Essential Reading for EEB214 Lecture 1-6

Lecture 1

Anne Holden's review of the history of the creationist movement on the Inkling site makes a really good read (in three parts):

Thy Will Be Done, Again and Again: The "Evolution" of Creationism in America

The first in a three-part series tackling the history of U.S. anti-evolutionary sentiment.

Remember high school biology? Somewhere between the Punnet squares and frog dissection, you should have had a few lessons on the theory of evolution. According to the Thomas B. Fordham Institute, the widely accepted theory that explains how species arise and change over time has been part of the science curriculum in many schools across America for at least a decade.

But did your teacher talk to you about an 'alternative' to evolution? If you went to school in the United States, chances are, about one in four of your teachers did. How is it that 25% of biology teachers are telling their students that evolution—the cornerstone of biology—is not the only scientific explanation for the origins of life? In this three-part series, we'll explore the origins of this debate in our nation's earliest days. We'll dig deep into the many legal battles that have forced the central tenets of Creationism itself to 'evolve' in order to hold on to its place in our schools. Finally, we'll examine the current status of the Creationist movement: how will it adapt next, and what will those adaptations mean for the future of American education?

Part 1: Sticking to the Fundamentals

A recent nationwide poll of American high school biology teachers found that 25% said they did discuss alternatives to evolution as part of their curriculum. When teachers raise them, these alternatives usually take the form of a supernatural explanation for the origin of life. Some merely espouse weaknesses in evolution. Others highlight the possibility of intelligent design to explain the most complex life forms. And a few come right out and discuss Biblical Creationism itself.

When American schoolchildren grow up, those views grow up with them. We don't see the same statistics in Canada, Great Britain, or France. The debate between evolution and Creationism is uniquely American.

The history of the United States is vastly different than the history of European nations. But what most of us don't realize is that the events in our country's history—everything from who the settlers were to how they survived the western frontier—set the stage for the birth of the Creationist movement.

In the 1800s, Americans left their homes along the east coast began to head west. They traversed the Appalachian Mountains of modern day West Virginia, the Carolinas, and Tennessee. Communities and villages exploded within just a few years.

But when people arrived at these frontier outposts, there wasn't much in the way of infrastructure. There were no police, no roads, and no schools. If these communities wanted basic services, they had to do it themselves. They set up police forces, constructed roads, and built schools. They did it without assistance from the federal or state governments, and they did it without consulting with nearby settlements. This strong local control over matters that were important to the life of the community persists today in various forms—including the power of school boards and districts. And it has proven key to the success of Creationism.

A second key to Creationism's success is our country's unique religious history. This nation was largely settled by religious dissenters. Arriving from England, Ireland, France, and Germany (among others), they came looking for religious freedom and headed west. Just as these frontier towns needed schools and roads, they needed churches. With no one back east in Washington (or Europe) to lend a hand, these frontiersman and women did what any God-fearing self-respecting, fiercely independent American would do: they started their own. In many cases, these regional churches were derivatives of the mainstream Catholic or Protestant churches from their homelands. But in some cases, these churches were so different that they were considered wholly independent sects. These included Seventh-Day Adventists, who believed the second coming of Jesus Christ could happen any minute, and Christian Scientists, who

shunned modern medicine in favor of prayer. Yes, these churches were the epitome of 'old school.'

Against this backdrop came a series of religious and cultural movements, birthed in Europe during the late 1800s, that played down the literal truth of the Bible. This broad intellectual drive, known as Modernism, seemed to threaten the validity Adam and Eve, Noah and the Flood, and even the virgin birth of Jesus. Modernists found inconsistencies in the Bible itself, things that didn't quite make sense in the the context of the natural world. They asked questions that many curious children in Sunday School have asked for decades. Did Noah bring fish with him on his ark? Where did Cain's wife come from? Why don't miracles happen anymore?

Well this didn't sit too well with the American settlers. As their new churches grew, their religious leaders touted the fundamental truth of the Bible as a work of history written by God himself. There was no wiggle-room here. Even today, religious sects with American origins are more focused on the Bible as a historical account than almost any others in Western society.

