design flaw. Replication is when independent people follow the methods of the study to redo the study exactly or similarly to see if the results hold up. If they are way off, this can mean the study was a fluke. Flukes happen by random chance, mathematical errors, or more nefarious trickery when researchers might have intentionally faked data or used poor methods. Reproducibility is a way we can also look for these issues. That's when an independent person runs the same or similar analysis on the same original data, to check the original scientist's work. All scientists should be willing to give their data and complete methods to others for review but as humans, we fail at this sometimes.

When there are two or more possible explanations the simplest is usually the correct one. This is Occam's Razor, also known as the law of parsimony. Now, the world is a very complex place, and often the simplest answers may not be the most accurate. But in the context of looking at different explanations if you find yourself doing mental gymnastics to explain away your results you're probably leading yourself tumbling further from the truth. We seek straightforward answers all the time in our lives but we also have to acknowledge that the world is a complex place and have to live with the uncertainty of not knowing everything about the causes of the outcomes.

And that which is offered without evidence can be dismissed without evidence. This is known as Hitchen's Razor, "Extraordinary claims require extraordinary evidence." Both of these are related to the burden of proof; when making a scientific claim the person making the claim is the one that has to supply the evidence.

This is an expansion on the philosopher Bertrand Russell's teapot around Jupiter. Suppose I tell you that there is a teapot in Jupiter's orbit right now. But being so far away and Jupiter so big, it's impossible for us to see it. The burden of proof is on me to supply evidence of the teapot, not on you to disprove it. But there's a catch; absence of evidence is not evidence of absence. What this means is I can't say the teapot is not there, it's just incredibly unlikely. Which brings us to another key concept in modern science; falsifiability.

Surprisingly, falsifiability is only an idea that came to be articulated by the philosopher of science Karl Popper in the 1930s and it was not even been published in English until the 1950s. Falsifiability is the idea that if you were to make a prediction or a claim about the world, it should be able to be shown to be false. If that's confusing hear me out. In the most famous example, imagine you're walking along a pond and you see a bunch of white swans floating about. You would make the reasonable prediction that all swans are white. This prediction is falsifiable because as you're sitting there on the bench enjoying a lovely day at the park looking over a pond a Black Swan could come and join the flock. If so, your prediction has been falsified. It's important to note that it's not that it will be proven false, it's just it has the ability to be. What's also important is that your initial prediction wasn't outright wrong it was just less right. It was further from the ground truth and now you are closer to the ground truth about the existence of all swans. Your new prediction is now that most swans are white, but a small amount of them are also black. This is what the famed science fiction author and philosopher of science Isaac Asimov discussed in his famous essay about the relativity of wrong and how science is seeking to become less wrong as we go. Our early theories may be more wrong but they were still a stepping stone towards the ground truth of reality.

These ideas are often misused by tricksters to force an idea of false equivalence. Efforts to show "both sides" of a topic are often misleading and imply more of a controversy than there really is. These tricksters argue since technically, there is an exceedingly small likelihood of a teapot around Jupiter, that the teapot is just as likely as no teapot. Don't fall for these tricks. Because even if there is one black swan, most swans are still white. Even if some people smoked cigarettes and did not die from smoking, most people did.

CHAPTER FOUR
THE TOOLS OF THE CRAFT

Science is by no means monolithic. What phenomena a scientist studies will affect how they ask their questions. Each discipline within science has specific tools and rules for its craft. But as you have seen, the underlying philosophy and history are shared. So let's dig into the shared tools and major concepts across the sciences. Much like baking a cake, finding the truth requires specific rules and clear measures. If not, then it's GIGO: Garbage In, Garbage Out.

You may have heard of the terms Hard versus Soft Sciences. This oftentimes comes up in the context of saying that certain sciences like the life sciences or physical sciences such as biology, chemistry, physics, and geology are "Hard Sciences" whereas "Soft Sciences" are typically the ones that fall in the more social sphere such as sociology, anthropology, psychology, and political science. There's something you need to do with this information; take it and throw it out! This is a false dichotomy because science, like reality, is a very complex and interwoven world and all of the disciplines are interwoven, including some of the so-called Soft Sciences with the so-called Hard Sciences. Psychology interacts greatly with biology. Archeology and anthropology interact greatly with chemistry and geology. A geologist may see their variables more clearly looking at a rock than a psychologist studying memory. But even then, when we get down to a molecular level we as humans can't really look at the physical world. We only see traces of subatomic particles and subtle evidence of their existence and there's so much we still don't know and don't understand, like looking at the traces of memory as a psychologist might.

Especially today science is often incredibly complicated to undertake. It is a long arduous process to get from idea generation through funding through acquiring technology to struggling through iterations of data collection to getting results to getting through peer review then finally to publication. This technology invented to do science can be incredibly advanced such as the Large Hadron Collider, a massive loop under the city of Geneva, Switzerland where they accelerate particles to smash into each other to understand what we don't yet know about the subatomic world. Or the Event Horizon Telescope where collaboration amongst a couple dozen telescopes across the Earth came together to essentially turn the Earth into one giant satellite dish to give us the first imagery of a black hole, something predicted by Albert Einstein's mathematical models. The complexity of an MRI (Magnetic Resonance Imaging) machine allows us to understand the structure and function of our brains.

No matter how complex the measuring device, it is still but a mirror of the truth. Sometimes all it takes is a clever scientist and very simple technology to push science far forward such as the simplicity of the self-awareness task used in psychology and biology to try to understand what an animal knows and can know about their self. By simply showing an animal themselves in a mirror with a dot of paint on their forehead we can make inferences about their inner understanding of themselves based on how they respond to the foreign dot. That doesn't seem that remarkable until you start looking into what is required for that to happen. It means that they know it's them in the mirror so they have a knowledge not just of their current self but of their past self, requiring certain aspects of memory. And in a way, they're also using the mirror as we would as a tool which shows another level of complexity of their inner world.

This may be quite a surprise but the application of statistics into science is a relatively new development. Modern statistics as we know it only came about in the early 1900s. Mathematics and scientific inquiry have developed together. When we are talking about statistics,we are looking at the probabilities of phenomena occurring or describing things like averages and rates of things occuring. So today science is oftentimes falsely dichotomized into two camps of qualitative versus quantitative research. Quantitative research is the use of numbers and statistics to understand the variables that you are studying. You are simply signing numeric values to them in some way. Qualitative research, on the other hand, is less common today but more commonly seen in social sciences as a way of looking at the question you have without reducing the properties of your variables into numbers. It goes beyond the scope of our journey here to look into the philosophical underpinnings of qualitative research but in short, a lot of it rejects some of the ways we test hypotheses. It's a good example of how there is no monolithic way of doing science.

So it's important to know now that science is an ever-evolving process that takes many shapes and forms and there is not one proper way to do science. As you'll discover later in your journey hypothesis testing is not the only way that people do good science. When we quantify variables and use probabilities and rates and trends, while incredibly valuable, by design we are distilling a rich phenomenon down to a simple measurable outcome and therefore are losing some quality of what we are studying. So we also see more often now in medicine and psychology a mixed methods approach where even if they are using quantitative inferential statistics they are adding qualitative aspects such as quotes from patient's experiences to give a more robust understanding of the questions. And some fields such as anthropology exist in a plane where both of these kinds of methods are used often. No matter the type of science or discipline you are in, it's critical to have clear, concise, and measurable definitions of what you are studying.

A construct is ubiquitous across the animal world. Your domestic dog has a construct of what it means to see a cat instead of another dog. We, in our day-to-day lives as humans, have numerous of these, some of which can be inaccurate and problematic like stereotypes about different types of people. But we also use constructs in our definition of our variables. Is a hot dog a sandwich? Well, that depends on how you would define the construct of what a sandwich is. Is soup a beverage? Well, that would depend on how you could measure that. If a soup can be sipped through a straw or drank directly out of a glass maybe that's how you might operationally define a beverage.

