

**Evolution: Fossils, Genes, and Mousetraps (2006)**  
**Dr. Kenneth R. Miller**

**1. Preamble: Kenneth Miller. (00:10)**

It's a pleasure to be here a special pleasure to speak to so many members of the scientific community of the future, because that's exactly who you are and I hope you, you take that role seriously. I hope you enjoy that role as well. One never really knows how one is gonna be introduced, so I figured I would introduce myself a little bit. I am a cell biologist, I work as he said on the structure and function of biological membranes, I am at Brown University in Providence. We work on things like, in this case the structure and organization of the endoplasmic reticulum membrane, part of the cell that's involved in the synthesis of proteins and my lab was one of the very first to visualize the channel which is now called the translocon by which proteins enter the ER. That sounds very technical, but is a very important problem in cell biology. Over the last few years, collaborating with a terrific guy named Joseph Levine, I've written a whole series of high school biology textbooks, which are widely used around the country, elephant book, but we have a couple of other books as well including the dragonfly book, which is the most current book, and these are used in probably 35% of the high schools in the United States, which is a nice thing. My own daughter in fact, Tracy... I have two girls, the oldest one is a wildlife biologist, the youngest one is a high school history teacher, and Tracy, the younger one, had to suffer the indignity of using her old man's book, the elephant book, in freshman biology in high school in Dighton-Rehoboth Regional High School in Massachusetts where we live. And I still remember one night, Tracy comes home for dinner and we're all sitting around the table and she says "You know, Dad, because of you I'm the envy of everybody in the "high school biology class." I thought that was really cool. Because I thought, it's so rare that children ever compliment their parents for any reason whatsoever and I thought this was one of those moments and I threw my chest out, I felt really good. And you saw how big that book was. And Tracy then went on and said, "Yeah, I am the envy of "everybody in the class 'cause I am the only one who doesn't "have to lug that thing home at night." Because the others kids had caught on. "Tracy doesn't need this. "My dad wrote it, I got a copy at home, I don't have to "bring it home." That was what we were good for, what we were used for. A couple of years ago at the urging of quite a few people I wrote a book on evolution and religion, which is called *Finding Darwin's God* and the subtitle of that is *A Scientist's Search for Common Ground Between God and Evolution*. I think there really is a great deal. And as it turns out that book has been a surprising success in terms of not just my publisher, but also people writing to me and saying that, what I wrote about in here about science and religion connected and connected with them.

**2. Evolution controversy. (02:46)**

Now, evolution, as I'm sure you all know, is a controversial topic in the United States today and just to pick one U.S. state, certainly not the only one where it's been controversial, I picked the state of Kansas. I actually spoke in Kansas just a couple of weeks ago and some of you may know that seven years ago, the Board of Education in the state of Kansas voted to entirely delete evolution from the state science requirements in Kansas, they simply took it out. That led to a popular outcry and these are newspaper headlines from the times and people were confused as to what this meant, what do we teach now? A lot of people thought that this was a controversial issue; therefore, the schools were best left without it. Since then, every time there has been a school board election in the state of Kansas, evolution has been the issue on which the election turned. In 2004, an anti-evolution majority took control of the board and they rewrote the standard. Back in 2000, a pro-evolution majority took control. This year it looks like a pro-evolution majority will regain control of the board and they will rewrite the standards again to make them consistent with the National Science Education Standards. Kansas isn't alone in this. It turns out there are a lot of states in which evolution is indeed a major issue in the election. One of the candidates for governor in the state of Michigan right now has made evolution and something called Intelligent Design, one of the key issues in the

governor's election in that state. So we see this literally all around the country and you might say that we live, as a result, in very interesting times. Some of you if you read the newspaper closely might remember that a few years ago there was a county in Georgia called Cobb County and Cobb County is not a rural county, it's the second largest school district in the state of Georgia. They adopted new biology textbooks and the school board thought they were so dangerous that the textbooks had to have a warning sticker pasted on the inside to tell students that evolution was just a theory, not a fact, don't get worried about it, and you might wonder, my God, what textbook was it that was so dangerous that it required a warning sticker on the inside and sure enough... that's the book and this is what the warning sticker actually said. And the sticker said "This textbook has material on "evolution. Evolution is a theory, not a fact, regarding "the origin of living things. This material should be "approached with an open mind, studied carefully and "critically considered." And I remember when that sticker went on, a reporter for the *Atlanta Journal-Constitution* called me up and she said "Dr. Miller, aren't you "outraged at the sticker they just put on your book?" And I thought about that, and I wondered "Why did she "phrase the question that way?" And then I realized she probably wants to write an article with sort of an inflammatory headline. She's trolling for a quote and she wanted to write an article that says "Author "Slams Board of Education" or "Author is Outraged," or even better "*Northern* Author Criticizes Board of "Education"--something like that would go over well. And I decided I would not give her that satisfaction, and I wanted to have some fun, so I said "No, I like "the stickers." She said "You do?" and I said, "Yeah. I think the stickers are "great--they just don't go far enough!" and she said "What are you talking about?" and I said "Well, the book has material on evolution; it's got a lot of "other material too."

### **3. Is evolution a theory? (06:04)**

Is evolution a theory? Of course it is! One of the chapters in my book is called evolutionary theory, so of course it's a theory. But when you say "It's a theory, not a fact," you make it sound like theories and facts are opposite things, as if they're either one or another, and that's not the way we understand theories in science at all. So for example, I explain, let's suppose that a young person went to the University of Georgia and decided to study physics. One of the courses they'd have to take would be a course in atomic theory. Why do we call that atomic theory? If we get really certain about atoms at some point in the future, will we change the name of that course to atomic fact? The answer is, of course not. We call it atomic theory because a theory is something that explains hundreds of thousands of facts and atomic theory explains observational and experimental facts about the nature of matter. Evolutionary theory, in the same token, explains hundreds of thousands of observations and experimental facts relating to the nature of living things. That's what a theory is. But I told her that the sentence that really bugs me is the last one. And the last one says "This "material..." that means evolution of course, "approached with an open mind, studied carefully and "critically considered." And she said "What, are you "against open mindedness?" I said "No, you don't understand. "You know what that third sentence tells students? "It tells students we are certain of every single "subject in this book, except for one. "And that's evolution." Now, I don't object to that as an evolutionist, I object to that as a cell biologist. Because apparently what that tells you is if you study ecology, you don't need an open mind, and if you study biochemistry, you don't have to study carefully, and if you study cell biology, you don't have to apply critical analysis, and in fact everything in science should be approached that way. So I said "I'll tell you what I'll do... no charge, I'll rewrite the "sticker for the Cobb County Board of Education, and they "can use the new sticker if they want." So the way I rewrote the sticker is what you see right here. I would phrase it, "This book has material on science. "Science is built around theories which are strongly "supported by factual evidence. *Everything* in "science should be approached with an open mind, studied "carefully and critically considered." That's the right way to consider it. Alas, they didn't take me up on this, they stuck with the stickers, they got sued, they went to court and they lost and the stickers were ripped out at the end of last summer.

### **4. Evolution is central to biology. (08:26)**

Now, even if you haven't taken a course in biology, you probably know that if you open just about any biology book, and mine is a pretty good example, you'll very quickly come to a chapter which tells you all about evolution, and we have this sort of thing as well. Why is it? Well, many biologists would say very simply that evolution is the central organizing theory of the biological sciences. A very famous biologist once wrote that nothing in biology makes sense except in light of evolution. Other people have said that, without evolution, biology is just stamp collecting. Now what they meant by that--and I used to be a stamp collector, so it's not a slur on stamp collectors--is that without evolution to tie things together, the characteristics of organisms are just a bunch of isolated facts, and what evolution actually does is to show how those facts fit together. So how do you explain evolution? I was thinking about that when I was preparing to meet you this morning, and one way to do it would be the way that Charles Darwin did, which is to write a book, and Charles Darwin explained evolution in *The Origin of Species*... depending upon the edition, it's about 400, 455 pages. So, one good way to spend much of the time in this lecture would be for me to open page one, and start reading *The Origin of Species*. And I hope that at some time in your life--I am not kidding about this--every one of you reads *The Origin of Species*, and the reason for that... I know it looks old and I know it looks dusty--this is a great book and it is still a great book and when you read books written as this was, 150 years ago, you find yourself connected with the thought of somebody who lived at a different time, in a different society, in a different century, different era and you will connect with Darwin, just read one chapter of it, you'll see exactly what I mean. But that would take a little long,

