ADAM AND THE GENOME

Reading Scripture after Genetic Science

DENNIS R. VENEMA
// AND //
SCOT McKNIGHT

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FOREWORD

In 2009 the world commemorated the two hundredth birthday of Charles Darwin and the one hundred and fiftieth anniversary of the publication of his groundbreaking work *On the Origin of Species*. Many decades after the appearance of that book, evangelical Protestants find themselves once again in a bitter conflict over the theory of evolution. Though the controversy still rages with those outside our theological family, particularly the "New Atheists" such as Richard Dawkins, the most heated discussions are now taking place among evangelical Christians—between those who believe that one must make a choice between the Bible and evolution, and those who argue that the Bible and evolution are not in tension with each other.

Fuel for this intra-evangelical debate comes from the mapping of the human genome, which was completed in 2003 under the leadership of Francis Collins, who is not only a leading biologist but also a devout evangelical Christian. The evidence provided by the genome, added to the mounting evidence of hominid fossils, further testifies to the persuasiveness of the theory presented by Darwin in the mid-nineteenth century.

To compound the conundrum, the research of evolutionary biologists also points to another conclusion that disturbs many evangelical Christians—namely, that humanity begins not with a single couple but rather with an original population of some thousands of people. This evidence leads to the now-much-discussed question of the historical Adam. If Adam and Eve were not historical individuals, is the Bible true? Were humans originally innocent? Was there a fall? Is there such a thing as original sin? If so, how does original sin affect us today?

These are crucial questions that aren't easily answered. They are also questions that cannot be ignored by refusing to address them or by vilifying those who hold opinions that are different from the ones we are used to.

Further, the evidence is clear that the church has a credibility problem in the eyes of our youth when it unthinkingly rejects evolution. When presented with the choice of evolution or the Bible, many are choosing evolution. Those who choose the Bible and reject evolution often do so at the cost of their intellect.

As we will see in this book, to force such a choice on our youth (or anyone for that matter) misrepresents the Bible and has worked great harm.

To deal with these issues, we need to marshal our best theological and scientific thinking. With Dennis Venema and Scot McKnight, we are getting exactly that.

I have known Dennis for about five years and have come to appreciate him for his intelligence and his devotion to God. His knowledge of biology and, in particular, the genome is impressive, but so is his ability to explain complex research to laypeople like me. I have found him to be an incredible resource for understanding biological science, and I know that you will too.

I have known Scot for a long time as a fellow laborer in biblical studies and as a friend. Over the past three decades, he has taught New Testament in both college and seminary settings. He has established himself not only in the academy but also in the church. Scot is that rare academic who knows the scholarly material extremely well but is also able to communicate what is important to a broad audience in an understandable and winsome way. He is passionate about Jesus, and he wants Christians to love God with their whole selves, including their brains. Scot has devoted his life to the study of Scripture because he knows that it is the Word of God and it is in Scripture that we hear the voice of God.

I can't imagine a better combination of thinkers to help us navigate the difficult and controversial waters of questions surrounding evolution and the historical Adam. Dennis and Scot deserve our attention, and their arguments demand our careful consideration. I, for one, thank them for their lifelong work in elucidating God's "two books," Scripture and nature, for us.

Tremper Longman III
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INTRODUCTION

Like many evangelicals, I (Dennis) grew up in an environment that was suspicious of science in general, and openly hostile to evolution in particular. Yet I had a deep longing to be a scientist, even as a child. For a long time, I reconciled my two worlds by rejecting evolution—after all, evolution was "just a theory" pushed by atheists and supported by "evidence" so flimsy that even a child could see through it. Moreover, Jesus was the way, the truth, and the life, and "what the Bible said about creation" was good enough for me.

I almost didn't become a scientist; despite my childhood dreams, I intended to be a medical doctor, I think largely because I could see that role as having a place within Christendom. I was keen to use my mind and skills for the kingdom, and when I was a teenager, medical missions seemed to me the closest fit. I decided to use biology as a way to prepare for medical school, and along the way God rekindled my childhood interest in science. Looking back, I wonder if my path would have been less circuitous if the church had had a better relationship with science to begin with and "scientist" had been on the unofficial list of acceptable Christian careers. To be sure, "evolutionary biologist" is, at present, certainly *not* on that list.

Now I'm on the other side of the equation, teaching biology to undergraduates—many of whom, like me, come from an evangelical background. Like me, they've heard that evolution is evil and that they have to choose between the Bible and science. I wonder how many of their friends have already made that choice and aren't in my class. How many of them, I wonder, might have become the next Francis Collins? And how many of the students that do come to learn biology, upon realizing that the Sunday-school flannel-board theology they learned as kids just isn't up to the task, will abandon their faith, despite my best efforts to walk them through it with love and pastoral sensitivity?

We as a community need to do better—for the future of the kingdom.

One way for us to do better is to learn—to learn what modern evolutionary biology is really all about, not the caricature that I absorbed simply by being a Christian. With that information on the table, then it's time to have a careful look at Scripture, allow it to speak for itself without our cultural baggage, and consider carefully what we teach our young people. Science has called us back to the text before, and it is doing so again. That is what this book is about, and it is a book I have wanted to write for a long time.

That said, I knew that I wasn't up to the entire task. I needed someone with expertise in theology and exegesis—preferably someone with expertise in the New Testament. For though Genesis was key, I was finding more and more that the conversation was shifting from Genesis to Paul—specifically, to what Paul says about Adam.

In March 2012, as I pondered these things, I attended a BioLogos meeting in New York where Scot was one of the featured speakers. As he gave his paper, I was startled to hear him mention my name and some of my work on evolution, specifically referencing its implications for Adam and Eve. I had no idea that a *theologian* was reading one of my papers—and considering that paper's dense, technical language, it's a testament to his tenacity that he got anything out of it at all. Like me, Scot had also been wrestling with these questions from a theological angle, and he was more than willing to add his voice to the conversation.