Measures are the tools by which we detect our variables. How can we see evidence of atoms? Of crime? Of emotions? We can't directly see another's mental processes or subatomic particles. We can't be omnipresent and know all instances of a crime occurring in real time. So a scientist must find ways to measure these. As science becomes more advanced, these measures also become more sophisticated. The goal is that we are getting closer to the ground truth. Let's look at crime. A criminologist can detect crime rates in numerous ways, but none will get the whole picture. They could look at police reports, but that would miss any crimes that went unreported. They could survey people about what they have seen or experienced, but unseen crimes and faulty memories will mean some go undetected, or even some being over-reported. And what does the researcher even mean by crime? How is that defined, and what are they even interested in studying? This is by no means limited to the social and behavioral sciences. An astronomer uses satellites and telescopes to study the universe. With these tools, we have a very small sample of the vast cosmos. What have we not seen yet? How might it change our theories of the universe?

As we discovered when looking at the history and philosophy behind science, we don't have a direct line of observation to the real world; we only have the interpretation based on our sensory experience and our interaction with the world. Within science, this also creates a quagmire because we can't always directly see the variables that we are studying. We have to look for ways to measure the variable even if we can see it. We only get traces of the phenomena that we are looking for. And we may also look at the same thing in different ways with different measures so what's incredibly important in science is what we call an operational definition. The definition is just an explanation of what something is. In the operational sense, that is the explanation of what that variable is in this specific context. How are we using this definition? Researchers may have slightly different operational definitions for the same variables. Our variables are only defined by the measurements we are using.

It is commonly said that correlation does not necessarily mean causation. When we say something's correlated we are saying that there are two or more variables that seem to trend together like there could be a relationship. But we humans are pattern seekers so we run the risk of finding illusory correlations. Such as in superstitions. A superstition is created when we see a connection between two variables or two phenomena in the world and we falsely decide that there is a causal relationship. We are pattern seekers, searching for connections in the world to try to understand how the it functions. Other animals can also fall trap to superstitions as the famed behavioral psychologist B.F. Skinner showed that he could accidentally cause superstitions in the pigeons that he was training. You might see it if you have a dog that's not a fan of the mail carrier. Your dog may successfully chase away the mail carrier every time they bark at them through the window. They think their bark is successful in chasing away the person just going about their day and leaving your porch on their own accord so it's frustrating to them that they come back every day and they have to start barking more and more to fight off this potential intruder. But it doesn't ever seem to work for them, does it?

Many sciences are predominantly correlational. Not only much of the so-called social sciences such as sociology but also fields like astronomy and meteorology. They rely heavily on looking at only the associations between variables but cannot immediately discern causality. That does not mean that they can't do so it just takes more work and finesse. They must try to control for any hidden confounding variables and pull from what laboratory and experimental research can be done to paint a more complete picture of their topic.

The commonly accepted way to tease apart causality is through an experimental design. This is when the scientist manipulates the independent variable to see if it affects the dependent variable. But it gets more complicated than that. The researcher must also try and control all those other variables floating around that could be causing hidden effects. There are a myriad of ways to do this.

Control and comparison groups are used where the researcher changes the independent variable differently in subgroups of the total sample. These subgroups should look as identical as possible to the others. We do this through random assignment sometimes as simple as flipping a coin on who goes where. If the sample is big enough, the groups should look similar in the end. We can also intentionally create similar groups in a matched sample where the scientist preselects groups to look similar in as many variables as possible. Without these control and comparison groups, they can not know if their intervention where they changed the independent variable really worked or if something else came in and made the change

The scientist should also block as many potential confounding variables as possible. Small changes in temperature, time, location, etc. Could secretly mess up the results. This is why taking science into controlled laboratory settings is often critical to isolate the causal effect they are looking for. Often, criticism occurs because it does not look like "real life." We as scientists should always remember concerns about ecological validity- will this really work out in the big messy world?

Here's a creepy example; the myth around the Black Widow spider is that the female almost certainly eats the male after mating. This myth is so pervasive that the namesake is now used to describe the femme fatale archetype in cinema and literature or murderous wives. The catch is while this is often seen in captive populations, it's almost never seen happening out in nature. Now many species of animals do engage in sexual cannibalism, with Black Widows joining in once in a while. But it's not a behavior seen commonly out in the "real world." But it's also important not to discount research because it looks artificial. Keeping with our creepy example, we know from field observations and population-level healthcare reports that Black Widows biting humans is exceedingly rare. They are timid and shy animals when out in the world.

The current standard for ensuring causal relationships is by manipulating the variable you think has an effect on the other. I'll be the first to admit that these terms were the least salient or sticky that I think early philosophers of science could have come up with. With that, these two terms are critically important to science: independent and dependent variables. Now there is original logic behind the terminology but it's created much consternation amongst science teachers and scientists ever since. An independent variable is what you think will have an effect on the dependent variable. So if we're talking in the context of cause and effect, the independent variable is the cause and the dependent variable is the effect. That's the most simplistic way of looking at it but it's important to know that sometimes there are

many independent variables playing into one or many dependent variables. And the independent variables more often than not only have some effect on the dependent variables but not all of it.

As you can see, the world is a very complex place and while science is always seeking to find causal connections between things, rarely is there a single cause to a single effect. So scientists must try to sort through this complexity. One of the most common ways we do that is to try and control for what we call confounding variables. These are variables that are lurking in the shadows, hiding from the scientist which give the illusion that the independent variable is having a stronger effect or any effect at all on the dependent variable.

This can become more complicated in that the confounding variable could actually be a hidden third variable affecting both what you hypothesized was the cause and the effect. Why are you wearing what you are right now, this very instant? Surely you'll say things such as, you like it or it's comfortable. But why do you like it? Why is it comfortable? Fashion trends this year, your economic status, the subcultures you identify with, and whether anyone ever complimented you all affect how much you like it. Comfort is dictated by the weather outside and where you happen to be. Home in bed versus a coffee shop affects your experience of what would be comfortable right now. The outcome of what you are wearing right now is also affected by seemingly unrelated variables, like how busy you were this week- whether you had time to do laundry or not. We as scientists are looking for cause and effect relationships, these are rarely simple with one variable having a 100% direct effect on another, instead, we have multiple causation. Each independent variable above has some effect on the dependent variable, and many affect one another. The subcultures you identify with are affected by the random socio-economic status you were born into, making both interact to give you the outcome of what you are wearing right now.

No study can measure and map all of these at once, but instead, they will select a handful to test for relationships while trying to control for other hidden variables they may not think to account for. Each discipline in science has their own norms around how to control for and account for them. In your journey you should be able to think about how the scientists address (or don't address) these confounding and interacting variables in their research, knowing that no single study can address all of them, giving us another reason to rely on a consensus of studies that fit together like a jigsaw.

Critical in measuring effects and relationships with variables is size. How big of an effect are we talking about here? And does that effect really matter in the real world? Alcohol makes you drunk. That's a cause-and-effect relationship. A whiskey that's 45% alcohol makes you drunker than a 5% beer. How much you drink of each matters greatly. So this is why it's important to understand effect sizes; even if there is an effect what matters is the size of an effect Is it a small medium or large effect on the dependent variable? And even if it is small that could still mean it's important it could still be very useful information but it's important to understand how much of an effect there is, and how that plays out in the world. Small effects can still be important. If a new cancer treatment can increase remission by 1% that can still be thousands of lives saved.

While no measure is going to give you the entire ground truth, it does not mean that it's outright wrong. It's closer to the truth and less wrong than not having it at all. We must choose them based on logistical, financial, and ethical concerns. That being said, not all measures and methods are equal. So the scientist must be aware of the threats to their methods and measures validity. There are numerous subtypes of validity but for your journey here, just think about whether or not the researcher is measuring what they think they are measuring. A psychologist studying memory has to make sure they are not accidentally measuring attention. A biologist studying animal perception must be able to detect the sounds another animal makes, even if it's undetectable to the human ear.

Imagine you just took a pregnancy test and it says you are pregnant! Do you immediately run to the phone to call family, and post the announcement on social media for all to see? Probably not until you take another test, or visit your doctor to get a more advanced measure of your status. This is reliability. With nothing changing, do you get similar results every time? Since false positives could happen in your pregnancy test, you check the reliability to see if it's closeto the ground truth. Scientists must also test the reliability of their measures.