As Europe was busily exploring the idea of religious Modernism, and rural America was busy doing the opposite, another idea was making headlines. And to many Americans, it was even more dangerous than Modernism: the theory of evolution.

Darwin had published his seminal volume, On the Origin of Species, in 1859; by the turn of the 20th century, the vast majority of scientists accepted Darwin's theory. Yes, there were scientific debates on the details—the field of genetics was just beginning to take off—but the debate among scientists on whether evolution occurred was dying down. According to Eugenie Scott, Executive Director of the National Center for Science Education (NCSE) and author of the book, Evolution vs. Creationism, "the concept of a dynamic rather than static world, already accepted in astronomy and growing in geology, would...wash over biology as well."

As a result, evolution was quietly making appearances in high school biology textbooks. Considering evolution to be a close relative of the Modernist movement, American religious leaders began to take notice.

In 1910, the Bible Institute of Los Angeles (now Biola University), financed a series of booklets called "The Fundamentals." These booklets promoted the literal truths of the Bible, and they were written as a direct rebuttal to evolution. Throughout the writings are dark, threatening undertones: Evolution, they hinted, was the source of amoral behavior and harmful social trends.

The Reverend Henry Beach of Grand Junction, Colorado wrote in the chapter entitled "The Decadence of Darwinism:" "The teaching of Darwinism, as an approved science, to the children and youth of the schools of the world is the most deplorable feature of the whole wretched propaganda."

One of the biggest supporters of The Fundamentals was lifelong politician and former Secretary of State William Jennings Bryan. In an essay entitled, "The Menace of Evolution," he writes: "The tendency of Darwinianism, although unsupported by any substantial fact in nature, since no species has been shown to come from any other species, is to destroy faith in a personal God, faith in the Bible as an inspired Book, and faith in Christ as Son and Saviour."

Was this evolution thing really an idea American children ought to be studying?

The authors of The Fundamentals, as well as Bryan, did not stop at writing fiery treatises. They called for states to outlaw the teaching of evolution. In 1925, Tennessee became the first state to do so when it passed the Butler Act. But the passage of this and other acts in neighboring states did not squash the debate.

In fact, the fight was just beginning.

Of Monkeys and Men: The Trial(s) of the Century

The second in a three-part series tackling the history of U.S. anti-evolutionary sentiment.

In Part I of our series, we uncovered the nearly 200-year-old roots of Creationism in America and saw how they are deeply entwined within the settlement of the American frontier. In Part II we'll examine key events during the 20th century that shaped the evolution/Creationism debate.

The Scopes Trial (1925)

The first laws that outlawed the teaching of evolution did not go unnoticed. The newly formed American Civil Liberties Union (ACLU), which had been formed to defend American citizens arrested for socialist agendas, turned their focus to issues of free speech and the United States Bill of Rights. The ACLU was very displeased with the passage of the 1925 Butler Act, which outlawed the teaching of evolution in the state of Tennessee.

The ACLU had a two-pronged attack against the Butler Act: 1) the Butler Act was inherently religious, and therefore unconstitutional, and 2) The Butler Act caused the suppression of free speech.

But in order to get their case into a courtroom, they first needed someone to break the law. They found the perfect subject in John Scopes, a young, unassuming biology teacher in the small town of Dayton, Tennessee. As Edward Larson describes him in Summer for the Gods, "Scopes..looked the part of an earnest young teacher, complete with horn-rimmed glasses and a boyish face that made him appear academic but not threatening." *(Ed note: See photo above—yup!)*

So in 1924, Scopes was approached—some accounts say in the middle of a tennis game—by the ACLU. He agreed to their proposal, a warrant was sworn out, and Scopes charged with violating the Butler Act. He was then allowed to finish his game. The ACLU began to prepare for the "Trial of the Century."

The ACLU chose renowned lawyer—and noted atheist—Clarence Darrow to defend Scopes. The state of Tennessee chose William Jennings Bryan, a religious fundamentalist and former Secretary of State to Woodrow Wilson. Both sides originally wanted this trial to be a test of the validity of evolution. But it soon became apparent to the defense that it would be difficult to find respected scientists to challenge evolution. Bryan and the state of Tennessee switched their strategy at the last minute: they were only going to argue whether Scopes broke the law.