#### **5. Evolution: The 30-second version. (10:17)**

so I thought, "Well, "explain evolution in 455 pages? Too long." We need a shorter time period. And where would you find a shorter time period? How about we explain evolution in 30 seconds, of the sort that a poor unsuspecting scientist might be asked to do, if he went on *The Colbert Report* with Stephen Colbert? So here you're gonna hear an explanation of evolution in 30 seconds. Our guest is a professor of biology at Brown University and a leading critic of Intelligent Design. I am gonna ask him where he gets off. Please welcome Ken Miller! Thank you so much for doing the show! This is such a thrill for me! It's a thrill for me! Let me ask you something. Walk me through. I want to give you a shot here. Explain evolution from the primordial soup to how I got here today in my limo. That's a... Walk me through it! Take 30 seconds. Okay! How about if we crawl? Basically what evolution tells us is that we are united. We're put together in the fabric of life with every other living thing on this planet. Up until about 2, 300 years ago, people thought that life on earth had never changed, but they immediately became aware at the end of the 17th and 18th century that life had changed and the process of change, explaining that, has been one of biology's biggest projects for the last 150 years and that explanation is evolution. Well, Colbert had more to say, and if you want to see the rest of it, you can Google "Ken Miller on The Colbert Report," and you'll find it somewhere on the internet for the entire six-minute interview. But I want to come back to a couple of things that I said very briefly in that 30-second exchange about evolution. And that is,

#### **6. Living forms change. (12:16)**

one of the first things that people became aware of, which serves as the basis really for the theory of evolution, is the observation that life has changed over time. We take this for granted today, but it wasn't taken for granted in the 17th and 18th centuries. It was a surprising and startling fact. Fossils are the record of that change. And not just fossils themselves, but where they're found, what fossils they're found in association with and which layers they are found in. And fossils are not always fragmentary, in many cases they are extraordinary records that tell us a great deal about what an organism looked like and even acted like, and in some cases even what it ate, because in many cases fossils preserve soft tissues including the digestive system of these organisms. So that was in a way the first fact. The second startling fact was, these changes occur in a pattern. This is one of those charts that nobody has ever actually supposed to be able to read, so don't worry about it if you can't read it, but what has happened here is the geological periods are sketched over here and the first appearance of major groups of organisms is shown here, so for example

microscopic organisms appeared literally billions of years ago, multicellular animals in the Ediacaran Period about 700 million years ago. The first representatives of the vertebrates and others in the Cambrian, then jawless fish came later, bony fish, amphibians, insects, reptiles, dinosaurs appeared about here, dinosaurs became extinct during the Cretaceous, mammals, birds, and actually the most recent major group of organisms at the phylum level to appear isn't us, it's not mammals, it's the flowering plants, the most common plants in the world. The flowering plants didn't appear until the Cretaceous, about 125 million years ago, so not only has life changed, but it has changed in a very particular pattern and analyzing that pattern of change, it's very clear that the changes were successive and what I mean by that is very simple. The first amphibian to appear looked more like a fish than any amphibian that has ever existed since. The first reptiles to appear looked more like amphibians than any reptiles that had ever existed since and the very first mammals to appear looked so much like reptiles that they actually are called the reptile-like mammals and this notion of successive change impressed an awful lot of people well before Charles Darwin. When Darwin as a young man traveled around the world on a ship called *The Beagle*, he was struck by something that he called the succession of types. Gotta remember, this guy grew up in England, never been off of the island of England, suddenly he is in South America and he sees the weirdest animal that any European could ever hope to see, namely an armadillo. Now I don't know how many of you've ever seen armadillos in the flesh, travel to the Southwestern United States, you'll have that pleasure, they serve armadillo properly cooked in all sorts of restaurants, it's a delightful treat, I can tell you about this, but it really struck Darwin, these are really weird animals. Now, in addition to studying them, sketching them, dissecting them, and yes, eating them, Darwin was struck by the fact that there were fossils that were unique to South America of organisms like this one called the glyptodont. These fossils looked remarkably like armadillos, even though they were much larger and they had many internal differences in their structure and it struck Darwin--why should the extinct armadillo-like species that he found and armadillos themselves be found on just one continent and that continent he thought at the time was South America. Why should they be found together? It suggested something and what it suggested to Darwin was ancestry. The reason armadillos today are found on the continent where the most armadillo-like fossils are found is because these guys might have been the ancestors of these guys. Not just armadillos.

## **7. Fossils and living species. (16:07)**

There were extraordinary fossils which Darwin found of extinct giant sloths in South America, and lo and behold, the modern sloth, which is found in Central and South America, clearly is related to it. And Darwin wrote in a book that was published more than 20 years before *The Origin of Species*, "This wonderful relationship in the same continent between the dead and the living, the fossil and the living, will, I don't doubt, throw more light on the appearance of organic beings on the earth and their disappearance than any other class of facts." The fossil record shouted out that there was an ancestor-descendant relationship. Darwin was also a very experienced cultivator of plants and a breeder of animals and he realized that vegetables that we think of as remarkably different, such as Brussels sprouts, broccoli, cauliflower, have all been produced from the same ancestral wild mustard seed... wild mustard plant, believe it or not, by careful cultivation in the hands of plant breeders. So he realized that plants in nature show so much variation that a breeder can select for these different characteristics to produce plants that to us look completely different.

## **8. Natural selection. (17:23)**

And he realized that nature does exactly the same thing, and Darwin's insight was there was a force in nature which he called natural selection, and that natural selection automatically selected for animals and plants that were best adapted to their environment. The variation that appears in nature is acted upon by natural selection, and Darwin put this sketch--it's the only picture in *The Origin of Species*--to illustrate how he thought this process would work, and that is a species would develop increasing variation until finally it split into two, a process called speciation, that results in the formation of new species. Once diversity divides the species into two, each of these new species can be acted on separately by natural selection and this is where

species come from. Contrary to popular imagination, evolution doesn't transform one species into another, it takes existing species and splits them into two or three separate species, which then go their own way and evolve in separate directions. What impressed Darwin was that he thought he could actually see this process in motion. On the Galapagos Islands, off the western coast of South America, he found a number of species of birds, which clearly had different styles of life. Some of them were woodpecker-like, some of them were finch-like, some of them were warbler-like. He bagged these animals--meaning he shot them, preserved them, brought them back to England--and gave them to bird experts and the bird experts told him, "You're not gonna believe this, that "thing you thought was a woodpecker? It's a finch. The "thing you thought was a warbler? It's a finch. The "thing you thought was a finch? Well, it is a finch." And it turns out that on these islands, there were no fewer than 13 different species of finch, that in just a few million years had evolved from a single common ancestor that had flown to these distant islands from the South American mainland. Because this was or these were the first birds to colonize it, these birds split and split and split again and were able to adapt to every one of these individual styles of life on the island. It's worth noting, this same process is happening right now in various places throughout the world.

### **9. New species arising now. (19:42)**

For example, scientific reports of an insect called the walking stick in California have shown that walking sticks right now are splitting into two species, one of which prefers to hang out on one kind of plant and the other which prefers to hang out on another type due to camouflage reasons. These species can almost... these two populations can almost be considered separate species and this sort of process therefore happens and it happens today. Now, we're able to analyze--Darwin couldn't do this--what goes on by genetics and genetics has shown us that these sort of isolating mechanisms which divide species into two can develop in just a few years, in the case of fish, 60 or 70 years, in the case of mice, as few as a few hundred years and in the case of flies and other microorganisms, perhaps just a few generations. So it's extraordinary that not only do these changes continue to take place, but we can study them with modern genetic mechanisms.

### **10. Fossils and whale evolution. (20:42)**

Now these ideas have implications and the implications are that we ought to be able to look at the fossil record and find a record of common ancestry, and it turns out we can. We've known for years for example that swimming mammals like whales and dolphins have evolved from terrestrial mammals and they did so about 80 or 90 million years ago and it turns out that the oldest known living whale called... sorry, the oldest known fossil whale, up to about 20 years ago which was called basilosaurus, and this is a basilosaurus skeleton, is remarkably transitional. It doesn't have a blow hole--still breathes from the very tip of the nose. It actually has tiny little hind legs or pelvic girdle here, concealed inside the skeleton, so it clearly is an intermediate form, but a lot of people who might be critical of evolution might say, "Yeah, well if this really happened, "where are the intermediates?" Well, that's a good question. It turns out that about 15 years ago a group of investigators in the Middle East began to discover fossils that clearly were whale-like fossils and once they realized that this was where this evolutionary process took place, they began to look harder and when they looked harder they found a series of fossils that were remarkably intermediate, fossils that clearly were terrestrial organisms that had begun to adapt to the ocean. So how many different species did they find? One or two to plug up the gaps? Well, no fewer than five. And recent estimates suggest perhaps a dozen or more. And we now understand in great detail how mammals made the transition back to the water and where modern whales and dolphins came from and it's an evolutionary process that we understand not completely because we don't understand anything completely in science, but we certainly understand it well enough to know that evolution drove the change. And this sort of discovery occurs all the time.