As we've learned, no experiment or study is perfect and we are merely taking samples of what we are studying and hoping to generalize it to the larger population- whether we're talking about humans, rocks, or stars in the sky. And sometimes we don't get the right answer. Oftentimes scientists like to refer to them as Type 1 and Type 2 errors but that's not a very salient way of explaining it. A Type 1 error is simply a false positive: it looks like you have an effect but it turns out that that effect isn't actually the way it works out in the world (you aren't actually pregnant.) A Type 2 error is a false negative; there is a connection between the variables you are studying but you do not see it in your results. Small sample sizes are at higher risk of false positives and false negatives. One pregnancy test probably shouldn't be trusted. You need more data points to ensure if you are pregnant or not.

The origins of scientific knowledge and of our scientific methodology sometimes come from surprising places and probability is included in that. Studying probability is simply studying the likelihood that some outcome is going to occur. What are the odds that you're going to win a card game or some other game of chance? So from games like poker, we got our early beginnings in statistics in the late 1800s and early 1900s.

I promised no math on this journey so bear with me. I won't use any numbers but it is important to understand the role of statistics in science. There are essentially two distinctions but in the types of statistics you'll see the first is your descriptive statistics. These are your averages and the rates of change of some variable or a measure of some aspect of a group. How old are they? Inferential statistics on the other hand are where you use statistical methodology to make predictions about the outcomes of the relationship between variables; you are predicting a relationship.

A major aspect of testing inferential statistics is to compare the means of multiple groups. If I want to ask, "Are men taller than women?" In doing this I can gather up a group of people, separate them according to a sex binary then create an average of those groups. We probably

would say that men are taller than women but you know that there are women that are taller than men in the world and this is because the average only is working at a population level, not looking at the individual data points. Can you say this person is this tall therefore they are this sex? No, you simply cannot. Another example of this is the unfortunate history of eugenics. In many sciences and even in the early creation of statistics ideas were floating around that intelligence varied across different socially constructed racial categories. Now there are numerous examples of why that question is problematic to begin with, but in short, we know now there is no connection between individual's constructed race or ethnic background and their intelligence.

When we talk about bias here, it is not how it's often used in popular culture. In popular culture, people use it as a way to claim someone who has a different opinion than them is wrong. That is not bias in our context. Bias in science occurs when some way that the research was done systemically skews the results towards one direction, potentially skewing it away from the truth. It's important to note it is not necessarily intentional. If intentional, it steps into the unethical trickster territory of data fabrication. Scientists should take what efforts possible to minimize bias to avoid threatening the validity of their research. There are many different types of bias that can sneak in but let's discover the major ones here.

A sample in research is just like a food sample at your local grocery. One sample bite is presumably representative of a box you grab off the shelf. But there is uncertainty. How the sample was selected is a common risk for what we call Selection Bias. Ideally, you want your sample to look like the population in question. If the sample is different (say in age) that can limit or bias your results. Children might like ice cream more in general than adults, so you'll get different results depending on the average age of your sample.

Too homogeneous demographics (meaning your sample was too similar) might introduce less generalizable results. For example, surveying only college fraternity brothers about their favorite beverage probably doesn't represent the preferences of most of the country. With that said, sometimes the researcher wants a homogeneous sample since they are isolating specific variables and don't want to accidentally introduce those noisy confounders. Animal and in vitro (think petri dish or test tube) studies are critically important for exploratory and basic research. But their results are always a far way from application to the real world.

This can be because the people, animals, rocks, and planets are somehow different than the general population. So that covers issues of what goes in. Survivorship bias is when your sample going out of the study might skew your outcome. Attrition happens in research. People drop out or animals disappear for any number of reasons. But if they are dropping out for the same reason, that could skew your results.

Case Studies are deep looks into one person or case. They can be good starting points for research and academic discourse but are never generalizable to the whole population since they are only one sample and the researcher can not tease out correlation or causality. Testimonials about health, wellness, or medicine as you might see on bad daytime talk shows do not meet the standards of science and are not the same as case studies.

Observer bias is when someone doing the research inadvertently skews the outcome. In much of science, there are judgment calls made in measurement. So the observer could unintentionally skew results, especially if they know the hypothesis, since they may unintentionally drift towards the hoped-for answer. We can address this by blinding the researchers who do the measurement and analysis from the hypothesis and groups. We can also have multiple people make the same measurements to ensure their numbers overlap sufficiently in what we call inter-rater reliability.

Confirmation Bias is so ingrained that even other animals do it. This is the trickster you will come across the most. We default to looking for confirming information and ignore or forget disconfirming information. In complex issues, especially socially or politically charged ones, it's easy to cherry-pick the evidence that supports our previously held beliefs. We all do it, so watch out for others and watch out for yourself. In science, we seek to show all data and all results, regardless of whether it supports the hypothesis.

We really are all good skeptics, but we don't apply this same level of skepticism to everything. Because of confirmation bias, we are more critical of evidence that goes against our worldviews, and more naively accepting of evidence that supports it, something also called motivated skepticism. This is the same reason first impressions matter so much in your social and work life. Once someone has a model construct of who you are, it's tough to change it.

There is a saying, "Close only counts in horseshoes and hand grenades." This is not true. Close also counts in science. When a scientist comes to an answer, remember all data collected is only a (hopefully valid and reliable) approximation of the ground truth. This then begs the question- how close to the truth is it? How sure are you of your results? There are ways to estimate this with statistics such as estimating confidence intervals and margins of error. This is not a weakness but a strength- the humility to say that the data is closer to the truth but not impervious to better, more advanced research that may come along and be less wrong is a necessary skill of the scientist. Acknowledging the range of possibility that you may be wrong is important.

Another trickster can sneak in here, so it's important to mention. There are rules of thumb for certain thresholds the researcher should hit to ensure a certain level of confidence in their results. One often used metric are p values, which are estimates on the likelihood that the results you got are due to chance, a fluke. There are ways researchers can massage their data to hit the desired threshold they want in what's called P-Hacking. This is where researchers intentionally or not try to over-massage or torture their data into getting them over the hump to the commonly held rule of thumb of reaching a statistical significance threshold for having a p-value of less than .05. What does that mean? Essentially it means there is a less than 5% chance the results found are due to chance. By doing trickery like increasing or decreasing sample size or tweaking subgroups one might get over that threshold.

A sibling trickster goes by the name of HARKing which is Hypothesizing After Results are Known. In hypothesis testing, you should predict your hypothesis and hold on to it through the study and if the end result can't support it, you start over. HARKing is changing your

hypothesis to fit what data you got after the fact. Why is this considered bad? Because it's all too easy to explain away things via mental gymnastics after the fact- just think about your last failed romantic relationship. But there is no falsifiability in that. It was totally their fault, every time. Another reason is that especially with large data sets, it's all too easy to find illusory correlations and patterns that are not actually there.

Now, there are sophisticated arguments by some to reconsider this approach, that by gathering large datasets, we should be able to let the patterns emerge without prior hypotheses. But even with these newer techniques, it's important that the scientist is still grounded in theory and can connect the emerging patterns to previous research and theory. So like in all aspects of science, considering the entire context is important. One number will never tell us the whole story.

Hypothesis testing ,while the most common type of quantitative method that many sciences use, is not the only type of inferential statistics that is out there. Starting about the same time as the early inferential statistics founders such as Fisher and Pearson were people arguing for what we now call Bayesian tests. Now as promised we are not going to go into the complexities of statistics and methods here but in short Bayesian tests seek to find a more ecologically valid way of testing ideas against reality.

These tricksters lead us away from the intended goal of science; finding the truth. People are led away because of the bias toward publishing only statistically significant results. The rationale is that a failed hypothesis may be true, but may also be due to other issues like poor research methods. We will discover some of those issues in more depth next.

CHAPTER FIVE

HELP ON THE WAY

While it's easy to conjure up the image of a lone mad scientist working away late into the night, the entire publication process is far more collaborative. From the initial idea to publication and beyond, many more people than the authors are involved in the process. Ideas and new hypotheses are generated by scientists attending conferences and talking to presenters, reading the latest peer-reviewed research, and chatting with friends and colleagues in the halls and coffee shops of college campuses. When a researcher has a new hypothesis, before any data can be collected, there are two things that must be done: funding and ethical oversight.