As soon as the trial started, the judge also ruled that the case could only be argued narrowly. The anticipated 'test' of evolution was not going to take place, as Darrow and the ACLU had hoped. Their expert panel of witnesses were not allowed to testify. Darrow was, however, permitted to call Bryan himself to the stand as an 'expert on religion.' While Bryan was enthusiastic in his chance to prove his expertise, Darrow's line of questioning made Bryan appear to be largely ignorant of many fundamental Christian concepts. Darrow even got Bryan to confess his lack of expertise.

But all of Darrow's effort didn't make a difference in the trial's outcome. Scopes was easily found guilty of teaching evolution, and fined $200.

The Scopes trial did have a lasting effect, however. Bills similar to the Butler Act were defeated in other states, and anti-evolution sentiment seemed to become confined to the American south. In order to avoid conflict and to keep the southern market happy, textbook publishers quietly removed evolution from their textbooks. According to Eugenie Scott, author of *Evolution vs. Creationism: An Introduction*, evolution (and as a result, Creationism) went into hibernation for the next 25 years.

The Genesis of Creation "Science"

America woke up with a start from its post-war idyll with the Soviet launch of Sputnikinto outer space in 1957. Much to the chagrin of the US government, Russia had beaten the United States in round one of the Space Race. In order to to stay one step ahead of the Russians, America realized, it needed a complete overhaul of its science education.

For the first time in decades, science textbooks were rewritten—this time by subject matter experts and master teachers. These new books stressed important scientific concepts and experimental science. Most importantly, they included evolution. Evolution was not only mentioned, but was rightly described as a fundamental concept of biology that must be understood if Americans were to become leaders in scientific research and discovery. As John Moore describes in *Science and its Public: The Changing Relationship*, "...nearly every objecting school board ended up adopting the books...there was community pressures on school boards to be up to date, even if a little wicked, rather than be behind the times and fully virtuous."

This resurgence of evolution did not go unnoticed by Creationists. The federal government wanted American students to learn cutting edge science, and that included evolution. The Creationists reasoned that, if students had to learn evolution, then they would also have to learn alternative scientific views for the origins of life as well. Creationism had to become scientific.

The origins of the Creation Science movement can be traced to one man, Henry M. Morris. A hydraulic engineer, Morris was

convinced in the social evils of evolution. In his 1963 book, *Twilight of Evolution*, Morris writes, "And today, this God-rejecting, man-exalting philosophy of evolution spills its evil progeny—materialism, modernism, humanism, socialism, Fascism, communism, and, ultimately, Satanism—in terrifying profusion all over the world."

Morris spent his life using his engineering experience to disprove evolution by proving in the scientific accuracy of the Bible. In his most widely read work, 1961's *Genesis Flood*, Morris and his co-author John Whitcomb describe geological features like the Grand Canyon that provide proof for such a flood. He also argued that there was scientific evidence for a young Earth; an Earth that was created in seven days and could be no more than 10,000 years old.

Despite the fact that *The Genesis Flood* was - and is still today—a best seller among Fundamentalist groups, it had trouble breaking into the mainstream scientific community. By the late 1960's, it seemed to some that the Creationist movement was relegated to a small minority of Morris and his followers. The last of the anti-evolution state laws were finally dissolved in 1968, when the United States Supreme Court ruled that banning the teaching of evolution on religious grounds violated the First Amendment (*Epperson vs. Arkansas*).

MacLean vs. Arkansas (1982)

But the Creationist movement wasn't in decline; it was reinventing itself. For years, with the help of Henry Morris and others, Creationists had been quietly marketing Creationism as scientific, and their efforts were finally starting to pay off.

A central tenet of the Creation Science movement was that all scientific theories on the origins of life should be taught to students. This included not only evolution, but Creation Science as well. In the late 1960s and 1970s, so-called "equal time" laws began cropping up in state legislatures around the country.

