Learning To See

My deepest thanks to the local chapter of Phi Beta Kappa for the invitation, and the honor, of sharing this moment with you. Being with you today is a special privilege and, befitting the occasion, has wrought a considerable amount of reflection.

I spend an inordinate amount of time looking at rocks. I've looked at rocks in deserts, near both north and south poles, even along roadsides in Pennsylvania. And all of this looking has been in the service of one big goal— to find the skeletons of long dead fish. For me, the best kind of rock is one with a fossil fish fin sticking right out of it.

While this may seem an utterly esoteric goal, three decades of staring at rocks in the ground have given me a certain perspective on life and the universe. They have revealed to me nothing less than our place in nature. They have helped define for me what it means to be human. And, importantly, they continue to teach me ways to strive to be a better human.

The story begins soon after my own graduation in 1982.

The initiation to my life's work was inauspicious. I grew up wanting to find fossils, much like the dinosaurs you see at the museum, so entered graduate school here at Harvard to study paleontology. By that time, the famed, and aptly named, Harvard Crew, led by late Farish Jenkins, had made monumental discoveries finding fossils in some of the most unforgiving places on earth.

During my first year in the program, I received a huge opportunity—I was one of the invitees to one of their field expeditions headed to the deserts of northern Arizona, a land of mesas, buttes, and barren red rock. Exploring those rocks was our goal—we were sent there to find

200 million-year-old fossils, and hopefully some of the earliest mammals in the fossil record. Typically, fossils just erode out of the rock, so you spend days walking and scanning the rock surfaces for the fossil bones and teeth that emerge.

Not knowing much about finding fossils myself, I shadowed one of the seasoned veterans on the team, a man named Chuck who had spent the better part of forty years on Harvard expeditions of one kind or another. Chuck was generous with his time and for days we walked the vast plains together looking at the rocks on the surface. For several weeks, Chuck talked about and discovered fossils at our feet while I found absolutely nothing. I returned home each day empty-handed. Where Chuck saw bones, all I saw were dirt and rock.

With the growing frustration of each passing day, I remember asking Chuck how he finds bones, what they look like, and what kinds of cues he uses to recognize them. He described his methods, but for the life of me I could not understand him. And, to add insult to injury, he was picking up bones, sometimes with my own boot print nearby.

Then, one day I saw it—a brilliant piece of bone that sparkled in the light. It was a tooth and the way it glittered was different from every other rock I had seen to that point. As I looked around, I saw more teeth and more bone. Suddenly, it was as if the entire desert floor opened up in front of me. I felt as if I was wearing a new pair of glasses; bones were everywhere. My fossil turned out to be a jaw of an ancient mammal-like animal. This was the first time I had seen bones on the surface, but actually, I'd been looking at them for weeks. What was mere rock to my eyes just days before, was now fossil bone.

What changed? The thing that changed was my ability to see.

I had learned to find fossils by seeing objects around me in a whole new way. Now, 30 years later, I find myself going through the exact same mental process I experienced with Chuck each time I go

somewhere new. Rocks and bones look different in each place, and I need to learn to see again in a whole new way. I need to unlearn my past search images and find new ones. My experience working in different places has given me confidence, and the patience that comes with it, that somehow I'll eventually learn to see again.

Physicists can tell you a lot about light, wavelengths, and color. Biologists can speak of how light travels through the different structures of our eyes and how nerve impulses carry the signal to different parts our brains. But seeing, of course, is more than optics and vision. What led me to the Arizona deserts and other remote places in the years since is a much more profound way of seeing.

This type of seeing derives from the ideas that shape the ways we learn about and interpret our world. At any given time, our own seeing is derived from thousands of years of humans challenging existing thought, often questioning their own assumptions, and learning to look at the world in a whole new way.

My own field is a case study in how ways of seeing have emerged over time. Our ancestors have looked at rocks for hundreds of thousands of years. They made tools out of rocks, used them for shelters—even dug through them to mine ores and minerals. And, during all of this digging through rock, people saw things that looked like teeth, shells, and bones. But what was their meaning? For most of recorded history, these objects spilling out of the rocks were thought to be no different than the rocks themselves. They were just rocks that happened to look like teeth and bones. The whole concept of a fossil, so utterly familiar today, did not exist.