I (Scot) remember that meeting when I met Dennis, but what I remember even more was reading Dennis's article the first time some months earlier. It took me a good week to read it—so full of charts and information and terms that were not part of my vocabulary and thinking patterns. Along with Dennis's exceptional article I read the other articles in the magazine, and I blogged about them—convinced that if Dennis was right about genetics, then I had some work to do. It was time to do exactly what Dennis and so many others were suggesting: take a new look at Adam and Eve in the light of modern genetics.

It is undeniable in my circles that every time someone brings up evolution—no matter how it is framed (old-fashioned Darwinian evolution, radical materialistic evolution, theistic evolution, evolutionary creation, or some forms of intelligent design)—the question eventually comes to this: *How do I, Scot, believe in Adam and Eve if I embrace some form of evolution?* The perceived implications of embracing evolution haunt many: if evolution is true, the Bible can't be; if evolution is true, the historical Adam never existed; and thus, if evolution is true, there is no reason to preach the gospel to all. I call this theological construct the "historical" Adam and will discuss what that means at the end of chapter 5.

When Dennis contacted me to ask if I would participate with him in a BioLogos grant project on the genome and Adam, I knew the time was ripe. It was time for me to get after the problem and resolve the intellectual tensions in my head or to hide in the library behind my Bible and just do Bible studies. Here's what I did after agreeing to work on this project: I propped up Dennis's article on the genome and hominins next to my computer and proceeded to rewrite the whole thing in language I could understand. It was hard work for me, but I wanted to understand the science of genetics better so I could appreciate more deeply the conclusion of many geneticists today: the DNA in current humans could not have come from a pool of fewer than approximately 10,000 hominins. (These terms will be defined and Dennis's article will be noted in the chapters that follow.) Once I was done with that I sent it off to Dennis, and he informed me that I basically got it right—which was his kind way of saying that I'm a theologian and not a scientist, but that I understood the big picture.

What follows in *Adam and the Genome*, then, is a basic introduction to the science of evolution and genetics and how it impinges on the basic claim of many Christians: that you and I, and the rest of humans for all time, come from two solitary individuals, Adam and Eve. Genetics makes that claim impossible—as I understand it. But instead of leading me to hide behind the Bible or insult scientists, genetics sent me into the stacks of books in the library to investigate science with freedom and to ask yet again what Genesis 1–3 was all about in its original context and then how Jews and the earliest Christians understood "Adam" when they said that name. Did they, I will be asking, think the way we did about the so-called "historical" Adam and Eve? Did they somehow escape the "science" of their day to join hands with what we know today and write things that accord with modern science? Or, which I shall seek to explain in my chapters later in the book, did they think the way ancients thought and offer to their world a brilliant vision of the nature and mission of humans in the world—all captured in that golden expression, the "image of God"? Did they not counter the ancient world's views of God and humans with an alternative theology and anthropology that have become, even among many scientists, the widespread belief of the Western world?

Thus, the book has two parts: science and Bible. The second part (chaps. 5–8, by Scot) assumes the correctness of the first part and seeks to explain Adam and Eve as they were intended to be understood in the ancient world. The first part (chaps. 1–4, by Dennis) offers an accessible introduction to the major topics that have created intellectual tensions in the minds of many Christians.

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Evolution as a Scientific Theory

I (Dennis) grew up in a small town in northern British Columbia, Canada. As a child, I spent a lot of time out in the woods with my father and older brother, hunting and fishing. It was there that I first developed a sense of wonder about the natural world and a desire to understand it better. When we cleaned a fish or a grouse, we examined its stomach contents to see what it had been feeding on. While my father fished for salmon, I puttered in the shallows and back eddies, catching minnows and aquatic insects with a net. At home, I concocted potions and brews from whatever household chemicals I could find. While other kids wanted to be policemen and firefighters, I wanted to be a scientist. Real science, as I understood it from my private-Christian-school workbooks, matched up perfectly with what God said about creation in his Word. "Darwin" and "evolution" were evil, of course—things that atheist scientists believed despite their overwhelming flaws, because those scientists had purposefully blinded their eyes to the truth. I distinctly remember that even hearing those words said out loud felt like hearing someone curse, and not mildly.

I am grateful to my colleagues at BioLogos for their support, encouragement, and shared wisdom over the years as I have worked on this volume. I am also grateful to my friend and brother Doug Chaffee, who read early drafts of my chapters and offered valuable suggestions. Lastly, I am deeply thankful for the love and support of my family as I wrote over many a late night.

My interest in science continued as I moved over to the local public high school, though, ironically, I found biology to be a dreadful bore compared with physics and chemistry. Those subjects required that I learn and apply principles, rather than slavishly memorize. Biology seemed to have no organizing principle behind it, whereas the others did: understand an atom, and you understand chemistry; understand how forces and matter work, and you understand physics. Biology? Here, memorize this laundry list of facts. No thanks.

Living in a small town also meant that I did not know any scientists beyond the ones I saw on TV. Thus I couldn't really picture science as a career, despite my youthful ambitions. My friends didn't want to be firemen or policemen anymore either, and "scientist" seemed to be as whimsical as those aspirations had been. I had, however, spent two summers on short-term missions trips, and I thought that perhaps becoming a doctor would be a good choice for a career that could be useful in the mission field. I had good grades, so medical school seemed like a viable option. So off to university I went to study biology, because a degree in biology seemed like a good way to prepare to be a doctor. My family explored the possibility of my attending a Christian university, but it was more than we could afford. So a secular university it was, and I braced myself for what would surely be a trial for my faith. One Sunday our church prayed for and "commissioned" us graduates as we went off to university or Bible college. Our pastor thanked God for those headed for the safe confines of further Christian training, and prayed that those of us headed to secular settings would not lose our faith in the process.