On such "balanced treatment" bill, Act 590 in Arkansas, argued that the teaching of evolution alone created a hostile environment for religious students. Other alternative ideas about the origin of life, including Creation Science, should therefore be taught alongside evolution. Act 590 was signed by the governor of Arkansas in 1981. It was immediately challenged by the ACLU.

Methodist minister William MacLean was the lead plaintiff on behalf of the ACLU. The case itself was tried before a federal district court, and argued two main points:

1. Creation Science was inherently religious, which violates the First Amendment.
2. There is no secular purpose for teaching Creation Science in schools, and it should therefore not be taught alongside evolution.

The defense was blown out of the water. They were reluctant to put any well-known Creationists like Morris on the stand, for fear they would emphasize the religious underpinnings of Creation Science. The judges easily ruled in favor of MacLean, and the state of Arkansas did not appeal to the US Supreme Court.

A similar case, *Edwards vs. Aguillard*, did make its way to the Supreme Court a few years later. The justices ruled that Creation Science was inherently religious, not scientific, and therefore unconstitutional. But the justices did leave a bit of wiggle room in their remarks: if a valid scientific alternative to evolution did arise, then it could be taught alongside evolution.

This criteria laid out the Creationists' next move. They would have to reinvent themselves once again.

Don't Call it a Comeback: Creationism Evolves

The final piece in a three-part series tackling the history of U.S. anti-evolutionary sentiment.

In Parts I and II of this series, we looked at the history of the Creationist movement and Creationism's first foray into establishing itself as science. In this final installment, we'll explore the latest attempts to insert Creationism into science classrooms, and discuss what the future of American science education may hold.

Creation Science Part II: Intelligent Design

The legal losses it suffered in 1982 and 1987 caused the Creationist movement to take a step back. The US Supreme Court had ruled Creation Science to be inherently religious, and therefore concluded that its presence in schools was unconstitutional. Some

movements would have given up the fight, but the Creationists soldiered on, reinventing themselves once again with something called Intelligent Design.

Intelligent Design (ID) argues that certain aspects of life are too complex to have evolved naturally. Instead, there must be a form of intelligence, a "designer," to provide guidance along the way. Michael Behe, a professor of biochemistry at Lehigh University, is one of the central proponents of this idea, though he is a bit vague as to who this "designer" may be. Behe's 1996 book, *Darwin's Black Box*, outlines the main principles of ID.

ID is deceptively attractive. Its failure to identify a "designer" means that it can distinguish itself from the religious overtones of traditional Creationism. It creates the appearance of being a secular idea.

Rather than attempting to prove Creationism as the best explanation for the origins of life, ID proponents focus on disproving evolution. Looking for weaknesses in evolution is one of the central strategies of the ID movement. And, unlike earlier Creationist movements, they have had some success.

Kitzmiller vs. Dover

Perhaps one of the most well-known examples of ID entering the classroom was in the small town of Dover, Pennsylvania. In 2004, the Dover School Board passed a policy requiring biology teachers to discuss a scientific alternative to evolution, namely Intelligent Design, with their students. To assist them, teachers were given copies of a textbook called *Of Pandas and People*. *(Ed note: Adorable name for such an insidious publication.)* This book espoused the ideas promoted by Behe and others. It was promoted by the Discovery Institute, an Intelligent Design think-tank based in Seattle.

On the surface, Pandas seemed to be a mostly benign book that discussed the complexity of life. However, one look inside will reveal its true nature:

Intelligent design means that various forms of life began abruptly through an intelligent agency, with their distinctive features already intact—fish with fins and scales, birds with feathers, beaks, and wings, etc. Some scientists have arrived at this view since fossil forms first appear in the rock record with their distinctive features intact, rather than gradually developing.

This argument is central to ID. ID argues that evolution by natural selection can't be the best explanation because we have yet to discover any 'transitional fossils:' plants or animals that seem to exhibit features of two different types of animals.