### **11. Fossils and fish to tetrapods. (22:36)**

So an article, April of this year from the *Wall Street Journal* pointing out that new discoveries continue to answer questions on evolutionary theory and in this case it was the spectacular discovery of an intermediate fossil in the Canadian arctic that shows very clearly how the fins of lobed-fin fishes evolved into the forelimbs of terrestrial or land-dwelling vertebrates. So the intermediate forms continue to show up. And we can look at the fossil record anywhere and see examples of new species formation. Here for example is the development of a new species--it actually turns out to be a diatom--by this process of diversification, exactly what Darwin suspected in the fossil record, and this species became increasingly diverse around three and a half million years ago, split into two. These two species went their separate ways and as it turns out they are both still with us today. So we see examples like this all the time, but if you're really passionately interested in evolution, you might say, "Well you know that's a diatom and nobody "really cares about diatoms. Show me a species that I'm "really interested in." So I figured I would do that today.

## **12. Fossil record for humans. (23:45)**

What you see here is the fossil record of another species. Looks remarkably similar to the last one and just like it, in this case, about two million years ago, it underwent a diversification, it split into two major lines, they existed side-by-side for about a million years. This one went extinct, this one continued to evolve and what you see here is the size of a very important organ in all of these species and as you can see this guy is still with us to the present day. Now, I don't know if this looks familiar to you or not, but it should and the reason, for that is, it's us. What you're looking at is a fossil record showing the development of the brain size in human beings. We make an arbitrary split between the *Australopithecines* and our genus, *Homo*, that split occurred about two million years ago, human beings or pre-humans lived side by side with *Australopithecines* for about a million years before they went extinct and we might have had something to do with that and the line leading to us showed a rapid increase in brain capacity in just the last million or so years. Many people who are critical of evolution literally refuse to believe that we have intermediate fossils that connect us to our pre-human ancestors, but we certainly do. And every year we discover more of them, and these are not fragmentary remains, these are not bits of a jaw bone or piece of a tooth, in many cases they are complete skulls that show us a great deal about these individuals and a great deal about what they were capable of. One of these skulls was reported in the journal *Nature* several years ago, it's called *Kenyanthropus*, the guy on this side, and when I opened the issue of *Nature*, I saw a summary in the paper showing not just *Kenyanthropus*, which is right here, but showing all of the fossil species--who is related to whom or who we think is related to whom--and these are species that lived in just the last five million years leading to us. And I opened this, and I looked at this and I had one of those really weird moments, I looked at it and said "I've seen that before." "Where have I seen it before?" "How could I have seen it before?" Because this is the latest issue of a scientific journal--they must have drawn this diagram up. But I was positive that I had seen that diagram before and I couldn't imagine what it was. So, I thought about it, I got better things to do, went to sleep, woke up the next morning, I don't know when I do my good thinking, when I'm conscious or not, but I woke up the next morning, I thought, "I know where I saw it before. "I saw it before in *The Origin of Species*." Unintentionally, that summary of the human fossil record is literally a dead ringer for that back-of-the-envelope sketch that Charles Darwin put in *The Origin of Species*. This was his sketch as to what evolution would look like if we could capture all the intermediate forms and visualize all of the evolutionary speciation events. Lo and behold, what we know right now around our own species matches that in a way that I think Darwin would never have anticipated. So the human fossil record turns out to be an almost perfect match for Darwin's rough back-of-the-envelope sketch of evolution.

## **13. Molecular evolution: Chimps and humans (26:44)**

Now we live, as all of you know from your education, in a molecular age, and so far just been talking about fossils. So a fair question is, what about the molecular evidence? Does it support the idea of evolution? This is the cover of the scientific journal *Nature*, published almost exactly a year ago today. And it has in it the chimpanzee genome DNA sequence and this is, these are a few lines from one of the papers in this issue.

And I wanted to show you what one of the authors who worked on this study actually wrote, and what he wrote is that "more than a century ago, Darwin "posited that human share recent common ancestors with "the great apes in Africa. Modern molecular studies have "spectacularly confirmed this prediction." So molecular studies support it and they support it in a very dramatic way. And, as I'll tell you after the break, today is a special day for me because exactly one year ago, I was on the stand being cross-examined in a trial on the issue of evolution, in Federal Court in Harrisburg, Pennsylvania. And at that trial we had to decide, how were we going to bring this brand new evidence because it was only a couple of weeks old at that time, into the courtroom in a way that would make this dramatic point with the judge. So I want to show you how we did this, because molecular evidence can be complicated. Let's take the hypothesis of common ancestry, namely, the hypothesis that we share a common ancestor with chimps, oranges, gorillas and the other great apes. Now the fossil evidence for this is overwhelming, the anatomical evidence is good, the genetic evidence is extremely strong, but you know there's something funny about it. We human beings have 46 chromosomes. All the other great apes have 48. Now if you study biology and I think most of you have, you know that those 46 chromosomes we have are actually 23 pairs. Each of you got 23 from mom and 23 from dad. Baby chimp gets 24 pairs, 24 from mom, 24 from dad. So where's our missing chromosome pair? What happened to it? Is it possible that in the line that led to us, a pair of chromosomes just went missing, just got tossed out? The answer to that is no. We know way too much about primate genetics. The loss of a whole chromosome pair would be fatal--be fatal in us, be fatal in gorilla, be fatal in orangutan. You wouldn't even get past embryonic development if you lost all the genes on a whole chromosome. So the only possibility is that, during the evolution of a line that led to us, one of the pairs of chromosomes in one of these pre-human ancestors must have gotten fused together, must have gotten stuck, so instead of having 24 pairs, two of them are stuck together in us, that's why we have 23. Now that, as it turns out is a testable prediction, meaning that we want to be able to look at the human genome and find that fused chromosome somewhere in our DNA and if we can't find it, then the hypothesis of common ancestry might be wrong. So we have to now go to the human genome, scan around and see if we can find a chromosome that sort of shows the scotch tape that holds together two pieces of other chromosomes, so see if we can do that. Now, how would we recognize that? Well, a biology student will tell you it's much easier than you might think and here's why. Chromosomes have at their tips special DNA sequences called telomeres, only found at the tip, near the center they have special sequences called centromeres. If, in the lineage leading to us, two primate chromosomes got stuck together, you'd have a chromosome with telomeres in the middle where they don't belong and you would also have a chromosome with two centromeres. So that's what we're looking for. So now we're gonna look at the human genome and see: Do we have a chromosome with telomeres in the center and two centromeres, and if we don't have it, this common ancestry thing might not be true. Well, it turns out we do. It's chromosome number 2, and this is a paper published last year in *Nature* showing that our human chromosome... why don't we read from the paper, even though it's sort of technical. "Chromosome 2 is unique to the human lineage of evolution, "it emerged as a result of head-to-head fusion of two "chromosomes that are still separate in other primates." We know the precise fusion site. It's at base 114 million 455 thousand 8 hundred and 23. We know the exact base pair where the scotch tape is hanging out. We've got the extra telomeres right here and lo and behold, there are two centromeres, one of them is inactivated. The inactivated one corresponds to chimp chromosome 13, the active one corresponds to chimp chromosome 12. What does this mean? It means that we're descended from common ancestors with the other great apes that had 48 chromosomes and we can see that lineage in chromosome number 2 where the fusion points come together. Is there any way to interpret this factual data as being evidence for an intelligent designer or the spontaneous creation of our species out of nothing? The answer to that is no, unless you're willing to think of a designer who wanted to fool us by giving us a chromosome that only looked like it had been descended by pasting these two guys together and if you want to believe in a super force that is so deceptive, well go ahead and do it, but it certainly isn't the scientific point of view. Now what I'd like to do right now is to take a break, answer a few questions and after you guys get an opportunity to ask a few questions, basically, I want to tell you about what happened in that court room in the trial that began a year ago, yesterday. Thanks a lot and I look forward to your questions. Don't forget we have substantial bribes and if no hands go up, I'm taking them all home! Okay.