I must admit that I did not like my first two years of study. Again, memorization seemed to be the order of the day, and every so often the "evolution thing" would come up. Thankfully, evolution was mentioned only infrequently and easily ignored. Still, I wasn't doing that well, and biology seemed to be as boring as it had been in high school. I doubted my grades would be enough for the hypercompetitive medical school application process. But in my third year, I turned a corner. Having struggled through the basic introductory courses, I was finally getting into more interesting material where understanding principles was more important than memorizing details. Cell biology and genetics were especially interesting. I decided I wanted to earn an honors degree and write a research thesis. Why I thought this would be a good idea, given my lackluster performance to that point, I do not recall. Still, I found a professor willing to take me on, and I eagerly started working in her lab.

It changed everything. I was working on an open scientific question, one without a canned textbook answer. To address the question, I needed to understand the principles of developmental cell biology, genetics, and how gene products work at the molecular level. I was designing experiments to test hypotheses, and troubleshooting them to get them to work properly.

For the first time I was doing real science, and I was hooked.

Not surprisingly, my grades improved dramatically. At last I was being graded on my ability to think like a scientist, rather than regurgitate textbooks. While I had been worried that my average was too low for medical school, my last two years more than made up for my slow start. I had the grades for medical school now, but I had lost the desire. I didn't even bother applying, but rather signed up for a PhD program in genetics and cell biology directly out of my bachelor's degree. My childhood dreams were coming true, and I was as happy as a kid on a field trip to the fire hall.

Just a Theory

I later came to understand why biology suddenly came alive to me in the lab, and why up to that point it had seemed so dull. What had been missing was what I had glimpsed in high school chemistry and physics: underlying principles that gave order and cohesion to a body of facts. For me, it meant exploring biological theories of genetic inheritance and development, and understanding the details (facts) in light of those organizing structures (theories). Once I understood the theories, the facts were no longer unconnected details to be memorized: the facts made sense.

At this point we need to clarify some terminology: "theory" in common usage unfortunately means almost the opposite of what a scientist means by it. In common usage, it means something like "guess" or "conjecture." In science, however, it means anything but. In science, a theory is an explanatory framework for *why* the facts are the way they are. Theories are not developed overnight—on the contrary, they are the products of a long process of making observations, forming hypotheses, and testing those hypotheses with experiments.

Perhaps an analogy will help. When my children were younger, they liked to play a game called "Guess Who?" In this game, both players have a card with various characters on them, from whom they select one. The object of the game is to guess the character the other player has chosen. Each player takes turns asking questions to try to narrow down the options, questions such as "Is your character a boy or a girl?," "Does your character have glasses?," and so on. The initial guesses are just that, guesses. As the game proceeds, however, one begins to have a better-informed guess since some options have been eliminated. And once you've guessed correctly, every question you ask will be answered as you expect it to be.

A scientific theory is formed by a similar process. It starts with a guess of sorts—perhaps an educated guess, based on prior observations. It looks to the available facts and asks *why* the facts are the way they are. The result is a hypothesis—the technical term for "educated guess." A scientist can use that hypothesis to form a prediction: if this is why things are the way they are, then *such and such* should be the case. Then an experiment can be set up to test the prediction, and the result will either support or fail to support the hypothesis. If the prediction is not supported, a scientist will reject the hypothesis. If the prediction is supported by the experiment, the scientist will *fail to reject* the hypothesis. Note that this is not the same as "accepting" the hypothesis—an important distinction within science. *Accepting* a hypothesis would mean that no further tests would be required. This would make as much sense as deciding, on the basis of one or two correct guesses in the guessing game, that one had discovered the character one's opponent had selected. Not so—future tests may show that our hypothesis is not perfectly accurate. Sure, the character is female with a hat and glasses, but she *doesn't* have a purple scarf. Well, then, it's time to readjust the hypothesis in light of the new evidence.

In science, a hypothesis that is *not rejected* after many, many predictions and tests eventually becomes a broad explanatory framework that has withstood repeated experimentation and that makes accurate predictions about the natural world: in other words, a theory. The term "hypo" comes from the Greek for "less than," and "thesis" is another word for "theory." So "hypothesis" simply means "less than a theory." If a hypothesis withstands the trial of repeated experimentation, eventually it becomes a thesis—a theory.

Good theories, then, are close approximations of how the natural world actually works. Scientists don't ever fully "accept" them as "true" or "proven," but many theories in science are so well established that it is highly unlikely that new evidence will substantially modify them. The chromosomal theory of inheritance and the germ theory of disease are examples of such theories: the evidence supporting them is huge, and every new technology that scientists have developed to study either one continues to support them—though they have been revised and improved in the process. "Just a theory," then, is high praise from a scientific viewpoint—there is nothing better in science. A good theory, since it is a very close approximation of what is actually true, is very useful for making predictions about the natural world. Moreover, it provides a logical framework for making sense of current data—something that my high school biology experience lacked.

Science, Falsely So Called

Even though scientists know what they mean by the word "theory," nonscientists can be forgiven for thinking it means "relatively uninformed guess." We've all read headlines about scientific discoveries that "overturn previous theories" and "change everything we thought we knew." The truth is, these headlines are misleading and are often more the result of journalists looking for a catchy headline rather than accurately representing a new scientific finding. Often, the scientists themselves are eager to portray their work as novel and exciting, and so aid and abet the journalists. "Incremental advancement to a large body of prior knowledge!" just doesn't sell papers in the same way.

Another confounding issue is that often the topic is dietary science. One day cholesterol is bad; the next day it's fine. One day tomatoes are linked to cancer; the next day they've been shown to prevent cancer. (I'm not actually making these claims, of course—the point is that we've all seen headlines like these, many times over.) Why can't scientists make up their minds? It looks, for all intents and purposes, like they're just guessing. This sort of thing makes science look pretty wishy-washy—and leads many Christians to think that they're better off sticking to the plain truth of the Bible. There is a good reason why these news stories crop up so frequently: they naturally have a strong interest for the average person in ways that many areas of science don't. You don't as often see news stories on genetics or particle physics, unless something about a new finding is particularly interesting to average people. Dietary research is naturally interesting to everyone, since we all want to know how to lose weight and stay healthy.