Proposals for funding are typically reviewed by a committee of academics based on merit and need. In the United States of America, the vast majority of research funding comes from the federal government through organizations such as the National Science Foundation and the National Institutes of Health. There is not enough money to go around, so it is very competitive. Additional funding can come from universities, private foundations, and private industry.

Depending on the type of research, scientists may need to submit a research proposal to an ethical review board. If they are working with human participants, they go through an IRB (Institutional Review Board), and if they are working with non-human animals, an IACUC (Institutional Animal Care and Use Committee.) Researchers may also be under strict legal oversight from federal agencies such as the Food and Drug Administration, Drug Enforcement Agency, or Environmental Protection Agency depending on the research question. Once the money is in and the ethical oversight has started, data collection can begin. From the endpoint, it may look like it was smooth sailing but far from it. Research is messy. Equipment breaks, disasters strike.

Most research never sees final publication. This can be for two reasons. First, the world does not work in the way the scientist predicted in the hypothesis. That's great, because it's still good info to know, as science is about testing our views of the world against it. The second issue is that maybe the hypothesis could be supported, but not in the way it was tested giving them a false negative. Equipment could have not been sensitive enough, or they didn't have enough data to detect it. Or bad luck just struck. This is why research where the results are null doesn't usually get published.

While publication is the ultimate goal, scientists also get their research out in other ways. Academic conferences are a big part of the research endeavor. People share their ongoing and newly completed research through presentations, poster sessions, panels, and over drinks in hotel bars.

Another way researchers might get their info out there is through what's called a "white paper." Popular with government agencies, think tanks, and research non-profits they will simply self-publish their report. While the info can be quality, it's important to remember that it has not gone through independent peer review and there is a higher risk of a bias present.

It's important to make sure that the claims being made in academia are of a high enough quality. So the gold standard is to publish in a legitimate peer-reviewed journal. Now, there are issues with this process that we'll get to, but it's an important step in getting good science out into the world. And by "high enough quality" we mean the methods used and claims made by the results are considered rigorous enough to become part of the discussion for that scientific discipline.

There are thousands of peer-reviewed academic journals. Often they are in partnership with specific academic societies, and all except some of the biggest ones focus on specific disciplines. So the scientist submits research to an appropriate journal. Then waits…and waits…and waits some more.

It takes time because the journal editor then sends the manuscript to 3-5 peers who are also experts in the field. They usually try to keep it anonymous, but often since these wise ones are all experts in specific content, they likely have crossed paths and are generally familiar with one another's work. The reviewers send back their comments and the editor makes a decision. There is typically one of three outcomes: Accepted for publication, revise and resubmit, or an outright rejection. That is the long journey from first idea to publication. Each published article creates more ideas and questions to be tested. It's a long slow process, but it aims to create the best scientific knowledge possible.

The strength of the process is there are checks and balances to keep most of the riff-raff out. As science is collaborative, the ideal is that the quality of the science is that much better in the end. But it's not without its weaknesses. Science is still a human endeavor. We strive to be objective, but that's not always completely possible. Being experts themselves, peer reviewers might be overly skeptical of research that goes against their preferred theories. While peer review might catch some major problems like fabricated data and plagiarism, trickster stuff still sneaks through at times. When necessary, journals will retract papers or put notes explaining an issue that was discovered, but sometimes it's too late and the disinformation and misinformation spread into public awareness. An example of this was the poorly done and outright fabricated research of Andrew Wakefield that claimed a causal connection between vaccines and autism. While the medical and scientific community self-corrected and retracted the paper in question and ultimately barred Andrew Wakefield from practicing medicine, the myth he promoted still pervades popular culture, causing unnecessary suffering and death.

One of the most talked about issues right now is what's called the "File Drawer" problem. Journals have limited space to publish research, so are biased toward publishing research with positive results, where the hypothesis was supported. But, as mentioned before, most hypotheses are not supported. So some of the results getting published may just be lucky. No matter how good the methods were, and honest and thoughtful the researchers were, they could have found a false positive. There is a movement to create databases of all those "File Drawer" reports so that researchers can dig into them to look for trends and to learn more about what to not do.

This relates to another topic, the so-called "Replication Crisis." Part of the scientific process is to have replication of results, to ensure the results weren't faulty. So when a paper is published, other researchers will try to replicate the results. Results of a number of prominent studies have not been replicated. Why is a complex issue, but it's important to know that it is science working as it's designed. We should be going back and seeing if early research holds up to the methods and technologies we have now. So it's very important to remember that one study, no matter how well done, is not the be-all-end-all. It is only one piece of the jigsaw puzzle.

As we saw, research can be slow and messy. Sometimes researchers let their hypotheses "drift" until they get a positive hit. They may start fishing for something in the data they got that's redeemable. Generally, this is considered unethical and may be feeding into the replication crisis. So, it's becoming more common for researchers to publicly pre-register their hypotheses so they can't drift unethically.

Peer review is also slow, and when researchers want the information disseminanted quickly and to as many people as possible, they may post preprints for everyone to read, or articles they expect to pass peer review. This is good for fast-moving situations like we saw with the COVID-19 pandemic, but remember, preprints have not been peer-reviewed yet. They are still rough drafts.

Act II

CHAPTER SIX
MAKING DIFFICULT CHOICES

Science constantly deals with gray areas, uncertainties, nuance, and complexities. This does not only happen in the data but in how we come to get that data. For example, much of humanity's greatest scientific achievements came to be through the military-industrial complex: space travel, nuclear energy, and even our understanding of the brain.

We also have some pretty atrocious examples of the way that people of color were mistreated in medical research. The two most famous examples are the Tuskegee syphilis study and Henrietta Lacks' cervical cancer cells. Henrietta Lacks was a poor black woman who had a very aggressive form of cervical cancer. Seeking treatment at the Johns Hopkins University hospital, her cells were cultured, and due to their aggressive nature, they could replicate over and over and over again. So lines of these self-replicating cells are referred to as HeLa cells and are still used today to test all sorts of medicine and treatments. She died from the cancer shortly after the culture. Her family still lived and struggled outside of Baltimore, Maryland in poverty for decades while many doctors and scientists made lucrative careers around studying her cells. However, she never gave specific approval to use her cells for research. It was only implied and coerced. Recently her survivors did get a payout from Johns Hopkins University but while she's been able to help so many people since, she was still wronged.

The Tuskegee syphilis study was where poor black men were getting free medical care to participate in the study of the long-term effects of syphilis before we had a cure. They were participating in the study where the severity of the disease was tracked over decades. During the study, a cure was found; simple penicillin (a very common antibiotic) but they kept the study going without informing the men that there was a known cure for syphilis so researchers could still see what happened, even though that scientific question was no longer important. When syphilis goes untreated it attacks the central nervous system causing dementia and ultimately death which means scientists passively allowed participants who were nobly trying to help humanity suffer and die.

There are numerous examples where scientists did what we would consider atrocious by today's standards in medicine. We also see this in the social and behavioral sciences. When dealing with ethical questions one of the big things that science must do is balance the potential perceived benefits from the potential perceived harms. Then they must create protections to minimize or prevent those harms. Harms may not only be physical but also psychological and social.

For example, an anthropologist or sociologist studying a group of people needs to protect that group of people from negative fallout due to what they are reporting. An example of this risk would be if they are studying recreational drug users or sex workers who are engaging in things that might be breaking laws or are socially stigmatized. Along with the legal risks, if someone is found out to be a recreational drug user or sex worker, that could cause harm from their community and family. But there is value in having a scientific understanding of that part of humanity, so studying it is important.

There are also psychological risks; there have been a number of psychological studies done where we have as scientists caused mental anguish in the individuals participating. One of the most talked about is the infamous Stanford prison study headed by Philip Zimbardo where he had young men engage in a kind of role-playing game of prisoner and guard to see how social interactions manifested themselves under the context of authority. How did authority affect the individual's behavior? From a research methods standpoint, that study was poorly constructed in a number of ways. But of more note are the ethical problems. There was no independent ethical oversight. There were no safeguards for the physical or psychological safety of participants. The researchers crossed boundaries and coerced behaviors out of participants. Participants were coerced to stay. Parents were lied to. This study which was supposed to last two weeks was cut off by day six when an independent observer saw what was going on.