#### **14. Q&A: How do you reconcile you religion with evolution? (32:36)**

You sir in the orange shirt. How does the evolutionist theory fit in with your religion? Oh, okay, you ask sort of the big question, which is, how does the evolutionist theory fit in with my religion? I think it fits in extremely well and what I'd like to do, if you don't mind, is to sort of defer that a little bit and at the end of the lecture if you're still interested in that, I'll show you another clip from the Stephen Colbert show in which he asked the religious question, but the way I would put it, is this way. What evolution tells us is that our species has a natural origin. In other words, we come out of the same process of nature and everything else. Well, if you read Scripture, Genesis tells us you're made out of the dust of the earth. Well, that's what evolution tells us too. In other words, we have a lowly origin and in the western scriptural tradition, God or Allah reminds us of that constantly, that we're made out of the dust of the earth, that's what evolution says as well. Having a natural process to account for our origins, to me is no more theologically threatening than realizing that the phases of the moon or the apparent movement of the sun are natural processes as well, even though in olden times people attributed those to the direct action of God. So, I don't want to get into detailed theology, but in a general way the problem, theologically, as far as I'm concerned, was solved by Thomas Aquinas in the 13th century. And Aquinas was one of the great Christian writers, his great insight was that God, if he exists, is the cause of causes. So showing that something has a natural cause, doesn't take it out of the overall plan of that divine force and to me that's how evolution fits in. I can talk more about that later if you want.

#### **15. Q&A: How are chromosomes numbered? (34:21)**

The right hand corner all the way over here, yeah. When you were talking about the chimpanzee you said that their chromosomes that fused together was 12 and 13, but when you were talking about the humans you said that the fused one was in 2. How did it skip up to number 2? Ha ha ha. Well, the answer is, don't forget we're the human beings, so we're the guys who do the numbering, okay? And we number human chromosomes, number 1 is the biggest, number 2 is a little smaller, number 3, number 4... so we numbered them by size. We actually made a mistake, the smallest human chromosome is 21, but 22 looked smaller to the first people who did the numbering, so we got those numbers messed up. The primate chromosomes have been numbered exactly the same way, so chimp and for that matter gorilla and orang chromosomes 12 and 13 are the 13th and the 12th smallest. When they were fused together, they became bigger, right, so that's why the numbering changed and when this work was done, primate geneticists all of a sudden realized the chromosomes we've been calling in other primates 12 and 13 don't correspond to 12 and 13 in human beings, they correspond to the two parts of number 2, so in the chimpanzee genome project, geneticists have now renamed the chimpanzee chromosomes, so what used to be called 12 and 13 are now called 2A and 2B. That way, they line up because the genes line up in a dramatic fashion with the genes on human chromosome number 2, so retrospectively after that paper we changed the numbering system.

#### **16. Q&A: Are humans still evolving? (35:59)**

Other question. Right in the back. Is it possible that our human species is evolving or will evolve in the near future, in the future? That's a good question and it's one I hear a lot--are we still evolving? Well, here's what you need for evolution to take place. Two things. One is you need variation within a species. OK, look around, we got one species in here, there's a lot of variation, height, weight, hair color, skin color, eye color, blood type, so we have plenty of variation in our species. And the second thing you need is differential reproductive success, meaning some people will leave more children than others. I am... this'll tell you exactly how old I am. In a couple of weeks I am gonna go to my 40th high school reunion and I've been e-mailing and corresponding with some of my old high school classmates. I have two kids, a couple of my friends have three, I've found over the internet a couple who have none and one of my classmates has 12. That is what I would call differential reproductive success and what that means is we've got variation, we've

got differential reproductive success, that's all you need for evolution. Now, can I predict where evolution is taking us? The answer is no. Evolution is an inherently unpredictable process, but evolution clearly is gonna continue on our species, even though science has enabled us to sort of manipulate our own evolution to some extent and I wouldn't be so bold as to predict how that will end up, but evolution is clearly going to continue. Okay, so let's see,

#### **17. Q&A: Could another species displace humans? (37:24)**

young lady right here. Do you think it is likely that eventually another species will come to be the dominant species instead of humans? Ah, that's a good question! In other words, how long are we gonna occupy this planet? I grew up in the 1950s, and when I went to school, we had air raid drills and we had to go under our desks and duck and cover because we thought the Russians were gonna come over and bomb us any moment and therefore in popular fiction, even on television, people speculated about our species--through nuclear war--bombing ourselves into extinction. Unfortunately, that's still a possibility. Let me speak however strictly, not as a politician, but strictly as a biologist. The average duration for a mammalian species, for a mammal, in the fossil record, according to a paleontologist at the University of Chicago, named Jack Sepkoski, is 2.6 million years. Our species has been on this planet, depending on when you trace the ancestry of our species, probably been a million, million and a half years. So, so far we've got about a million years to go, to reach the average length of a mammalian species. But that same study of the fossil record says that no mammal species has survived unchanged for more than 5 or six million years, so as a biologist, what I would say is the way of all species is emergence through evolution and extinction. Might that occur to us? It might. I have a feeling you and I'll not live to see it, but predicting the future except by reference to the fossil record is always pretty dangerous.

#### **18. Q&A: Did fused chromosomes make humans a species? (39:02)**

Okay. Right there. You said before that the, about the chromosome that's inactive in humans. I don't think I said anything about an inactive chromosome. Well, about the fused chromosome. Right. Right, sorry, and what part did that play in our development? The answer might surprise you. Probably none. And the reason for that is we can study chromosome fusions, which occur all the time, in laboratory mice, in fruit flies and *Drosophila* and other organisms, and for the most part the fusing of two chromosomes together doesn't have a very profound genetic effect, so the fusing of primate chromosomes 12 and 13 to produce human chromosome number 2 probably had very little to do with what makes us human. In other words, when you actually line up the primate chromosomes 12 and 13 with ours, you find that most of the genes match and the fusion site really has very little influence on gene expression. So very often when I talk about that, someone will get up in the audience and challenge--that's not what you did--but someone will get up in the audience and challenge and say "How could the fusion of two chromosomes change the "chimpanzee into a human being?" And the answer is, it can't, but this is simply a fortuitous, a lucky genetic rearrangement that occurred in the line that led to us that enables us to look at our own DNA and see where it came from, and in this case we clearly came from an organism in which those two parts of chromosome number 2 were separate, and we can look around and we see where those organisms are. They're the great apes.

#### **19. Dover, PA evolution trial. (40:36)**

So I want to thank you for your questions, I'll take some more at the end and now what I'd like to do is tell you a little bit about that trial. The trial involved events that took place in Dover, Pennsylvania. Dover is a small town. This is a high school that graduates about 150 kids a year. There are four high school teachers in Dover, that's all. And the reason I put the cover of my textbook up there was because in 2004, the teachers at Dover High decided that they wanted to buy new biology textbooks for their students. That's the book they picked. They then had to have this approved by the local school board. This is not the State of Pennsylvania, this is just the town of Dover and a number of school board members didn't like the book. One of them was

named William Buckingham and he said what he didn't like about this book was that "from beginning "to end, this book is laced with Darwinism." You know how authors try to sell books by putting little quotes on the back jacket, to tell you how good they are? Well, Joe Levine and I, my co-author, we're thinking about putting this on the back jacket of that book because we think under certain circumstances it might help us to sell books. But Mr. Buckingham and other board members persuaded the board to instruct the teachers in Dover to start preparing Intelligent Design lessons in schools. As this case moved along, an awful lot of people said, "Wait "a minute, this isn't a scientific issue the board is "pushing, this is a religious issue," and as I mentioned a trial took place about a year ago, a whole series of expert witnesses showed up in that trial and I had the honor, if you wanna call it that, of being sort of the first expert witness in the trial. It started a year ago yesterday, I figured that I would testify on Monday, get cross-examined, fly back to Providence and give the lecture which I always do Tuesday at 1 o'clock in my cell biology course. I had no problem. But my cross-examination went on and on and on and I had to be on the stand for two days, so I e-mailed this article from *Science* magazine to all the students in the class, so they'd understand the reason I had to cancel Tuesday's lecture wasn't because I was on a ski trip or vacation, but I was actually tied up in court, and they thought that was okay. I e-mailed them the link to the report about my testimony in *The New York Times*, they thought that was okay,

## **20. Dover trial makes *The Daily Show* (42:57)**

but I have to tell you they were not really impressed until they saw that the trial was being reported in what is, for you, I am sure, and for today's college students, the ultimate news source and that turned out to be *The Daily Show*. And as soon as they saw that Jon Stewart was reporting on the trial, they decided that's cool, this is important, it's okay for the professor to be there. The trial lasted more than seven weeks, as one person pointed out, in fact it was the judge who pointed this out, the trial lasted 40 days--think about that—and that's how, then the judge had to render his decision and the decision which came out in December of last year was a stinging rebuke of Intelligent Design, it simply slapped down the Board of Education, it was an extraordinary decision and it's well worth reading. The case is actually called Kitzmiller, "K" "I" "T" "Z" Miller. That was the name of the lead plaintiff. Tammy Kitzmiller. "K" "I" "T" "Z" Miller. Kitzmiller v. Dover. You can find it on Google very easily. The decision is extremely easy to read and this judge, who incidentally is a Republican conservative judge, appointed by President George W. Bush, and praised during his confirmation hearings as a strict constructionist, which he is, this judge wrote an exceptional opinion. Now what happened in the trial was remarkably interesting and there were many cartoons--you can't take pictures in Federal Court--this is *The New Yorker's* caricature of a fellow named Michael Behe who testified in defense of the School Board being cross-examined, this is MSNBC's sketch of me in the court room being cross-examined in front of the judge by the lawyers to the other side and the key in the trial was making the case for evolution and I wanted to have a few things to say about exactly how we did that.