Unfortunately, dietary science is one of the most challenging types of science to do well, and a lot of it is not performed to a high standard. Throw in an overeager, self-promoting researcher and a journalist on a deadline, and it is not surprising we get what we get in our Facebook feeds. One of the main challenges for this type of research is that it is difficult to exclude potential confounding variables: Are the two groups of research subjects as similar as they can be? Not likely. Has the research been properly scrutinized by experts in the field before being published? Perhaps not. Are the results shocking and therefore newsworthy? Press release!

One study that beautifully reveals the challenges and problems with this type of research and its subsequent news cycle came to light recently. It's not surprising that this study gained international attention; after all, it showed that eating chocolate was a way to lose weight!

> "Slim by Chocolate!" the headlines blared. A team of German researchers had found that people on a low-carb diet lost weight 10 percent faster if they ate a chocolate bar every day. It made the front page of *Bild*, Europe's largest daily newspaper, just beneath their update about the Germanwings crash. From there, it ricocheted around the internet and beyond, making news in more than 20 countries and half a dozen languages. It was discussed on television news shows. It appeared in glossy print, most recently in the June issue of *Shape* magazine ("Why You Must Eat Chocolate Daily," page 128). Not only does chocolate accelerate weight loss, the study found, but it leads to healthier cholesterol levels and overall increased well-being. The *Bild* story quotes the study's lead author, Johannes Bohannon, Ph.D., research director of the Institute of Diet and Health: "The best part is you can buy chocolate everywhere."[1]

Before you get your hopes up and dash off to the store with a newly cleansed conscience, I've got some bad news: the study shows nothing of the kind. In fact, the real experiment was to see if a weak study with obvious flaws could be published and grab public attention. In other words, its actual purpose was to see how easy it was to game the "dietary science" news cycle, as the lead author of the study revealed after the fact:

> I am Johannes Bohannon, Ph.D. Well, actually my name is John, and I'm a journalist. I do have a Ph.D., but it's in the molecular biology of bacteria, not humans. The Institute of Diet and Health? That's nothing more than a website. Other than those fibs, the study was 100 percent authentic. My colleagues and I recruited actual human subjects in Germany. We ran an actual clinical trial, with subjects randomly assigned to different diet regimes. And the statistically significant benefits of chocolate that we reported are based on the actual data. It was, in fact, a fairly typical study for the field of diet research. Which is to say: It was terrible science. The results are meaningless, and the health claims that the media blasted out to millions of people around the world are utterly unfounded.[2]

Reading Dr. Bohannon's full account of this "study" is well worth your time, since it reveals just how easy it was to pull off this stunt. The secret to "success" in this case was using a small number of test subjects and examining them for a large number of traits (cholesterol levels, weight gain, general feelings of happiness, and so on). With this experimental design, it is highly probable that at least a few statistically significant differences between the two groups (groups on a low-carbohydrate diet either with or without a small serving of dark chocolate) would be found. Those differences, however, are due to chance alone. Every claim of statistical significance is based on rejecting the probability of it being a fluke. Test enough variables with a small number of subjects, however, and eventually you'll find, by chance alone, a few variables that show "significance." In this case, a small chance fluctuation in weight and cholesterol levels in the right group was what gave the needed results and led to the subsequent rapturous headlines. Now, the peer reviewers of a high-quality scientific journal would easily catch those flaws—but Dr. Bohannon didn't submit his paper to a good journal. Rather, he submitted it to one that any working scientist would immediately recognize as a poor one, even one likely to be a solely-for-profit publisher—the scientific equivalent of a vanity press. In fact, it seems the paper wasn't peer reviewed at all. But that didn't matter: the media fell for it anyway. What surprised Dr. Bohannon was just how readily the media lapped it up. He had suspected that the diet-science, news-hype cycle was uncritically pushing bad science, but even he wasn't prepared for just how easy the process was.

So it's not surprising that many people may have a low view of science; the "science" they see in the newspaper day to day is always changing and constantly contradicting itself. The reason for this unfortunate pattern is simple: it's not rigorous science, and it's being reported by gullible and uninformed journalists. That's not to say that there aren't scientists out there doing careful work in nutrition science and slowly advancing our knowledge base in this important area. Surely they must pull out their hair at the sorts of poor studies that hit the news cycle. Moreover, there are journalists out there who handle science well—such as Dr. Bohannon himself. Typically, they have advanced scientific training as well as a gift for writing for nonspecialists.[3] Unfortunately, they are few and far between.

So despite the diet-fad news cycle, good scientific theories are out there. They're the result of years of careful study, critical review by experts, and a large body of supporting evidence. They make accurate predictions with boring regularity, and Christians typically don't give them a second thought. Some theories do appear on the evangelical Christian radar, though—and evolution is surely one of them. Even as a child I knew from my early church experiences that evolution was bad—it was a way to explain where humans come from that excludes God. Science and God's actions, at least in this case, were placed in opposition to each other. If science could explain human origins as a natural phenomenon without recourse to God's miraculous, instantaneous creation of our ancestors, then science was diametrically opposed to God and his Word. Everything science explained about our origins was one less reason to believe in God, and besides, we knew the science of evolution was full of holes. This reasoning made perfect sense to me as a child, and I accepted it uncritically.

One Book or Two?