Then, Leonardo da Vinci and a few others challenged that view. They saw that the teeth and bones are found in layer after layer of rock and that many of them are versions of creatures walking the earth today. They proposed the radical notion that those teeth-like objects and bony looking things in the rocks aren't just malformed rock. They are the remains of long dead animals. In their view of the world, these

things aren't just bizarre mimics, they are the bits and pieces of once living creatures buried inside the rocks. People looked at fossils for years, but da Vinci and others learned to see them.

Armed with da Vinci's views people found fossils from all over the world. Fossil after fossil was described. But it would take others to see these remains for an even deeper meaning.

Like the chain of events that was set off when a Professor of Theology descended a cave in southern Germany in 1748. Accompanied only by a local gamekeeper as a guide, he entered another world, recorded by a poem he originally wrote in Latin that went something like: "as I look down, I see horrendous human bones.... I can see bodies turned to stone and skeletons left lying on the floor." To him, the fossils were monsterous humans.

The real meaning of these cave monsters was to emerge at the hands of a German anatomist a few decades later. He had a motto that was to prove fruitful in his interpretation of the cave bones. "We should always, when forming opinions about the events in Nature, assume the most natural and common process... if we believe our senses, we shall have no grounds for self accusation." What did this sensibility lead him to conclude about the bones? With large teeth, jaws and skulls, they were from a bear, not a human. But they were different any bear known to science at that day. To the anatomist, the conclusion was obvious: the bones were from a kind of bear that went extinct. Why was this so revolutionary? The whole concept of extinction, something that spawns innumerable conferences, laws, and public policies today, was virtually unknown at this time. Up unto this time, species were seen as being perfect and eternal.

These new ways of seeing were only a prelude to a much more powerful idea. The reality of fossils and the fact of extinction were grist for Charles Darwin. Darwin proposed that species are not fixed, they evolve, and go extinct. And he revealed that the creatures on the planet today share a history. Just as our families have a history,

described by a family tree, so do species. Our family tree extends to all other creatures on the planet.

So great were his insights that we call the fruits of them the Darwinian Revolution. Why? There was a way of looking at the world before his ideas, and a whole new way of seeing it after. Before him, species were considered to be immutable and mankind was a special creation; after Darwin, all species are considered ephemeral and mankind is but one of many branches in great family tree containing all life on earth.

With a single insight, creatures as seemingly different as birds, fish, and people were revealed to have a shared past contained in the structures of their bodies and the fossils in the rocks in the world. Such as fossil fish our team discovered with arm bones inside their fins and with both lungs and gills.

My own way of seeing this can best be told my own struggles with teaching. I am in what used to be the Anatomy Department at a medical school. One of our main teaching duties is in Human Anatomy course. This is the classic course of the first year, where our students learn the structure of the body, including the names of every muscle, nerve, bump, hole, and bone. It can also be very stressful because of the sheer amount of material we cover and for the fact that we learn this mostly from dissection of human cadavers . Consequently, it is a very intense and emotional experience; students form images and friendships that often last a lifetime

I remember my own first days in the course. Students wanted to learn about me, about what I do, and what kind of physician I am. I'd tell them that actually I'm a paleontologist who works on fish. Though too polite to ask for a refund of their tuition money, the students would give me looks I'll never forget. At first glance you could not have imagined a worse candidate to teach future doctors.

But within weeks it became clear that being a paleontologist, and not just any paleontologist, a fish paleontologist, is a powerful way to

teach human anatomy. Why? The best and often simplest roadmaps to our own bodies are seen in other animals. The nerves inside our heads are a complicated jumble that only makes sense when you compare them to the simpler state of affairs in sharks. The basic structure of our bodies, including the DNA that builds them, is seen in fish, worms, and flies. The Darwinian view is a powerful way of seeing ourselves.

In fact these connections are helping to define our future. Just look at the Nobel Prize in Medicine and Physiology to ask what types of medical research have been honored in the past decades. It has gone to people working on yeast, mice, flies, sea slugs, and sea urchins. In fact two Nobels have gone to five people in the past 10 years who work on a little worm the size of a comma on a piece of paper. Yet that tiny and simple worm is providing insights into how our cells die, and how our DNA can be turned off in diseases like cancer.

I like to think that as we discover cures to everything that ails us—from Alzheimer's to various cancers — the breakthroughs that will improve our lives will originally be derived from work on worms, flies, and fish. I cannot imagine a more beautiful or profound statement on the importance of our connection to the rest of life on our planet than that.