While oftentimes ethics are talked about in a historical context, the reality is newer ethical dilemmas unfold as science progresses and technology advances. In the new era of Big Data with cameras, social media, and web browsers tracking your every behavior there is a trove of information we can learn about you. But did you give consent for that to happen? One of the biggest problems in many early studies in medicine and social sciences was the participants lacked consent altogether; they did not know they were in a study or they weren't allowed to say no. So now you must give informed consent to participate in high-quality research that will potentially be published in peer-reviewed journals. To be informed you also must have an understanding of what are the potential harms in participating and you are allowed to stop at any time. Plus you must always be able to say you want to quit the study without coercion. It must also be explained to you in language that you fully understand. Looking at the terms and conditions of any app you downloaded on your phone. Do you understand any of that? Do you know exactly what your rights are and what their obligations to hold your online behavior private are? Even bigger questions arise with the output of that data being collected. Is it valid? What biases are embedded in it? How is it being used?

Because of the major mistakes scientists have made in the past, to do good research with humans that you hope to get published in peer-reviewed journals must go through what we call an IRB: an Institutional Review Board. This is an independent group of experts made up of doctors, psychologists, lawyers, ethicists, and fellow researchers who decide if your study meets the ethical criteria that we currently hold in society. These are guidelines as there are no hard and fast rules outside of certain laws. So the committee decides on each study on a case-by-case basis to ensure that you are minimizing any potential or known harm to the participants, that those participants offer fully informed consent, that they are free to leave at any time without coercion, and that they know what risks and harms could possibly occur. Their confidentiality

is protected to ensure that they don't experience any social fallout and if there are potential psychological harms, that there are resources available to talk to a mental health professional. These questions are all context-based so in one social context there might be a different answer than another. As mentioned above, the questions are never fully answered as we journey further in this new wide world of technology where business ethics do not meet the same level of protection that we hold in academia. Whether academia should be interacting with those businesses to try to do research is a hotly contested question; should a psychologist get the treasure trove of behavioral data that a web browser might hold, and if so- when and how?

The vast majority of what we know about human anatomy and physiology comes from studying animals other than humans. This has been the case since before modern science. For example, Rene Descartes saw how there were similarities between the machinery of the time and the way an animal's muscles and tendons might move. So he did dissections and even vivisections (which means live dissections) on cats and dogs and sheep and so forth. Now from an unfortunate ethical standpoint, he did not believe that animals had souls which he felt was necessary to have pain so he would do these live vivisections without any painkillers on these suffering animals.

Today we have safeguards in place to try to minimize the harm to an animal if we are going to do research on them. But we do engage in very invasive and harmful actions to many different species of animals. The vast majority of what we know about the neuroscience of human memory comes from studying things like sea slugs and how their neurons and neurotransmitters work for them to learn. But oftentimes the animals are directly harmed or the study design might even require euthanasia which is the taking away of their life at the end to minimize suffering. This is one of the more dark night of the soul moments in your journey here. For any modern prescribed medicine, it must go through safety testing with humans and usually before that with animals like rabbits or mice. To fully understand the human brain we also look to many of our closer relatives and do research on the brains of other primates. This allows us to potentially understand the cause and potential treatments of Parkinson's or Alzheimer's which are neurodegenerative disorders that greatly affect and ultimately kill many humans. We are learning how to create neuroprosthetics: replacement body parts that amputees can control with their minds just as they could with their missing limb. To do this requires doing very invasive surgeries on these primates, and typically euthanasia.

We don't only study other animals for human benefit. We also study animals for the sake of the animals themselves, such as in wildlife conservation. We study the migration, feeding behaviors, and mating systems of animals to understand what those animals need in order to thrive as a species. We also have to worry about the intersection between other animals and humans and what happens when we get in close contact. We can be negatively affecting their behavior or we could be creating a higher risk of zoonotic diseases, which means they transfer across species.

So if you want to do good solid peer-reviewed research that you hope to publish you must go through an IACUC which is an Institutional Animal Care And Use Committee. Like an IRB, they are an independent group that conducts ethical oversight of your study that you must get approval for in advance. They are gatekeepers in a scientist's quest to ensure the safety of the people participating in the study and the animals being studied. Are these animals being fed well? Do they have the things that they need to have a somewhat enriched life? For example, if they're a social animal do they get to interact with other animals? If they are burrowing animals do they have a place to hide? Do they have adequate warmth, water, and food? If there are risks or known harms to the animals how are those harms being minimized? What is the minimum number that you need for your study to be successful? Is your study even worthwhile? There must be a reason why this study needs to occur and these animals need to either experience harm or be at risk of harm. They also look to see if the study is well constructed because if it's a poorly constructed study then the data is garbage and the whole study should have never been done to begin with. A bad study that wastes time and resources or promotes bad data is unethical, even if there is no physical or psychological harm to humans or other animals.

Ethics will never give us hard and fast answers. Ethicsal guidelines are wise gatekeepers to use as a map to help us find the kindest way to ask the question. But they will never give you specific directions. People have very well-thought-out reasons as to where they land on using animals for research. As we study other animals we're finding more examples where they are probably more aware of their circumstances than we initially realized. So the lines that we draw change as our scientific understanding of those animals changes too.

Humans and other animals are by no means the only stakeholders when it comes to the science that is conducted on this pale blue dot we call Earth. Let alone space for that matter. For too long scientists did not take into account what the potential harms and risks of scientific discovery could be on the environment. While we certainly have to be mindful of the effects we have on life we also have to be mindful of how this is affecting our systems like water, weather, and even the rocks we stand on. This is bound up with human and animal concerns in the realms of environmental justice. We must consider what are we doing to the planet and the ecosystems that we rely on. Historically this was probably the least thought over aspect of ethics but we are now finally seeing in our journey that scientists are starting to think about what new technology may do to the planet. Ethics, like science, is a process that never ends and by having these questions and concerns we can also start to see and be inspired by how science itself can address those concerns.

CHAPTER SEVEN
WHO GETS WHAT, WHEN, HOW.

Science is self-correcting, at least that's the goal. But there have been many times throughout the history of science where we've done very problematic things or we put forward very problematic theories. An example of this is the unfortunate history of eugenics in science. Eugenics is the idea that we should select for specific genes in humans. This can be done by either using what was called positive eugenics, which is encouraging only people arbitrarily deemed genetically superior (in appearance, intelligence, etc.) to have children. Or by what was called negative eugenics where people incorrectly deemed genetically inferior were either prevented from having children through forced sterilization, or worse- murder and genocide. This incorrect understanding of genetics was applied in the legal and political world not only in places like Nazi Germany and the Holocaust, but in the United States when the Supreme Court approved the forced sterilization of women deemed intellectually inferior, by either developmental disability or social variables unrelated to their genetics; classism, racism, and educational elitism. It was misguided even though major founders of science were proponents of it. For example, Pearson and Fisher were both important founders of modern statistics and they were both Eugenicists. Charles Darwin even had problematic beliefs about race and evolution documented in what was otherwise a critically important book in our understanding of evolution, On the Origin of Species. These misunderstandings of human genetics still linger in some circles today. It's important that we talk about these errors and show that we have moved beyond them so we do not make the same mistakes again.

Millions of people died due to the dictator Joseph Stalin's regime in Russia, then the U.S.S.R., because he refused to allow good science to be used to feed his people. Instead, he imposed bad ideas by his scientific advisor Trofim Lysenko who refused to believe the then already well-established science of Mendelian genetics could be used to help raise better crops. Why? Because genetics, to them, seemed to go against the ideology they held so dear, they suppressed it through violence and torture. They failed to accept disconfirming information that went against their previously held worldview, which is our old trickster, confirmation bias. They took it to an extreme with the torture and execution of scientists just trying to grow crops to feed the country they tried to love.