Later, I would learn that this view sits in strong tension, to put it mildly, with centuries of Christian thought and practice. The long-standing tradition is one that views both nature and Scripture as “books” authored by God, and holds that science, properly done, is a way to understand the sustaining principles that God has built into the created order.[4] One of God’s books is Scripture, and we interpret and apply its truths through interpretation (exegesis and hermeneutics). The second book is the natural world, which we interpret through the scientific method. Science flourished in Christian Europe in the Renaissance as it did because many scientists were Christians and thus felt that the universe would have logical, orderly underpinnings because it was the product of God’s design. As Isaac Newton famously declared,

> This most beautiful system of the Sun, Planets, and Comets, could only proceed from the counsel and dominion of an intelligent and powerful being. . . . This Being governs all things, not as the soul of the world, but as Lord over all: And on account of his Dominion he is wont to be called Lord God.[5]

Thus science was seen as a praiseworthy activity for a Christian—the study of science *and* the study of nature revealed God’s truth. Moreover, Newton was busy determining laws of motion and describing how they played out for planetary bodies. He viewed his discoveries as understanding the mind of his Creator and the laws that Creator had put in place. Regrettably, evangelical Christian communities seem largely to have lost these convictions for some areas of science.

If indeed nature and Scripture have the same author, as Christians affirm, then there cannot, ultimately, be any disagreement between what we “read” in one book and what we read in the other. The problem, of course, is that our “reading” of either book is not perfect. Science does not yet have a full picture of many aspects of the natural world. Similarly, our exegesis and hermeneutics are not infallible. As a result, there may *appear* to be conflict between science and Scripture, and it may take a long time to sort out apparent disagreements as we wait for improvements in science and theology.

Learning from History

Of course, the church has worked through apparent disagreements before—most notably, the disagreement over whether the earth is at the center of the known universe (i.e., geocentrism), or if the sun is (heliocentrism). Nowadays, we wonder what all the fuss was about. For those who lived through the process, however, it was as real and as pressing as the evolution issue is for us. The basic issues that were on the table for them are the same as they are now: the veracity of the new science, and its perceived threat to biblical authority. Then as now, there were plenty of apologists who thought the new science was wrong and that the Bible was clear in its endorsement of a geocentric universe. Take, for example, the following excerpts from a popular apologetics book from the late 1600s written by John Edwards. He mounts a case against the new science of Copernicus (i.e., heliocentrism) with, as he sees it, both Scripture and science firmly on his side:

> The Copernican Opinion seems to confront a higher Principle than that of Reason. If we will speak like Men of Religion, and such as own the Bible, we must acknowledge that their Assertion is against the plain History of the Holy Book; for there we read that the Sun stood still in Joshua's time, and went back in King Hezekiah's. Now this Relation is either true or false. If it be the latter then the Inspired Scripture is false, which I take to be as great an Absurdity as any Man can be reduced to: If it be the former, i.e., if the Relation is really true, then the Sun hath a Diurnal Motion about the Earth; for the Sun's standing still could not be a strange and wonderful thing (as it is here represented) unless its general course was to move. . . .
>
> Again, I argue thus, the Motion of the Earth can be felt, or it cannot: If they hold it cannot, they are confuted by Earth-quakes . . . I mean the gentler Tremblings of the Earth, of which there are abundant Instances in History, and we our selves have had one not long since; so that by too true an experiment we are taught that the Earth's Motion may be felt. If this were not a thing that had been frequently experienc'd, I confess they might have something to say, they put us off with this, that it is not possible to perceive the moving of the Earth: But now they cannot evade it thus; they must be forc'd to acknowlegd the motion of it is sensible. If then they hold this, I ask why this Motion also which they speak of is not perceived by us? Can a Man perswade himself that the light Trepidation of this Element can be felt, and yet the rapid Circumvolution of it cannot? Are we presently apprehensive of the Earth's shaking never so little under us? And yet have no apprehension at all of our continual capering about the Sun?[6]

The English language has shifted somewhat since the late 1600s, so some translation here might be helpful. (We will actually explore language change over time as a particularly apt analogy for evolution in the next chapter.) First and foremost, Edwards holds that when science and Scripture are in tension, it is science that must give way, since the Bible is a "higher Principle" than that of science ("Reason"). He goes on to argue that either the sun moves about the earth or Scripture is false, given the plain sense of Joshua 10 (Joshua's "long day") and the narrative of Hezekiah's miracle, both of which were common scriptural touchstones for anti-heliocentrists.

Edwards then shifts to a scientific argument: earthquakes can be felt (i.e., they are "sensible": they can be sensed). I recently had an experience of a small earthquake here in the Vancouver area, giving me a renewed appreciation of the force of this argument. When the earth moves, it moves, and you can feel it. In light of such experience, are we really to believe that we are careening around the sun at fantastic speeds and cannot feel it at all? Edwards drives the point home further:

> Nay, truly, if the earth were hurl'd about in a Circle (as these Persons assert) we should feel it to our sorrow, for we should not be able to keep our ground, but must necessarily be thrown off, and all Houses and other Buildings would be thrown down, being forcibly shaked off from the Circumference of the Earth, as things that are laid on a Wheel are flung off by it when it turns round.[7]

Game, set, match—at least in 1696.

Edwards cannot really be faulted for the stance he took at the time, even though there was good evidence, even in 1696, to support a heliocentric universe—evidence such as Galileo's observations, Kepler's laws of planetary motion, and Newton's work on gravitation. What was missing, however, was a key piece of evidence, and Edwards was keenly aware it was missing. One of the key predictions of a heliocentric universe was something called "stellar parallax." If indeed the earth circles the sun once per year, then as its position in space shifts, we should observe shifts in how stars are positioned relative to one another.

Perhaps a demonstration will help. Extend your hands in front of you and hold up one finger in each hand. Place the two fingers in line with each other, one about one foot from your face, and the other about two feet. Close one eye and move your head from side to side. Your fingers will appear to move relative to each other. This is what was expected for stars: if your head moving from side to side represents the earth as it revolves around the sun, then the expectation was that stars would appear to move relative to one another, just like your fingertips do.