## **21. What is Intelligent Design? (44:41)**

Now, I've talked about this thing called Intelligent Design, which was the theory that was presented as an alternative to evolution. So what is Intelligent Design? Religious people of all stripes believe that there really is an intelligent design to the universe, which is the work of the creator and for what it's worth, that's what I happen to believe myself, but this is actually, in this context, not what is meant by Intelligent Design. Intelligent Design in terms of this argument means something else. And it is the claim that design--and what is meant by design here is outside, supernatural, puff-of-smoke intervention--is required to account for the origins of living things. That means that Intelligent Design or ID as I will call it, is actually a doctrine of special creation. Species appear because a creator makes them and in this respect it's really nothing newer than good old fashioned creationism sort of spiffed up to make it sound scientific and to appear non-religious. So I want to tell you how people go about arguing for this.

## **22. Bacteria flagella: Not irreducibly complex. (45:44)**

One of their principle claims is that evolution cannot explain the origin of complex biochemical machines. That's a bacterium and the little whips you see coming out of one end are called flagella. A lot of bacteria including *E. coli* in your stomach right now, have little flagella. These flagella are enormously complex and they spin around like crazy to propel this bacterium through liquids of all sorts including ones inside your body. Now the argument is that these flagella, which at a molecular level are really quite complex and quite beautiful, possess something called irreducible complexity and that means that even in principle they just couldn't have been produced by evolution. That's the argument. So if evolution couldn't have produced them, they must have been designed or they must have been produced in a puff-of-smoke creation. And Michael Behe, who did testify in the trial for the school board, says you can't produce irreducibly complex systems by modifying a previous system--that's how evolution would do it--because any precursor to one of these complex systems that is missing a part is, by definition, nonfunctional. If the flagellum has 30 proteins and you're missing 2 or 3 or 4, it doesn't work, and therefore evolution could not gradually have produced 10 parts, 15, 20 parts knowing that a couple of million years in the future these parts would be useful, they gotta be useful right now--that's true by the way--and therefore it couldn't have produced this flagellum. That's the argument. Now in case people don't get this flagellum, Dr. Behe likes to make an analogy to a mousetrap and some of you may have noticed I brought... I'm sure that all of you lead such vermin-free lives that you've probably never seen a mousetrap, but I brought one along with me, and a mousetrap has five parts, it's got a base plate, bait holder, a little hammer, a spring and then a catch. And it's true that if you take any of these parts away, the mousetrap seemingly will not work, so all these parts have to be together at the same time in order to have function, and as Dr. Behe has written, all the components have to be in place for it to catch any mice, therefore it's irreducibly complex, just like the bacterial flagellum. Now putting it in a more graphic way, the machine itself, whether it's a flagellum, whether it's a mousetrap, or whether it's some other combination of proteins, has a function and that function can be favored by natural selection. But the individual parts, he argues, don't have any function till you put them all together. Because of that they couldn't have evolved and what he has written is since natural selection requires a function to select--no argument there, it's true--an irreducibly complex biochemical system would have to arise all at once for natural selection-- that as you'll see is not true--but that's the argument for all of this. So putting it again graphically, if you have a complex machine, it has a function that can be favored by natural selection, but the individual parts have no function, therefore they cannot be shaped by natural selection, therefore this machine couldn't have evolved, therefore, proof of the designer. That's pretty powerful. How does evolution explain that? Well, the way that evolution explained it, and Darwin actually explained it as well, is that's a false view. These complex machines actually arise from simpler machines with limited numbers of parts and the components themselves originate with different functions. As these parts get put together, new functions emerge and the final function emerges only when you put the parts together, so natural selection can work on these all the way through. Now that's not evidence, that's just an argument, but the cool thing about this, is it enables you to test this argument by holding these two up. If you take... if the Intelligent Design guys are right, the parts of these complex machines should be useless on their own. But if evolution is right, these parts should turn out to do other jobs in the cell. So let's check it out, let's see exactly what happens. Let's start with that bacterial flagellum--there it is, and this is from a *Biochemical Review* article, it's got about 30 different proteins, so let's do an experiment. Let's take away not one part, not two or three, let's take away all but 10 of its parts. Now the cool thing about computers is they make these experiments really easy! Watch this! Oops, there they go! So I have taken away all but 10 parts and the 10 I've left are the 10 that span the biological membrane. Here is another review showing exactly what these 10 parts are. Well if the Intelligent Design argument is right, then what's left behind--because we've taken all these parts away--this should be nonfunctional, but it turns out it's not nonfunctional. These 10 proteins perform, to the cell that has them, an absolutely vital function that has nothing to do with flagellar motility. They make something up called the type III secretory system, which is a little molecular syringe that really nasty bacteria use to pump our cells full of poisons and to kill them. Now these 10 parts have nothing to do with flagellar movement, but they are still functioning. So what does that do to the argument? Remember what the argument was. Any precursor to an irreducibly complex system that is missing a part is by definition nonfunctional. There is the complex

system, this guy is missing 20 parts. Is it nonfunctional? Uh-uh. It is perfectly functional. So what that tells us is, this statement, which is not a peripheral one, this is the heart and soul of the Intelligent Design argument, it tells us that statement is wrong. There is no other word for it. And it turns out when we analyze the bacterial flagellum itself, these are the proteins associated with the type III secretory apparatus, but it turns out just about every other protein in the flagellum actually has a function of its own in a system elsewhere in the cell unrelated to flagellar movement. And you know what that means? It means that when we actually analyze the flagellum, it fits the evolution prediction, which is that the parts should have functions of their own and so they do.

### **23. Blood-clotting factors: Not irreducibly complex. (51:57)**

Now the flagellum is not the only argument where this breaks down. These guys make the same argument about the complex series of proteins that clot the blood. If you are missing even one of these proteins, your blood doesn't clot properly--that part is true. So the argument is made that these proteins are only used to clot blood, in the absence of any of the components, blood does not clot and the system fails. Evolution, therefore, couldn't have produced it, 'cause it would have to produce all the parts at the same time rather than to produce a few gradual. And in fact the textbook called *Pandas and People* that is used for Intelligent Design classes makes exactly the same argument. You need all the parts in working order, all the proteins have to be present simultaneously or blood clotting doesn't work. It's a bold claim and it would be a powerful argument against evolution, if it were true, but it ain't. And it turns out we can do an experiment and check. Here is a drawing showing all these complicated proteins, so let's eliminate one component and I'm gonna pick a protein called factor XII, very important 'cause it actually starts the cascade, so let's eliminate it, again these experiments are easy to do in PowerPoint, there they go, it's gone. Will the blood clot? Well, the answer turns out to be yes, whales and dolphins in fact, lack factor XII right at the molecular level, they don't have the gene for it. This turns out to be an adaptation for deep sea diving, but it also means that they can miss a component and their blood doesn't clot. Well, maybe they got it wrong, maybe you can eliminate one component. Okay, fair enough. So this time let's go a little farther, and let's eliminate three parts and the three parts I want to eliminate are this entire cascade up here, now let's see what happens. Well, it turns out that puffer fish lack all three of these parts--there's a puffer fish for those who haven't gone fishing recently--and it turns out they are lacking all of these components and guess what? They have a perfectly functional clotting system. So once again, the core of this argument, which is that in the absence of any of these components blood will not clot and the system fails? Sorry, it's wrong! So all of these biochemical arguments fall apart. And actually when you look at these systems in detail, we can actually, by comparative genetic analysis, see where the parts of the clotting system came from in very simple chordate animals and we're finding more and more about the evolutionary pathway that really did produce blood clotting all the time.