Stalin's horrendous regime refusing to believe in science and suppressing good application of modern genetics is by no means the only example of political regimes and politicians pushing against basic knowledge. We saw this constantly throughout the COVID-19 pandemic across many countries including the United States. In various state leaderships, such as in Florida, scientists were silenced and research was manipulated to show a result that was not really there in order to promote a political agenda.

You discovered in the journey through ethics how science does not exist in a vacuum and there are important moral, social, and cultural considerations when deciding what science should be done and how it should be done. That helps make science the tool that will help humanity and the Earth in the long run, even if it is difficult and contentious at times. But when people in a position of power use that power to not only argue about the nuances and complexities of science but directly falsify or suppress scientific research, that goes against everything that science stands for about discovering the truth no matter how uncomfortable that truth may be.

Anti-science has also been fighting in our education systems since the beginning of those formal systems. Evolution by natural selection has been contested by people who believe that it does not fit within their fundamentalist worldview of creationism. Still today people are trying to minimize what evolution by natural selection is and attempting to suppress it. On the social science front, we also have people trying to stop the public from understanding what we know about structural issues like racism and sexism. This ugly little trickster of confirmation bias is being taken to extremes. The journey of the hero is a long and arduous one and to return changed takes a lot of work in not just learning facts, but also looking inward and growing a level of scientific humility that we humans do not naturally possess. This is a journey that exists forever and many expert scientists certainly could use some more humility. But there is no replacement for the long training that experts such as doctors and researchers go through to understand their field, and while we know that science is never perfect it is as close as we can be. Fighting this pulls us back away from this journey and blocks humanity from moving forward.

In two examples here you've seen a poor understanding of a major discipline in science: genetics. In one example, there was a refusal to understand how genetic traits truly are inherited and it led to torture, murder, and mass famine. In the other, you see scientists themselves overemphasizing the role of genetics and heritability and it led to medical torture and genocide. Harold Lasswell said political science is the study of who gets what, when, how. So is genetics.

A final point brings us to J.B.S. Haldane, a critical pioneer in the great synthesis of modern biology, bridging our understanding of the emerging field of genetics with Darwin and Wallace's evolution by natural selection. A gregarious and prolific writer, he was a Marxist and saw the emerging understanding of biology as evidence for his political and economic views. While he was prominent, what instead became mainstream was that natural selection was evidence for Capitalism, "survival of the fittest," as they say. The empiricist philosopher David Hume said we shouldn't derive an ought from an is, meaning here that science can only describe what the world is and that it is up to politics and ethics to describe what the world ought to be. Our journey here is not to decide what political and economic systems humans should have, but this point is critical. While scientific discovery will influence our understanding of ourselves and force us to apply it to questions like politics, our pre-existing worldviews will shape our interpretation of those discoveries. Science and politics cannot be disentwined; they are forever bound together.

CHAPTER EIGHT

THE WALLS OF THE IVORY TOWER

Peer-reviewed research is one of the cornerstones of good science. Essentially, if you want to publish the research you did, it has to get past a group of your expert peers. Without it, you get your uncle sharing weird blogs about conspiracies. There are some issues with the peer review process but the biggest is that society typically has to pay to get access to published peer-reviewed research.

A lot of peer-reviewed research is dense, super technical, and not written well. Thankfully, there is plenty of good science journalism, books, and documentaries that talk about the research in ways you want to learn about it. Just be mindful that it doesn't always get it right. Use the tools you learned earlier when reading these.

Most of the peer-reviewed research is locked behind massive paywalls in an absurd system that serves no one well. Scientists do research, mostly for low pay through taxpayer money, submit it to peer-reviewed journals without getting paid anything more, and then most of these private journals lock those research papers away and require exorbitant fees for researchers and taxpayers to get access to what they paid for and created.

It does cost money to maintain websites and pay copy editors but they have exorbitant profits for very little overhead costs. All with free labor from scientists and bankrolled by the taxpayer. But you can get to some of it. Here are some ways, from most to least legal.

If you happen to already be associated with a college or research institution, they are already paying many of these subscription fees. So do research through those databases. Public libraries also have access to many of the same ones that universities and colleges do. Ask your friendly local librarian how to get access to them. Google Scholar (scholar.google.com) will search for peer review articles. This is different from the regular Google search. If you have immediate free access to an article there will be a link on the side of the search hit. These free ones come from random webpages or Open Access journals which are free to all. Journals with paywalls will typically ask you for $35 or more per single article! Ask the authors or a scientist friend directly. It is perfectly legal for people to hand off individual copies for educational and scholarly purposes. Scientists are busy, and contact info changes, but it is worth trying.

A new movement has come to put research manuscripts that have not been published out for others to see. This is a cool movement for two reasons. One, since not all research gets published, we can get a bigger understanding of the research as a whole and avoid the File Drawer Problem where unpublished work languishes in a "file drawer" somewhere. And two; peer review takes a while. So in cases like the COVID pandemic, you can get important information out quickly. The downside is they have not been vetted yet. Some of the early COVID papers that got a lot of press exposure were pre-prints that researchers had to walk back on. Large examples of these databases are arXiv and the Open Science Foundation.

OK, we are now going into a darker realm where the hero sometimes has to make tough decisions that may be disapproved of by the leaders of their world. Groups and forums across social media platforms do exist for people to share articles with one another. While it is legal for people to share articles, these exist in a legal gray area due to the size of this ability to share.

Sci-Hub is a large database where you can download a massive trove of research articles from around the globe. It's a database considered illegal in most countries so the host site keeps getting chased around the world. It's Napster for scientists to download articles. For you Gen Zers, Napster was where you could download all the music (and ultimately computer viruses) you wanted for free back in the day in a massive peer-to-peer file-sharing platform. Sci-Hub's search database is more robust and easier to use than most legal research databases.

Information wants to be free and most scientific research is fully funded by the taxpayers and college students in that country. The lack of access to science has direct consequences for a society where misinformation and disinformation fly freely and scientific literacy is being undermined in our education systems. Open access movements (like this book) are trying to get science shared more equability and democratically.

CHAPTER NINE
THE BEAUTY IN IMPERFECTION

There is no final destination in this journey of science. It is a forever-evolving process of discovery. As the various sciences expand and advance, we will continually look back and see where we faltered. This is not an affront to the beauty of science but instead shows us how science is working well. In its ideal, it self-corrects as it matures.

With that said, science is still a human endeavor. There is no grand design to discover or pre-destined endpoint. We design as we go which means we do run the risk of moving further from, not closer to the truth. As this journey unfolds, we will encounter more trials and tribulations with ethics, identity, society, and politics. If we do not force ourselves to atone with the past violence, oppression, and environmental harm science contributed to, we will ultimately fail at this journey.

Our understanding of the world will never be perfect. As beings trapped in this exact point of space and time, we can never get out of our own experiences. Our understanding of the world is forever imperfect, no matter how close we get to the truth. But this means there is always an opportunity for more discovery.

Act III

CHAPTER TEN
A HERO (SANDWICH) SIDE QUEST.

This side quest will teach you how to read a peer-reviewed article. While formats will vary, any primary research article will have some version of these sections. By knowing what to look for you can come to understand much of an article's content even if you are not a specialist in that field. So let's go on a mini hero (sandwich) journey through each section. Think about the article like a hero sandwich (also called a sub or hoagie, but I'm trying to force this metaphor.) On each end is the bread that creates structure and support while the middle has the details which are all the specific trimmings for that sandwich.

THE TITLE PAGE

Don't ignore the title page! There is lots of good info there. Along with telling you the title and the authors of the paper, it will also tell you what journal it came from and the institutional affiliations of the authors. There will typically be a "corresponding author" noted. This is the person whom you should reach out to if you have questions, comments, or want to get a copy of the article if you don't have access to already.

The order of author names is important. The norms are that the one who did the most work is first and, if a long string of names, the last author is often the "Principal Investigator (PI)" or the lab supervisor. They are often the top dog of the research lab.

Sometimes there will be a "Conflict of Interest (COI)" statement where authors disclose if any affiliations or funding could be construed as a potential source of bias. For example, a nutrition researcher may have an appointment on the board of a food corporation, or they may have received funding from a private company. It's important to note that just because a COI may be declared, it does not immediately mean the research is bad. It is worth noting that they may only be presenting data that supports that company's goals.