What was not understood in the 1600s, however, was just how far stars are from the earth. They are so distant that observing parallax requires high-power telescopes that simply weren't available at the time, since the apparent shifts in position are tiny—imagine trying to detect parallax in closely spaced fingers from a distance of a few hundred yards. As a result, the church could bide its time and withhold its assent. In fact, it wasn't until the 1800s that the technology became available to detect stellar parallax, although other convincing lines of evidence were in place by that time. Since this progression in science played out over centuries, the church also enjoyed a slow pace in changing its stance on this issue. In the 1600s, pretty much all Christians were geocentrists, with only rare exceptions. From the 1900s through to the present day, the situation is reversed (yes, there are still Christian geocentrists out there, though they are extremely few in number). The shift, then, was a gradual one, with plenty of opportunity for gradual theological change within the church along the way. And what of Edwards's strong assertion that if heliocentrism is true, then Scripture is false? Well, it seems that few believers see it that way today.

Though the church has made its peace with a heliocentric solar system, many of us have yet to do so with evolutionary biology. My Christian grade-school books had no problem describing the solar system and gravity in ways that would have made the dear Mr. Edwards blanch, but they (and I) remained resolute on evolution. It was "science, falsely so called," to borrow the King James turn of phrase.[8]

Interestingly, I would remain an antievolutionist through the course of my PhD and on into my career as a professor, now teaching at the very same Christian university I was unable to afford as a student.[9] What would come as something of a shock to me as a young professor is that, contrary to the claims of my Christian grade-school workbooks, evolution is a theory in the scientific sense. Charles Darwin's original hypothesis—that modern species share common ancestors and are shaped by natural selection—has withstood over 150 years of vigorous scientific testing and remains a productive explanatory framework in the present. Make no mistake: there is not a biologist on the planet that would not dearly love to overthrow evolution and replace it with an even better theory. Doing so would be a sure path to research grants, likely a Nobel Prize, and to enduring scientific fame. Biologists have been trying to do just that for over 150 years; however, though we've improved on Darwin's ideas significantly, his core ideas remain intact. His original hypotheses have long since become a theory. Thus there is over 150 years of scientific evidence for evolution that we could discuss, and even a lengthy book could only scratch the surface. We'll turn to some of that evidence now, to illustrate how evolution has stood the test of time and remains our best explanation for biodiversity on earth.

Fish out of Water

One of the things I have come to love about the theory of evolution is how it often forces scientists to make counterintuitive predictions based on the available evidence. For example, evolutionary biology predicts that animals with backbones and four limbs (i.e., vertebrates and tetrapods, respectively, with tetrapods being a subset of vertebrates) are the descendants of fish. This is certainly not what one would intuitively predict apart from evolutionary theory. Fish are fish, and tetrapods are tetrapods; these groups seem very unlike each other. Fish, obviously, are aquatic, have gills, and lack limbs; conversely, tetrapods breathe air, have limbs, and are generally terrestrial. It would be hard to find two groups of animals so unlike each other in form and lifestyle.

Yet there are lines of evidence that somewhat force a biologist's hand in this case. The first clue is that all tetrapods are vertebrates, like fish are. Why might that be the case? Why are there not also *invertebrate* tetrapods? Secondly, as we go back in time in the fossil record, we observe a time when there are no tetrapods, but fish abound. When the first amphibians appear in the fossil record, they bear remarkable similarities to a certain group of fish that came before, some lineages of which persist to the present day—lungfish. Lungfish, as the name implies, have both gills and an air sac through which they can perform gas exchange (i.e., take in oxygen and expel carbon dioxide). These fish use their lung to survive in oxygen-depleted waters—often shallow waters. Even more interesting is that lungfish are lobe-finned fish, rather than ray-finned fish. Your standard aquarium goldfish is a good example of a ray-finned fish: these fish have fins that lack bones, instead being made of skin interspersed with thicker spine-like "rays." Lungfish, on the other hand, have fleshy limbs and bones within their fins; they are part of the group known as "lobe-finned fish." As it happens, early amphibians have a large number of features that are strongly reminiscent of lungfish. Curious, no?

It was these observations, and others, that prompted scientists to look for species in the fossil record that are intermediate in form between lungfish and early amphibians.[10] Knowing when the first amphibians appear in the fossil record helped, since any predecessor to amphibians would have to come before they appear. Now, it is important to understand that one will virtually never find remains of direct ancestors by looking in the fossil record. It is likely, however, that relatives might be found. This applies even to recent human populations. For example, I am of Dutch background, and there are surely individuals buried in the Netherlands who are my direct ancestors, perhaps stretching back hundreds or even thousands of years. The probability of finding one by digging up unmarked graves, even in close proximity to where my ancestors likely lived, is very small. On the other hand, it is likely that nearly any such remains are relatives of mine, to some degree. Examining their remains might be generally informative about my ancestors, even if they are not in my direct lineage. This same principle applies to species in the fossil record. Fossilization is a very infrequent event; nonetheless, careful work allows us to see what sorts of species lived at certain times in the past. If indeed amphibians descend from lobe-finned fish, then it is formally possible that the direct lineage connecting them could be found in the fossil record, however unlikely. There is a much better chance that at least some relatives of the direct lineage were preserved, however, even if those relatives lived before or after the transition took place. The types of species we observe in the fossil record thus could support the hypothesis that amphibians descend from fish, even if a direct transitional lineage remains elusive.

What is interesting is that paleontological work in this time period has found several species that have further blurred the distinction between "fish" and "tetrapod" over the past several years—one of which is informally (and affectionately) called a "fishapod"[11] because of its blend of amphibian-like and fish-like characteristics. These species are unlike any that persist to the present day, and while none of them are likely to be the direct ancestors of early amphibians, their characteristics are highly suggestive of an intermediate state. Thus it is now much harder to draw a definitive line between the categories "lungfish" and "amphibian." While such evidence is not "proof" of an evolutionary transition—recall that scientific hypotheses are not proven, after all—this evidence nonetheless supports one. Given this evidence, then, we *fail to reject* the hypothesis that early amphibians share common ancestors with lungfish. Indeed, on the basis of this successful prediction, it seems that this hypothesis is worth investigating further.