### **24. Mouse trap analogy. (54:26)**

Now, here's the question, why does this fail? It sounded... and look at the mousetrap, it sounded like such a good argument. You need all the parts or it doesn't work at all. Well, five or six years ago I was on a television program on PBS called *Firing Line*, hosted by a guy named William F. Buckley where they have these debates and Michael Behe was there and he had a mousetrap, made the argument about the mousetrap, I had a mousetrap in my briefcase and a pair of pliers, and to his absolute horror, I pulled the mousetrap out, pair of pliers, I yanked one of the parts off the mousetrap, threw it away. I bent one of the other parts and I still got the mousetrap to work. That was after his argument you take a part away, mousetraps don't work, so I want to show you I'm very proud of this. One of my great scientific achievements. What I did was I took out the bait holder and as it turns out if you take the hold-down bar and you twist it, so it just goes under the spring you have a four-part mousetrap, and lo and behold if you have a really stupid mouse, and it comes up and bumps this to the side when he takes the bait, the hammer goes down and he'll be just as dead as if he was killed with a five-part mousetrap. So it's not true that the four parts wouldn't have a function. I thought I

was pretty clever, but then I got an e-mail about a week later from a guy at University of Delaware named John McDonald--he is the clever guy. John said, "Dear Ken, I liked your four-part mousetrap "demonstration on the TV show, nice job, but why did you "stop there? Why didn't you take another part away to "make a three-part mousetrap, which would also hold bait "and catch mice and when that had sunk in take another part "away, you can make a perfectly good two-part "mousetrap, mouse comes over, bumps the cheese, this thing "comes down... and finally the ultimate, which is the "one-part mousetrap." And therefore, this argument about all the parts having to be there--it is fictitious. Now, there's a better point than that. Some of you may have noticed that I've been wearing what you think is a mousetrap as a tie clip. Well, it's actually not a mousetrap. I've taken two parts and thrown them away, so I only have three parts here, I have the base plate, the spring, and the catch. You can't catch many mice with this, but it makes a perfectly functional, if not very elegant or attractive tie clip. And that's the point, which is that the parts of a supposedly irreducibly complex machine can be used for different purposes and in fact if you have just two parts, you can even make a key chain, out of mice trap and I'll be selling these later on, on the way out in case you'd like to buy any of these. So the point to be made is the mousetrap, ironically, is a perfect argument for evolution, because it shows how the parts of what is supposedly an irreducibly complex machine can actually be used for other purposes, and you can look at what some of these other purposes are, directly in the slide and you might like to try some of them yourself, with the permission of course of your parent or guardian. So the mousetrap example unexpectedly provides a perfect argument in favor of evolution.

## **25. Intelligent design is religious doctrine. (57:23)**

Now the last thing that happened at the Dover trial is it exposed Intelligent Design as a religious doctrine masquerading as science and a very particular religious doctrine at that. How did we establish that? Was it by the expert testimony on our side of the case? Actually, no. It turned out that the best argument for that was the expert testimony on the other side of the case and that is, when we got the expert witnesses for the other side on the stand, look what they said. Behe said it's implausible that the designer is natural, therefore, he's got to be supernatural. Another witness said that for Intelligent Design to be considered science, we gotta change the ground rules of science, so that supernatural forces can be counted as part of science and another witness said, the whole idea of ID is to change the ground rules of science so that it includes the supernatural. We didn't have to make the case, it was just a question of putting these guys in the stand and just keep talking. Tell us all about it. And lo and behold supernatural forces... as many religious people might say, might be real, but they're certainly not part of science. So considering them as science I think profanes religion and corrupts science. There was a perfect example of that during the trial. Dr. Behe was questioned about how if you change the ground rules of science so that supernatural forces needed for Intelligent Design can be considered science, wouldn't it mean that other forces can be counted as scientific as well. And in particular it was pointed out to him that astrology would fall as a science by his definition and to everyone's absolute astonishment, when he was asked this question he agreed with the assertion that under his definition, astrology would count as a science and could be taught in scientific classrooms. Whenever I speak to gatherings of teachers or lay people interested in education, I always try to remind them that the leading scientific expert in favor of Intelligent Design, under oath at the Dover trial, got on the stand and lo and behold he said that if Intelligent Design is considered science, so is astrology. I don't think that's where we want to take the scientific classrooms in this country especially when we are involved in an international competition that will determine whether or not the United States remains the leading scientific nation in the world. I don't think teaching astrology in the science classroom is gonna be the key to our retaining worldwide leadership in science.

## **26. Science and new ideas. (59:54)**

There's another point that you hear sometimes as well and that is the scientific community is biased against Intelligent Design and we don't treat new ideas, we suppress them, we keep them out, so it's only fair to put Intelligent Design in the classroom. What this argument overlooks is the fact that science deals with novel

scientific ideas all the time. It's sort of the stock, lock, and barrel of science. It's the sort of thing that we love to have. So what happens with a new idea, with a novel scientific claim? Well, the people who back it go out and they do research. They subject that research to peer review and peer review means you write, you come to meanings, you argue, you debate, you accept criticism, you do counter experiments. In short, you try to establish that your idea has the evidence behind it and that it's useful and eventually if... and you really have the evidence behind you, you win a scientific consensus and then quite automatically these new ideas get into classroom and textbook. Just as an example, six years ago the notion of a process called RNA interference as being responsible for genetic regulation was unheard of. Then all of a sudden the evidence behind it began to mount and it is now clear that small interfering RNA molecules play a major role in development, differentiation, and gene expression. Textbook writers everywhere, and I am one of them, are now putting this material into the textbooks, not because state boards of education required it, but because the scientific community reached a consensus that this process is important. Now the people who advocate Intelligent Design like to say, "We got a new scientific theory too. Be fair to us!" That's cool! If they wanted to go through this process, I'd say great! See you at the next Biochemical Society meetings, see you at the Cell Biology meetings! Let's look at your evidence. Let's subject it to peer review. But you know what they want to do? They don't like this! They think this process is too messy and too time-consuming. Their idea of how things should work is actually more like this, which is to be directly injected into classroom and textbook, and wherever they have gotten the attention of boards of education or legislatures, they have consistently acted to short circuit the very process of science. I would argue then, far from being unfair to exclude this idea from the curriculum, it's actually unfair to include it without making it go through the process of review, debate, evidence and experimentation that every other scientific idea, including evolution, has had to go through in order to get into classroom, textbook, and curriculum. Intelligent Design, creationism in my view, is not rejected as some people say because it has religious implications. I think a lot of ideas have religious implications and they still find their way into science. The reason these ideas are rejected is far simpler and the headlines from these scientific papers tell you exactly what that reason is, and that is that these ideas have been rejected by the scientific and the science education community for a far simpler reason. And that reason is because the evidence shows it's wrong. Thank you, thanks for your attention.

### **27. Ken Miller on *The Colbert Report*. (1:03:16)**

Now, I was asked a question that I sort of deferred earlier on, like, how do you fit this in with your religious views? And I told you that Colbert had asked me that question and I figured, I'll show you my answer to it. You're a Catholic? Yes sir. I am a Catholic also. Have you forgot the creed, Jesus, through him all things were made! For us men and for our salvation! Exactly! I remember all this very well. Okay! So don't you see a conflict there? You got to choose. No, there's not a conflict, there's not a conflict There isn't? And you don't have to choose and here's the problem. The biggest thing that the opponents of evolution have going for them is a fiction. It's not true and that is the idea that evolution and religion have to be in opposition to each other. What it amounts to in a sense is that I have a higher opinion of God than the people who favor Intelligent Design, because they think he is sort of a little pedestrian God who has a lot of cheap tricks. He had to design this, oops! It went extinct! He designed that, it went extinct! The fossil museums of the world are filled with his mistakes. My view is I've got a higher opinion, this is the guy who was so clever that he set a process in motion that gave rise to everything on this planet and you and me and maybe even Bill O'Reilly. You know what? I agree with you about O'Reilly. All right? I think O'Reilly could be so involved that he is one of the X-Men. Okay, now let me ask you something. You think God is that clever, I think God is so clever that he just made it look like there is a fossil record. So. Isn't God powerful enough that he just sort of put all those dino bones down in there to give us the illusion we've been here for a while, when in fact nothing existed before I was born? So, your theory is essentially what I would call the Steve Martin Theory of Evolution, which is that God put all these things down here just to show us he is a wild and crazy God. Well, I don't reject that for scientific reasons, I reject it for theological ones, which is that I don't choose to believe in a deceptive creator. Mr. Miller, will you come back, we've got to go now, but will you please

come back in another show and explain to me this whole "sun doesn't go around the earth" thing? We'll work on it! Okay! Ken Miller! Thank you so much, we'll be right back! So I hope that's a more detailed answer to your question. Okay.