ABSTRACT

The Abstract is the "Movie Trailer" of the article. Just like a description of the sandwich on a menu, the Abstract only tells you whether or not you want to keep reading and order that sandwich. You don't watch a movie trailer for Lord of The Rings and walk away like you've seen all 9+ hours of the epic film series. The downside to this is that peer-reviewed journals are way more expensive than a movie ticket, even with the overpriced popcorn and soda included.

Press Releases of studies should be treated the same as Abstracts. They are typically pulled from Abstracts and may include additional quotes from authors. Remember, you can always reach out to the corresponding author or other experts in the field with questions. But they are busy little wizards so you may not get a response.

INTRODUCTION

This is the top bread slice of our hero sandwich. The authors will discuss context and the big picture, and review the current state of the research. They will also argue the "So What?" question. Why does this matter, and why does this need to be studied? This will typically end with them stating their hypothesis that was tested.

METHODS

Now we get into the err… meat of the article. The Methods are your sandwich fillings. How did they test their hypothesis? It should be detailed enough that other researchers could take their recipe and be able to replicate it, just like in a cookbook. You should be given detailed operational definitions of their variables. What do they mean by "spicy" peppers? It's often overlooked but this is the most important part because how you ask a question affects the answer you get. Fine differences in temperature, texture, and flavors will greatly change your experience of that sandwich. Whether the deli worker washed their hands or not greatly influences the outcome of eating that sandwich.

By looking closely at the methods you may find risks for bias. Bias is any trend or deviation from the truth in data collection, data analysis, interpretation, and publication that might cause false conclusions. Bias can be intentional, or most likely, unintentional. In science, bias is not in the end result or the opinion of an individual, but when the means to achieve whatever that result was had been skewed.

The methods used should also be valid and reliable. There are many types of validity, but generally, are you measuring what variables you think you are? You ordered pastrami on your sandwich, but did you actually get pastrami? The way researchers measure variables should be reliable. Just like if you order the same sandwich every day, it should have the same ingredients and taste similar every time.

The sample is the participants or materials being studied. You'll see a description of the demographics of human participants: Average age, gender percentages, geographic location, race/ethnicity. Or if they used animals, cells in a petri dish, or rocks gathered from the field. It's also very important to avoid applying too strong of conclusions about humans from animal or cell studies. Much more work must be done to make any promising conclusions relevant to people.

RESULTS

This is the immediate outcome of the study. It is the deepest jargon and can be hard to understand if you are not in that specific field. There will be complex statistics and weird symbols that you can't be expected to know. That's OK. You can probably skip much of it. Or talk to an expert. But look at the figures and tables. The visual representation can be useful.

DISCUSSION

This is the bottom slice of the bread where they zoom back out to the general structure of the sandwich. What you didn't understand in the Results should be explained in more understandable language. They should explain what hypotheses were supported or not. They should also explain the limitations of their study. No study is perfect so they should be clear about what issues and limitations they foresaw. They will typically also talk about where the research should go from here. Every answer creates more questions in our journey. They should also go back to the "So What?" question. So what should researchers do next, and what should society do with this new information?

REFERENCES PAGE

This has various titles depending on the field but this is where they list all cited sources. This is a great place for finding more studies to read on the topic. But academic silos can occur. Ideally, it's not happening but different camps may be cherry-picking and only citing one silo of research. The pro-meatball theory might only cite studies that gave positive results for meatball subs. So don't just take their word for it… go look for more studies done by different researchers at different institutions. Or talk to other experts for their analysis of the work.

LITERATURE REVIEWS AND META-ANALYSES

Sometimes you can get a much bigger picture of a topic by reading literature reviews and meta-analyses. Since one study is never the whole story, a literature review is when an expert covers a large portion of the studies out there on a topic. This can help you as a reader gather a more complete understanding. Meta-analyses are a systematic way of looking at all the research. They use statistical techniques to get an average result of the studies. This can help control for those outlier studies that may not be that close to the truth.

NOW GO EAT MORE SANDWICHES!

Just like you'll probably eat more than one hero sandwich, you should read more research articles. One study does not give us the whole answer, only a piece of it. Replication is important so that we know we are getting reliable results. So go add more to your plate.

CHAPTER ELEVEN
COMMON KNOWLEDGE

Science in its ideal is democratic and public. Scientific discovery is intended to be applied to the benefit of the planet. It should be shared with all people, but we have already seen the barriers to that. It is often locked away in ivory towers, paywalled by publishers, or hidden away for only people participating in traditional higher education to access and understand. Even when available to the commons, it's jargon-laden so requiring hyper-specialized training to fully grasp.

But the commons want this information. Science is a human endeavor- for all humans. Our species holds an insatiable curiosity for understanding how the world around us works. Which brings us to science communication; how can the community access and understand the discoveries scientists are making?

With the vast amount of knowledge we have accumulated over the brief history of science, it is impossible to know and understand every specialization and discipline. So it is also the responsibility of the scientist to be able to share their discovery in a way that's useful to the world. But they are busy up in their towers and are rarely trained to have conversations about science in situations outside the ivory tower. This is where the science communicator comes in.

Popular science writing and science journalism are large fields. The community wants to learn about all these great discoveries. It is critical that the communicator make a concerted effort to draw in the public, and to represent that science as accessible and accurately as possible. More than just dumping facts into people, it must also be an engaging multi-directional conversation. Surprisingly, the scientific community in general was actually against engaging in public science communication until very recently. Carl Sagan was refused membership in the National Academy of Sciences because of his famous public engagement of science. While the sentiment has changed overall, most scientists are still not trained as effective storytellers and communicators. Science has a long way to go to catch up with other types of public engagement as we see in advertising and politics. This lag has direct consequences on the well-being of humanity and the planet. Global warming is caused by human activity- notably the use of combustible fossil fuels and deforestation. This is a well-accepted fact in science that much of the public still thinks is a unknown. Scientists are losing the battle because we do not have the weaponry, the skills and resources, that the merchants of doubt have to spread disinformation which is intentional falsehoods masquerading as facts.

Why are scientists so unwilling to share their work in more accessible ways? To be fair, much of it is due to their strict desire to present only the truth and to avoid spreading misinformation, which is the unintentional spreading of inaccurate information. Since we can't all have the hyperspecialized knowledge required to fully understand all the research presented details must be simplified and omitted which opens the door to errors in understanding, in the eyes of the scientist.

While those concerns are valid, if scientists can not learn to counter disinformation and misinformation in effective and engaging ways, then the final step in the journey, sharing discovery for the betterment of the world, fails. Conducting research to create effective science communication, along with inclusive movements like open access are key tools in spreading scienctific knowledge.

CHAPTER TWELVE
THE NEXT STEPS IN OUR JOURNEY

You, the hero, come home forever changed. With all sorts of new knowledge and understanding of the world previously unknown. But as you learned along the way, science is never over; the process will always continue. Which is nice because that means you have a never-ending supply of sequels. The science questions that are answered always open the doors for more questions. As we illuminate the room with Carl Sagan's candle in the dark, we see more but there's always a world hiding just outside our view. From mysteries to problems to be solved. So what is just beyond that dim edge of the new known world? We can't know for sure but there are certainly some things that are likely about to step out of our imagination and into our view. So let's finish this book by looking to see what cliffhangers we might leave here.

You like science. After all, you chose this adventure. Too often the adventures are only available to the privileged ones within the ivory tower of academicia. The wizards of the Ivory Tower were the only ones allowed to take those journeys. But this is changing with a number of movements including one that's often referred to as citizen science. Traditionally, the wizards would study and do great work and they would have apprentices below them who would carry out the experiments, right up the results, collect the data, and then share it with the other academic wizards. These practices exist within physical walls. Access to educational institutions varies greatly across political borders and class structures. And as with any social group certain norms, practices, and biases emerge.