Of course, some might argue that it simply pleased God, as Creator, to create a series of unrelated species at this time in earth's history that happen to suggest an evolutionary relationship. Many Christians find this plausible; but note how this type of argument cannot ever be ruled out by additional evidence. Any additional such species we find in the fossil record would then merely be more separate species that God elected to create at this time. This explanation also leaves scientists bereft of a hypothesis to test with further research. If the species we observe in the fossil record are the direct, special creations of God, then we will not necessarily find a pattern in the fossil record. Faced with such an explanation, a scientist would not have the ability to make predictions about what should be found in the fossil record at certain times.

There and Back Again?

A second example of a counterintuitive prediction that evolution makes is that some tetrapods, after having adapted to a terrestrial environment, nonetheless returned to the sea. After tetrapods appear in the fossil record, we observe a proliferation of tetrapod forms—dinosaurs, birds, mammals, and so on—that are simply not to be found prior to the time suggested by the fish-fishapod-tetrapod transition. Indeed, such gradations of form are known that there are entire groups with names like "mammal-like reptiles" followed by "reptile-like mammals," with, as you might expect, creatures in between that could be reasonably included in either group. Mammals are tetrapods, it would seem, because mammalian characteristics arose in a lineage of tetrapods. Life comes to us in "nested sets," and "mammal" is a subset of "tetrapod." In other words, though all mammals are tetrapods, not all tetrapods are mammals. The probability of mammalian characteristics (such as having hair and feeding their young with milk, as well as a number of defining skeletal characteristics) arising in a separate, unrelated lineage is a pretty big stretch. Therefore, evolution predicts that all mammals are the descendants of terrestrial tetrapods: four-limbed animals that live on land, even fully aquatic mammals like whales, dolphins, and porpoises—even though these mammals have virtually no hair, and even though they have only front flippers and no hind limbs to speak of.

Darwin himself was driven to make this prediction, since the suite of mammalian characteristics is too improbable to assemble twice in unrelated lineages, and whales are clearly mammals. Darwin had no idea what terrestrial mammalian lineage led to whales, but he was convinced there was one. He speculated that the ancestor of modern whales may have been a carnivorous, bear-like mammal:

> In North America the black bear was seen by Hearne swimming for hours with widely open mouth, thus catching, like a whale, insects in the water. Even in so extreme a case as this, if the supply of insects were constant, and if better adapted competitors did not already exist in the country, I can see no difficulty in a race of bears being rendered, by natural selection, more and more aquatic in their structure and habits, with larger and larger mouths, till a creature was produced as monstrous as a whale.[12]

Not surprisingly, critics found the suggestion laughable. For example, R. Seeley wrote:

> Thus Mr. Darwin, while he finds it impossible to believe the plain words of Moses that on the fifth day, "God created whales"—"sees no difficulty" in

> believing that a race of bears, by contracting a habit of swimming, gradually lost their legs, and were "developed" into whales of a hundred times their own bulk! And this sort of trash is called "science"! . . . Let us look, for a moment, at this whale, or bear, or bear-whale. What says Geological Science to it? Geology replies that she finds bears in the crust of the earth, and many of them; and that she also finds whales. But that the whale-bear, or creature which was developing from a bear into a whale, she never met with. And, not finding it, she no more believes in it than in a phoenix or a roc. In a word, Geology, which is really a science, declares Mr. Darwin's bear-whale to be a rank impostor.[13]

Indeed, the criticism and ridicule Darwin received on this point was seemingly enough for him to shorten this section as early as the second edition of *On the Origin of Species*.[14] And not surprisingly, since the suggestion that so great a change had been effected through natural selection was incredible to many. Present-day whales (together with dolphins and porpoises, a group collectively known as "cetaceans") have many differences relative to terrestrial mammals. As we have mentioned, one obvious difference is that cetaceans lack four limbs. They have no hind limbs at all, only forelimbs. Moreover, other mammals have two nostrils on the front of their faces. In contrast, cetaceans have a blowhole on the top of their heads. Hair is a defining feature of mammals, yet whales are almost hairless—and the list goes on. If any group of mammals seemed inexplicable to Darwin's critics, cetaceans certainly seemed to qualify. Darwin, however, was a man before his time on this point, though he would not live to see his eventual vindication. Cetaceans are now something of a poster child for evolution, and for good reason. Once again, despite much effort, scientists have not been able to reject this hypothesis.

Fossils documenting the cetacean progression from land to water was a long-standing scientific puzzle. Even though we expect the fossil record to at least preserve relatives if not the actual lineage, no fossils even mildly suggestive of such a transition were known. One ancient whale had already been discovered, though it was likely that Seeley, if he knew of it, would have considered it merely a whale. It was first described from its teeth and vertebrae in the 1830s and thought to be a reptile of grand proportions. Accordingly, it was named *Basilosaurus* or "king lizard."[15] Not long after, however, this classification was challenged and *Basilosaurus* was correctly redescribed as a cetacean, though the attempt to rename it as *Zeuglodon* ultimately failed.[16] Interestingly, this group of ancient whales (a few Basilosaurid species are now known) have small hind limbs unable to support their massive bulk. The presence of hind limbs in these species was not known until much later, however, when better-preserved fossils were found. Aside from these whales, however, no other species blurring the distinction between modern whales and their hypothesized terrestrial tetrapod ancestors were known. This dearth of evidence persisted up until the 1980s, to the delight of antievolutionary apologists.[17]