**28. Q&A: Why have mammals evolved to be smaller? (1:05:34)**

Sir, in the striped shirt. Over time, like larger mammals, they became gradually smaller as they evolved, is there a reason for this or... I was reading an article yesterday and, is there a reason, like the giant sloth, now we don't have giant sloths any more, is there a reason to this? Okay, well, what you're asking me about is there an evolutionary trend to make animals smaller, okay, so I got a question for you. Sorry to throw the question back at you. What's the largest animal that has ever lived? Not sure. Anybody else? Blue whale! Okay. It's still here! So not all evolutionary trends reduce the size of animals and it depends upon local circumstances and nutritional circumstances. These are actually a very well-understood trend in ecology and evolution that when large animals find themselves on very isolated islands with limited food sources and other evolutionary pressures they tend to get smaller and the reason for that of course is that a smaller animal has fewer metabolic demands, can get by with less food and might be in a limited area where that actually happens. But evolutionary trends go in both directions. They go towards the larger and they go towards the smaller. So I don't think any one trend characterizes evolution and the persistence of the blue whale alive today, the largest animal that has ever existed, I think is a good indication of that.

**29. Q&A: When will the evolution debate end? (1:06:54)**

Right there sir. How long do you think it might take for the whole debate over evolution to be resolved? How long do I think it would take for the debate over evolution to be resolved? My short answer is, not in my lifetime. This is something that people have been kicking around for a long time and it's not a uniquely American debate either. It turns out there is a very strong Intelligent Design movement in Great Britain. This movement has made strides in the Middle East. Turkey for example, actually the country of Turkey actually surpasses the United States in the percentage of its people that reject the theory of evolution because there is substantial anti-evolution activity in the Islamic world. I think it's gonna be around for a long time. There're always gonna be people who for one reason or other reject the theory of evolution in spite of the overwhelming scientific evidence behind it. But I do think this and that is that right now in the United States this has reached a point of such controversy, we have people running for public office being asked to comment about it, school board elections being decided by this one way or another, it's reached a point where we're actually at what a systems analyst guy would call a tipping point, and I honestly think this country is gonna go one way or another, and as a scientist and an eternal optimist I think we're gonna go the right way and the right way is by an increasing embrace of the scientific ways of understanding things and also of an appreciation that science and religion ultimately can be in harmony, so I am optimistic that that's how things are gonna happen, there's always gonna be people who oppose evolution, but I think ultimately this country can come out of the current debate with a better appreciation for the nature of science and a better appreciation of the value of religion.

**30. Q&A: What is the origin of DNA? (1:08:38)**

Right here sir. How does evolution fit into the origins of DNA? The origins of what? DNA? Well, it's a very good question and that is, for quite a long time, people investigated the origin of life have wondered which molecule came first. Some very early experiments done with primitive earth conditions in the 1950s suggested that amino acids, the building blocks of proteins, form quite easily, spontaneously under primitive earth conditions. So they wondered if proteins might have come first, but of course nucleic acids, we now appreciate more than we did in the 1950s, carry the information. There's substantial sentiment within the scientific community that DNA is just sort of an offshoot, and that the first information-carrying molecule actually was RNA, and there are couple of reasons for that. One of the reasons is that RNA has a very, very

profound catalytic activity. The Director, the President, the CEO of the Hughes Institute, Tom Cech, won the Nobel Prize for the discovery that RNA can catalyze certain chemical reactions. One of the reactions that RNA can catalyze is its own replication. That has led a lot of scientists to speculate that primitive earth conditions formed some of the first bases, which became primitive RNA molecules that were capable of coding information and copying themselves, and once you get a molecule that can self-replicate, that means the conditions for natural selection are satisfied. The origin of DNA is a little more mysterious and the general sentiment--again, it's sentiment, not strong evidence--in the scientific community, is DNA emerged as a kind of safe repository from sort of the cauldron of engaging in chemical reactions. So the DNA was a sort of a storage or archival form of the genetic information that originally started out in RNA, and in fact one of the questions that my own freshmen students at college ask me all the time is, "Why "couldn't a cell make-do with just one kind of nucleic "acid?" In other words, why doesn't a cell have everything in DNA or everything in RNA? And I think the answer to that basically is that RNA is now used as sort of a cheap disposable copy that can be made from the archival copy--DNA in the eukaryotic cell nucleus which stays out of the fray--and RNA goes out into the cytoplasm and actually does sort of the business of expressing the genetic information, so that's a long way of saying we don't know for sure, but those are some of the thoughts of people who work on the problem. Okay,

### **31. Q&A: How is information added during evolution? (1:11:04)**

in the blue shirt. That'd be you. Obviously the evidence shows speciation over time and like the evidence that you've shown about mousetraps is that elimination of features doesn't eliminate the usefulness of the components. Such as in apes to humans, how does environmental stimuli, how can that be shown to increase the genetic information of humans, not found in apes, which is I think I heard about 300 million new DNA codings. Well, the first thing to appreciate is that we humans as a species did not evolve from apes, we didn't evolve from gorillas or chimpanzees or any species alive today. Rather we and the great apes share a common ancestor in the past. So, often people say, "Well, I didn't "evolve from any monkey." Well, no one ever said you did. What evolution says is that we and monkeys and for that matter all organisms share a common ancestor if you go far enough back. Now that we have the chimpanzee genome and we can analyze it, you say there's a certain amount of genetic information we have that's not in the others. Well it's not that we have more genetic information--we have about the same in terms of numbers of DNA bases compared to the other great apes--but our information is different. And one of the things that investigators have focused on in the last year since we've had the chimpanzee genome to compare with ours, and there'll be more focus in the next couple of years when we will get both the gorilla and the orangutan sequence, people are working very hard at these right now, is, we have been able to pinpoint the spots in our own DNA which have been subject to really, really strong natural selection and one of the interesting things about this and this is all very preliminary stuff 'cause the work is just starting to get published, is a lot of these areas of intense natural selection in our DNA concerned the development of the nervous system. Now that's really exciting, the brain, among other things. It's really exciting because the most striking thing about our own evolution is that one of our organs increased in size by a factor of 3 in a space of just about three million years compared to the other primates and for some of you in the audience with prurient minds, no it's not the organ you're thinking of, it's the brain that increased by a factor of 3. How natural selection... I should've been aware of what I am dealing with in the audience here... The interesting thing is it's been very difficult to understand how natural selection could have favored what is, by all accounts, an explosive increase in the size of the central nervous system in the brain. We now are beginning to understand the individual genes that were subject to natural selection that control the development of the nervous system and I'm pretty confident that within a few years of comparative genetics we will understand the forces of natural selection that drove that increase and I think more importantly for the study of our own biology the genes that actually control our own mental development. So I don't have an answer for you, but I think the answer is forthcoming very shortly. Good question! Okay,

### **32. Q&A: Is there a "God" gene? (1:14:09)**

right in the corner. The human genome is getting really close to being done and some people have been talking about something called the God gene or something like that. Yeah! Do you believe in that at all and do you think it's possible that, that could actually exist? Well, the... for the strict use of words I'd say belief plays no role in science. I don't believe in evolution, I don't believe in the Krebs cycle, I don't believe in the eukaryotic cell. I accept those things as the best scientific explanation on the basis of evidence. Belief is for things like theology or baseball or football. You might believe in the Redskins, but well.. I believe in the Red Sox and see how it turned out this year. But the notion of the God gene has been popularized by a number of writers in neuropsychology and what they've argued is that natural selection on our species has given us an innate capacity in our brains to accept religious explanations for things. The great Harvard biologist, E.O. Wilson, argued this almost 30 years ago in his book *On Human Nature*, and Ed Wilson argued that natural selection produced this sort of theological capacity which gives us an ability to unite, to join with fellow human beings around myth, ritual, and religious explanations for things and the reason that prevailed is because those organisms that were able to do that were better at raising food, hunting down animals, making more, and raising children, all of which are important civilized traits in one sense or another, therefore, that's why we have the capacity to believe in religion. Steven Pinker, a very popular writer on evolutionary psychology, has argued that our brain has a God module and the God module predisposes us to find religious explanations for things satisfying. Therefore, religion is nothing more than an artifact of this gene or this module in our brain. Now, Steve Pinker is someone whom I've talked with about this and I've talked with other people about it as well. I think that explanation is generally correct and I say that even though I consider myself a religious person, so how could you do that? Showing that natural selection produced part of our mental capacity, I think is no different from showing that natural selection produced the rest of our bodies and if you believe in a creator, if you believe in a supreme being who used natural processes to bring the physical part of our species into existence, why wouldn't that creator had used the same natural processes to bring the mental part of our being into existence, namely the God module and if I had to answer Steve Pinker, who says "Ken, you go to church on Sunday "because you got the God module and it's taken you "over," I'd say "Steve, natural selection, if it produced our "ability to form religion, you know what else natural "selection also produced? It produced our ability to do "science, and it produced our ability to like and accept "rational scientific explanations for things." I wouldn't disqualify science by saying that the brain of someone has a science module and that's why scientific explanations seem sound and reasonable and I certainly don't think you can disqualify religion by saying natural selection produced a God module that predisposes you to find religious explanations satisfying. That's a very good question and you certainly get a trilobite for that.