And how did this come about? By people marshaling evidence, understanding fossils for what they are, seeing the deep history of life and the planet, and from breakthroughs in genetics, molecular biology, and geology too numerous to mention. With each new great idea, we come to see and to appreciate all the surprising and wonderful things that are right under our noses.

The power of great ideas reminds me of those humbling days walking with Chuck 35 years ago. One moment I was looking at just rock, and the next, I saw the floor of the desert open up to reveal bone after bone. And the same is true with powerful concepts: they become lenses to allow us see our familiar world in a whole new way.

But learning to see means also means knowing where we are blind.

There's a profound analogy from physics. The light we see— in a range of colors from red, to green and blue— is part of the electromagnetic spectrum. This spectrum extends from gamma rays and x rays to microwaves and radio signals and it spans a range of wavelengths over ten orders of magnitude. The light that we see with our eyes is but an infinitesimally small sliver of that range. We see only .0035% of it. Think about that for a second. Our eyes are blind to 99.9965% the electromagnetic spectrum.

In a sense, this makes total sense. Our species is the result of nearly 4 billion years of adaptation to the conditions on earth. That tiny slice of the spectrum was enough to survive our predators, find food, have families, and participate in social groups. Survival meant seeing blues, greens and reds, not radio waves or gamma radiation. Our bodies are tuned to the conditions for a successful life on this planet.

But couple our limited senses with the fact that 95 percent of the universe is composed of dark matter and energy— entities that Science can't say much about other than that they exist— and we humans, for all our vaunted capabilities, are utterly blind to most of existence. The only way we will see it is with the tools we might someday build and the ideas we generate with our minds.

There is a deep lesson in visible light, a kind of metaphor for the times, locked inside all of this science.

We live in an age where people talk of alternative facts, fake news, and junk science. Those adjectives— alternative, fake, and junk, make it ever more important that we gain the ability to take a cold look at marshaling and evaluating evidence in making decisions. And doing that means confronting our own very human limitations.

Experiments have shown that cognitive biases make us blind to most ideas, concepts and opinions that lie out there. Indeed, behavioral

scientists have a huge taxonomy of the kinds of biases that affect our ability to see clearly to make correct decisions. With names like Group Attribution Error, False Consensus Affect, and Halo Effect among dozens of others, these biases reveal that, however rational we think we are, in many cases we are anything but.

Our biases, expectations and emotional states limit us every bit as much, perhaps even more, than the light receptors in our eyes.

Science, one of the most powerful tools humans have ever invented, has taught us many things. The first, and most obvious, is a powerful concern for evidence. The ways of seeing that I described were only possible because people found new ways to collect, critically evaluate and analyze evidence. Indeed a shared concern for the importance of evidence gives the scientific community a means to settle debates and to progress. Yes, the scientific community has its very human failings, but it is hard not to look at the past two decades as a golden age of discovery full of game-changing ideas and technologies that can impact every part of our lives and, indeed, our understanding of the cosmos.

But one lesson of science, for me, happens to be the least discussed — humility; humility in the face of the unknown, and more importantly, in the face of our blindness. A cold look at evidence requires humility — the kind I needed to learn from Chuck, the kind that comes from knowing how blind were are. Humility that there is always a better idea, a new approach, or a different perspective to be had and found. Humility that our own limitations may inhibit finding them.

Humility to face, and most importantly to recognize, what we don't know about the universe, other living things, and, most importantly, each other.

The famed cardiac surgeon, Michael DeBakey, once famously said that success in the art of medicine comes from "making the right call in

the face of imperfect information." I would argue that we are so blind that we virtually never have perfect information.

So given this, what can we learn from rocks, the electromagnetic spectrum and ancient fish?

To me, they teach a way forward that comes from cultivating a mixture of traits that seem so utterly in conflict— humility and confidence. Be humble to face and to recognize the unknown and confident that with a passion for evidence, and open mind, and an ability to learn from mistakes, whatever problems we face will, over time, be solved.

I hope that your time at Harvard has cultivated your appreciation for the importance of evidence in rational argument; that it has enhanced your ability to see what is important to you, to understand the meaning of what you see, and before you get too comfortable, to uncover your own blind spots so that you can ever *learn to see.*

Congratulations all.