What this left out was everybody else. Great tomes of information were shared amongst these scholars, ideally for the benefit of humanity, but most of humanity never had access to it. Nor were they able to participate in these adventures. With citizen science, a community is engaged to take the journey. A community becomes an active partner in the creation of the scientific project. Whether it's social, environmental, or even engineering, they become stakeholders and help shape their world through science. They also become apprentices where they collect data from their own community to share with the scientists. This levels the ivory towers to become more of an agora, a Greek word for the public common area where ideas were exchanged. There are a number of great outcomes besides just the leveling of the hierarchy. We create a more ethical and informed science. These wizards can seem pretty foolish banging around in a dark room trying to illuminate it with a dull candle when a citizen is standing there able to flip the light switch on. Hopefully, in your journey here you saw that no adventurer knows can know everything so they must gather information from everyone they come across along the journey. Because everyone comes to one another with knowledge and experience, it's up to the scientist to listen to those and take them to heart.

Information wants to be free. As you saw with issues surrounding publication and access to science, while science is supposed to be democratic and lift all of society up, most of society does not have access to it. One way to combat this is by using the cheaply available tools we have now to disseminate information. Symbolic language, both oral and written, pushed humanity into creating a robust culture across time and space. The printing press allowed books to leave the towers of the monasteries and universities and be spread cheaply across society creating widespread reading literacy and citizen engagement. From there we got modern computing and the internet where information can flow as freely as possible in a much cheaper way. So now we can have Open Access publications like this book here. Like ancient Greece, ancient Islam, and the Western Enlightenment, we are at a new milestone in science. We are creating ways of peer review that are more inclusive, democratic, and thorough. A free flow of information is here. This free flow of science will still be hindered by political, military, and corporate interests but the ideals of science go beyond those borders and there are numerous examples of scientists being able to engage outside of these silos. The internet forces this information out into the open for all to see.

It's a brave new world of technology. Every keystroke online, every location of your phone, and every movement of a mountain can now be tracked with advances in satellites and photography. We as scientists can now measure almost anything we wish most anywhere on the planet. This world of big data can give us insights never before seemed possible.

Yet we must be wise in how we use this data. What is noise, and what is truth? If all a scientist does is gather up data and pull what patterns they think they see then they are without guidance and likely to just find spurious relationships. What are the new ethical questions we must tackle? Even if the behavior of a person online is more valid than their self-report, did the participants really consent to that level of tracking? What happens when these large data algorithms are applied to society? We already know many of these magnify and perpetuate pre-existing stereotypes and biases humans hold- they do not prevent them.

Since the days of early machinery found in the ancient worlds of Islam, Europe, China, and the Americas the idea of artificial intelligence has always captivated the human imagination. Even in religious texts in the Western world, we see discussions in the Torah of Golem, a humanoid built from clay that can move and act as if he were living. The idea of creating an intelligent creature in the likes of us is been fodder for science fiction going back to Mary Shelley's Frankenstein. Renee Descartes saw how animals and humans were much like the automata of early machinery and hydraulics. With modern neuroscience and computer science, many feel that we might actually be getting close to something like a general artificial intelligence, which means computer programming that could be said to have the same level of intelligence as humans. Alan Turing, the father of modern computer science, felt that this was fast approaching back in the 1940s when he came up with the axiom that is now oftentimes referred to as the Turing Test. If a computer could trick the human into thinking the computer was a human then we have met his criteria of having true artificial intelligence. As you know this axiom didn't really come to be since we are surrounded

by chatbots trying to sell things, or scam us, and even trying to shape democracies through disinformation. Passing the Turing Test turned into annoyances far less profound. Still, this is science advancing. What was on the edge of understanding and a mystery to Turing, is now commonplace and mundane. And all this new technology is still human-made and shaped. It's clear that current AI replicates and magnifies our human and systemic biases, instead of moving past them.

Now we are at a place where we are seeing great advances in machine learning and computer processing where so-called artificial intelligence can create prose and poetry and even art. But whether it is intelligent would depend on your definition. Currently, most AI relies on language acquisition and production as Large Language Models. But as philosopher John Searle proposed in his Chinese Room Thought Experiment, there is no guarantee just because a machine can reliably create a language that it's aware of what it's creating. We must also consider that intelligence does not require language, as we see examples of aspects of consciousness and intelligence in other animals without complex communication abilities. Scientists, philosophers, and engineers are working on what that means and what it will mean in the future.

You've seen that science has historically been for the people of leisure and privilege to both study, learn, and create. Modern science is also been heavily dominated by the Western world and the powers that came to be through colonialism and oppression. You've also seen that science has always been a global practice seen in the great societies across the ancient world, even if much of it was lost or suppressed.

You are probably W.E.I.R.D. By that, you likely come from a Western, educated, industrialized, rich, democracy. W.E.I.R.D. people are not a good representative body of all humanity and culture across time and space. Your culture and point in time of your existence have greatly affected how you behave and how you think. It can also affect how scientists interpret their research. So when a scientist is trying to understand something like the mating systems of another species it can be skewed by that scientist's individual standpoint in society.

Globalization allows us to understand ourselves on a much deeper level, especially in the social and behavioral sciences. For example, our understanding of human development was greatly focused on a so-called ideal middle-American Protestant family. Much of our study subjects and most of our scientists were W.E.I.R.D. Now we can look and see how human development is both universal and unique by looking at family dynamics and development across the globe.

This is not without its concerns. Even though information can move more freely it is still within the confines of nationalism and geopolitics. This shapes science as we've seen with the militarization of scientific technologies. But it can also shape our science through collaboration to tackle global crises like global warming. The Silk Road of the past which allowed the exchange of information from East to West now exists in every dimension.

New statistical techniques and methods of practice are bringing much older research into question. Some canon are not replicable. This is not a crisis as many have proclaimed but instead proof that science is working as it should. Remember, science is a process. It's the journey and the map is not the territory. They are only a representation of reality. As we go further on our journey, our maps will become clearer and hopefully closer to the truth.

CHAPTER THIRTEEN
THE HERO RETURNS CHANGED

Science is not a noun; a thing, but a verb; a process. Or more like a vast interlocking network of noisy and messy processes. It is also not teleological meaning it's not on a predetermined purposeful path. It's created by us humans as we go. Continually through our adventure, we get things wrong sometimes to the detriment of ourselves, other animals, and the environment. There have also been times we have tried to hide these facts from ourselves and tried to wash away the noisy or uncomfortable parts to make it look like it was always a clean, clear process. But you've also seen that science is always about questioning our previous assumptions. That's why we left the happy village of naive tradition in the first place. And that's what makes all the different sciences so amazing to study. It is a journey that we will forever travel. It is a self-correcting process. But it is a human process. We seek the objective truth but we're still trapped in our own heads and so must always hold healthy skepticism and humility.

The hero's journey stories end by closing the loop where the hero returns back to the known world, to the happy village from where they left, except they are now forever changed. They know more about themselves and the expanded world. Then they are almost immediately summoned on another journey which gives us all those great and not-so-great sequels. That's science. It's never over, instead forever setting up for the next adventure. With the advances in technology and new social and environmental concerns or the deeper we get into the cosmos the more calls are going to arise. Some mysteries we can see on our horizon, but most we can't even comprehend yet what they are. What we do know is that the next heroes will take that journey. That just might be you, your kid, or someone not yet born somewhere else on this pale blue dot. Let's hope they accept that call.

Further Reading

"If I have seen further, it is by standing upon the shoulders of giants."

-Often attributed to Isaac Newton

Here is a list of references for this book. I typically did not include original primary sources because they are very old, boring, and difficult to understand. So instead I used quality secondary sources that can cover bigger concepts in more engaging ways. Most sources cross over multiple areas so I placed them where I thought they fit best. While I did use something from each of these, I do not necessarily endorse everything written in the books or expressed by the authors elsewhere. Sometimes giants are wrong about things and the fact we can see that means science is working as it should.

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ABOUT THE AUTHOR

Justice Morath co-founded multiple local and national science communication initiatives and is now expanding to share their love for science with the world through this book.

They also do not meet the traditional understanding of what it means to be an academic. They reluctantly dropped out of their PhD program while in good standing, partially because science and academia are not accessible to all, yet. Now they are an associate professor of psychology at Salt Lake Community College in Salt Lake City, Utah, United States because they are able to share their love for asking about the world to so many others. This book is an extension of that passion and was created due to the support of Salt Lake Community College during a year on sabbatical.