### **33. Q&A: What about panspermia or exogenesis? (1:17:33)**

Right there, yeah. What is your view on panspermia or exogenesis? Panspermia is the notion that life on earth didn't originate on earth, but came here from some other place. I find this to be an intriguing notion. I would argue... I think most biologists would say that the capacity for life is built into matter. In other words, the very laws of physics and chemistry give what we call inanimate matter--carbon, oxygen, nitrogen, hydrogen--the capacity to become alive when arranged in a certain way. I would be astonished given the vastness of the universe and the constancy of the laws of physics and chemistry, if this little planet zipping around a medium-sized star in a nondescript galaxy was the only place in the universe where that had ever happened. So I'd be very much surprised if life is only confined to this one planet. Do I think life might have come to this planet from somewhere else? It's possible. Meteorites fall into earth all the time that have organic compounds on them, complex chemicals. Now how do they originate? We think they originated by the same natural processes that primitive organic chemicals originated on this planet, so that means elsewhere, even in our own solar system, the building blocks of life might be in the process of assembling. I don't think, however, saying that life on earth arose by panspermia solves the scientific problem of how did life originate, it would just put it on another planet. One way or another, ultimately, a great scientific challenge is going to be to figure out where life came from. Panspermia doesn't get us any closer to that, but

I think it's an attractive idea given the vastness of the universe and the capacity of matter for life. Right up front.

**34. Q&A: Will evolutionary breakthroughs continue? (1:19:20)**

That'd be you. Do you think there will continue to be breakthroughs in evolution in the future? It's a good question! Will there be breakthroughs in evolution in the future? There are breakthroughs in evolution literally every time I open a scientific journal. I see one or another of them. There was a paper about three weeks ago that was published in one of the world's leading journals, talking about speciation mechanisms--the genetic mechanisms that take a single species and divide it into two and prevent the newly-separated species from interbreeding with each other. That's really the first step to forming two species and what these studies showed is that a very simple single mutation--this was in *Drosophila*, the fruit fly that we used for lots of laboratory studies--but a single mutation could separate two species so they could not longer interbreed. That was remarkable because prior to that people thought as I showed in one of my slides that this might take years or even decades. We now know that in certain cases it can happen in a single generation, so yes I think there will continue to be breakthroughs. We continue to find new fossils. A spectacular new fossil was found in Africa just last week or reported just last week. And finally, evolution is the tool that we use to investigate our genome. In other words the exploration of the human genome, the DNA sequences that make us human, that exploration wouldn't be possible without using evolution as a tool to compare ourselves to closely related and distantly related organisms to see where natural selection has happened on us and every time we do that we find new things out. So I am confident that new breakthroughs are gonna continue to happen. I should see, I should, take, should have brought a bag with a whole bunch of these.

**35. Q&A: Is evolutionary change predictable? (1:21:06)**

Sir, right in the center, blue shirt, yeah. So, because of these mutations people change, so, do we have actually a method of predicting as to when these possible mutations will take place? Well, one of the fun things if you want to call it that, about that, about mutation and genetic change is that it is to an extent unpredictable. In other words you simply don't know where errors or mistakes or duplications or translocations of DNA are going to pop up, so in that sense we don't really know. However, Sean Carroll, one of the people who gave the earlier lectures in the evolution series pointed out that we animals actually have a genetic makeup that builds the body, in other words that produces top, bottom, belly, back, head, tail, limbs, segments within our body which we can actually see in blocks of muscle and blocks of bone and so forth. And the genetic makeup that produces that body, he argues, is actually almost predisposed to produce useful variation. So even though we don't know where the genetic change is going to pop up, the genetic makeup of organisms around today is actually geared to accept that and to produce useful variation. Now one of the things that evolution does, and this is a technical term, is it explores adaptive space. Now what that means in a jargon sense is that organisms basically reach out in one direction or another and it's natural selection that fine-tunes that variation and finds the solution. So if we start to use new antibiotics in our hospital, we can be certain that the bacteria we're trying to kill are going to evolve resistance to those antibiotics. We don't know where the mutations will come from, we don't know when, but we can be certain, because we're creating a form of natural selection, that that can happen, and we see this kind of change all the time, so to that extent it's somewhat predictable. Okay? Thank you.

**36. Q&A: Do you believe in eugenics? (1:23:04)**

Right in the center, yeah. Do you believe in eugenics? Well, eugenics is a word that was coined actually I think by Francis Galton who was the nephew of Charles Darwin and it is... it generally is understood as describing the process of using genetics to improve our own species. And the answer to that is no, I don't. Because first of all I think it's naive to believe that we can look at you or me or Dennis or anybody else and

say "You know, you're not worth "reproducing, we don't like your genes, we're gonna let you have "a lot of children or we're gonna try to do this sort of thing." For two reasons, one is, it's inhumane, it doesn't respect the individual dignity that we all have as human beings, and secondly it overstates dramatically the extent of scientific knowledge. We don't know that much about human genetics that we could actually say how we can breed or make or otherwise manipulate a better human being. Now, having said that I don't believe in eugenics, because that's the way it's usually understood, I do believe that modern genetics and genomics give individuals the information that they need to make decisions about their own reproductive future and I'll give you a perfect example of a eugenics-like program that I think has worked extremely well. There is a serious inherited genetic disorder among... in this country, among Jewish people of a certain ancestry called Tay-Sachs disease. It's a recessive disorder, it's extremely rare. If a baby is born who carries two copies of Tay-Sachs, what happens is their nervous system breaks down, it breaks down dramatically between the second and third year of life, they usually die before they're old enough to go to kindergarten, it's very difficult for the family, it's extremely traumatic. So what has been operating within the Jewish community for quite a few years has been a program to encourage people who are about to get married to voluntarily get tested, to see if they carry one copy of this gene, because if they're then about to marry somebody who carries another copy of it, geneticists can tell them they have a 1 in 4 chance of producing a child with Tay-Sachs. Now they may take that information and decide they're gonna try anyway, or they may take that information and decide, tell you what, let's adopt children or let's otherwise undergo reproductive interventions that will ensure that we don't bring a child into the world with this horrible disease. But that kind of decision-making I would say is not eugenics. That kind of decision-making is basically giving people the information that they need to make informed decisions about their own lives and I think that's a good thing. Okay.

### **37. Q&A: How can life come from inanimate matter? (1:25:40)**

Try and move things around. Sir. When do you think that there is gonna be evidence of abiogenesis? When do I think there is gonna be evidence of abiogenesis? Abiogenesis is a term that means life coming from inanimate matter. Well, depends what you mean by that. Some people would say that abiogenesis took place about 10 years ago and it was 10 years ago, little more than 10 years ago, I think, when scientists took chemicals off the shelf, put them into DNA synthesizers, synthesized the DNA molecule of a virus and then were able to reconstruct a virus particle. So if you consider viruses to be living, that's abiogenesis. A very well-known scientist, Craig Venter, who worked on the Human Genome Project, is now trying to do exactly the same thing with a real cell, not a virus, a bacterium, trying to construct a minimal organism. Knowing this guy, within a few years he's probably gonna succeed. So that sort of ability to take nonliving chemicals and put them and make them come alive by mimicking the living cell, I think that's pretty close. The larger question that I think you're asking is how soon is it going to be that we will have an answer to the riddle of how the first living cell originated from nonliving chemicals on this planet? I am not optimistic that it's gonna happen anytime soon. And the reason for that is, happened a long time ago and it didn't leave much evidence, but there are a number of researchers who have put together pieces of the puzzle and I am certainly confident that that's exactly how it took place. Jack Szostak at Harvard has done some absolutely brilliant work that involves self-replicating RNA molecules and the simulations of conditions on the primitive earth, so I certainly think that it happened that way, but in terms of achieving a total understanding I think we're a couple of decades away from really understanding how life originated on this earth. Good question. Thanks for your attention. Thanks for the opportunity.