The issue, as it turned out, was that the Basilosaurids were widely dispersed on the planet, in part because they were completely committed to an aquatic lifestyle. This allowed them to disperse across oceans in ways their distant ancestors could not and, as a result, to be fossilized in many locations, which facilitated their discovery. Determining *where* the land-to-water transition had originally occurred was thus the key, and in the early 1980s it was finally worked out. The place to look for fossils was in present-day India and Pakistan. Once this was understood, a number of significant finds quickly appeared, and though they may not be the direct ancestors of modern cetaceans, these species make drawing a clear dividing line between "whale" and "terrestrial mammal" challenging.[18]

One characteristic of the modern cetacean skull is a distinctive thickened portion covering the middle ear, a structure known as the "involucrum." This characteristic feature was thought to occur only in cetaceans until it was also discovered in a diminutive hoofed mammal, *Indohyus*, an extinct species that lived in India approximately 48 million years ago.[19] *Indohyus* belongs to a group of mammals known as "artiodactyls": "even-toed" hoofed mammals, of which species like deer, cows, and hippos are present-day examples. The discovery that *Indohyus*, which is not a cetacean, nonetheless has a feature that was until that point considered unique to cetaceans, strongly suggests that it was at least a close relative of the ancestral cetacean lineage. Curiously, *Indohyus* was also found to have features consistent with a semiaquatic lifestyle. Its bones are thicker and heavier than one would expect for an artiodactyl of its size. Similar features are found in other aquatic artiodactyls such as hippos. Thick, heavy bones act as ballast when an animal is underwater bottom-walking, and *Indohyus* likely did this either to feed on aquatic plants or evade predators. This sort of behavior can be seen in a modern artiodactyl of comparable size, the African water chevrotain, supporting this hypothesis.[20]

One interesting feature of artiodactyls is that they have an ankle bone, the *astragalus*, that is readily distinguished from the astragalus of other mammals. A second group of ancient artiodactyl species from this region, the Pakicetids, also had this distinctive astragalus, as well as an involucrum and, like *Indohyus*, thickened, heavy bones. Analysis of the radioactive elements in Pakicetid bones indicates they were a group of semiaquatic freshwater predators. As their "cetid" name indicates, scientists include these extinct species within cetaceans because of the many skeletal features they share with modern whales. Relatives of Pakicetids, the larger Ambulocetids, also come from this region, except these extinct artiodactyls were semiaquatic marine predators. "Ambulo" means "walking," so their name literally means "walking whale." They probably would have appeared to us as gigantic otter-like creatures. They too have skeletal characteristics expected of both cetaceans and artiodactyls.

Later still we observe the Protocetids, a group of semiaquatic artiodactyls that have skeletal features indicative of a more fully aquatic lifestyle. The nostrils in Protocetids are not at the tip of the snout but are shifted back along the skull, and the hind-limb skeleton appears insufficient to bear the full weight of these mammals. Scientists believe these species behaved in a way analogous to modern sea lions: hunting and feeding in the ocean, but hauling themselves out to rest, mate, and bear young. Protocetids, like Basilosaurids, are widespread around the globe but were not discovered early like the Basilosaurids were. Basilosaurids, as we have already discussed, are fully aquatic with only tiny hind limbs unconnected to the rest of the skeleton that cannot possibly have been used for locomotion. Interestingly, when exceptionally well-preserved Basilosaurid fossils were discovered, they had the definitive artiodactyl ankle bones, despite their lack of locomotor function. While we cannot tell if any of these species are direct ancestors of modern cetaceans, these extinct forms support the hypothesis that modern cetacean lineage passes through something *Indohyus*-like, to something Pakicetid-like, and so on through Ambulocetid- and Basilosaurid-like forms. In other words, given this fossil evidence, we have *failed to reject* the hypothesis that whales, dolphins, and porpoises descend from terrestrial, tetrapod ancestors.[21]

Of course, this might be merely a series of coincidences—rather remarkable coincidences, to be sure, but coincidences nonetheless. Thus scientists seek corroborating evidence, even if a hypothesis has withstood some tests.

One way to continue to test a hypothesis that has made some successful predictions is to look to other areas of science. While paleontology supports the hypothesis that cetaceans are the highly modified descendants of terrestrial tetrapods, what about other scientific disciplines? Might there be other lines of inquiry that can be brought to bear on the question? In the case of modern cetaceans, certain details of their *embryology*, the study of their development in the womb, are informative. Modern cetaceans have two nostrils on the fronts of their faces as embryos, like all mammalian embryos do. Over the course of development, the nostrils migrate from this starting location to the top of the head and form a blowhole, with the process complete before birth. And strikingly, modern cetaceans are true tetrapods for a short period as embryos. Cetacean embryos develop forelimbs *and* hind limbs at the same stage that all mammals do, but later the hind limbs stop developing and regress back into the body wall. Studies have shown that the basic biological machinery for making a hind limb is properly activated in young cetacean embryos, but that a second set of instructions later causes the process to stop and regress.[22]

These features of cetacean embryology are very difficult to account for apart from an evolutionary explanation. They are strongly suggestive that modern cetaceans do indeed descend from terrestrial mammals, even if details remain to be discovered. Combined with the evidence from paleontology, the original hypothesis is supported by lines of evidence that converge on the same conclusion. Such convergence boosts our confidence that the hypothesis is at least close to the truth and suggests that it will continue to make accurate predictions.

Getting from Point A(mbulocetid) to Point B(asilosaurid)

It's common for people, upon seeing such evidence for the first time, to begin to reflect on the immense improbability of such large changes taking place repeatedly within a lineage. How could a mutation so large occur to change one animal from one form to another without killing it? How would such an animal breed with anything, unless these rare, massive mutations just happened to occur with a male and female in the same generation? Isn't this all wildly improbable?

Well, yes, such a process would be wildly improbable—so improbable, in fact, that no scientist thinks it could ever happen. This does not pose a problem for evolution, however, because *this is not how evolution works*. How it does, in fact, work is the topic we will turn to next.