Kevin Padian, professor of paleontology at University of California-Berkeley, begs to differ. As he describes in a critical review of *Pandas*:

The earliest known fish, for example, were quite different from the fish we recognize today. The earliest fossil forms lacked many of the characteristics possessed by fish today, including jaws, paired limbs and bony internal skeletons, and yet Pandas wishes to tell students that fish (and all fossil forms) appear in the fossil record "with their distinctive features intact.

Both teachers and parents in the Dover school district, led by parent Tammy Kitzmiller, filed suit in federal district court in 2005. They argued that Of Pandas and People - and therefore Intelligent Design - was not a scientific alternative to evolution. Instead, ID was simply Creationism reinvented. It was religious, not scientific, and therefore unconstitutional.

With the help of the ACLU, the National Center for Science Education (NCSE), and a whole host of scientific and religious experts, documents were discovered linking the Creationists to the ID proponents. Earlier editions and manuscripts of Of Pandas of People used the term "Creationism" instead of "Intelligent Design" and had explicit religious references. Central tenets of ID itself were proven to be unscientific and just plain wrong.

The judge, John E. Jones, ruled in favor of *Kitzmiller*, and his ruling was sweeping. In a 139-page memorandum opinion, Jones called out the Dover School Board and proclaimed Intelligent Design itself as a wolf in sheep's clothing:

We have addressed the seminal question of whether ID is science. We have concluded that it is not, and moreover that ID cannot uncouple itself from its creationist, and thus religious, antecedents. The citizens of the Dover area were poorly served by the members of the Board who voted for the ID Policy…

According to Nicholas Matzke, one of the key NCSE staff members involved in the case, Dover proved that "ID really is just creationism relabeled, and anyone who thought otherwise was either naively misinformed or engaging in wishful thinking."

Judge Jones' decision was definitive and sweeping. No appeal was filed. But Creationists and ID proponents did not go quietly into the night.

The Future of Creationism

Nearly five years after Dover, the debate continues in our schools, school boards, and in state governments across the country. The Dover decision forced Creationists again to reinvent themselves; today they are almost entirely focused on finding weaknesses in evolution, without ever proposing a valid scientific alternative. In 2007, a new creationist book called *Explore Evolution* appeared on the market. Unlike its predecessor, *Pandas*, this text focuses solely on poking holes in the theory of evolution without ever mentioning Creationism or Intelligent Design.

What does all this mean for the future of science education in America? The answer is unclear. Creationists and ID proponents are tenacious, as we have seen from their "evolving" strategy over the past century. The scientific community should therefore be equally tenacious. We must engage in open dialogue between scientists and politicians. We should get involved in our local school boards, making sure their curriculum decisions are based on science, not dogma. We must instill in our own children the importance of sound science in this country.

And we must continue to observe the opponents of evolution with a scientific eye. As Matzke stated after the Dover trial, "history shows that anti-evolutionism does not disappear after defeat in the courts: it merely evolves." If we are to succeed in fighting this highly adaptable "species," we must know its shifting shape as well as we do our own.

Lecture 2:
Darwin's Cambridge.mp3

Lecture 3:
Today we talked about the evolutionary step from terrestrial living to adopting the skies as reptiles became airborne, and so as reading for today's class I want you to think about another example of an evolutionary step, one from water to land. This is a story of a land-loving fish called Tiktaalik. The first article describes the original find: Fossil Called Missing Link From Sea to Land Animals. The second is about a new angle to this same story: Ancient Tracks Question Ideas About Tetrapod Origins

Fossil Called Missing Link From Sea to Land Animals

Scientists have discovered fossils of a 375-million-year-old fish, a large scaly creature not seen before, that they say is a long-sought missing link in the evolution of some fishes from water to a life walking on four limbs on land.

In two reports today in the journal Nature, a team of scientists led by Neil H. Shubin of the University of Chicago say they have uncovered several well-preserved skeletons of the fossil fish in sediments of former streambeds in the Canadian Arctic, 600 miles from the North Pole.

The skeletons have the fins, scales and other attributes of a giant fish, four to nine feet long. But on closer examination, the scientists found telling anatomical traits of a transitional creature, a fish that is still a fish but has changes that anticipate the emergence of land animals — and is thus a predecessor of amphibians, reptiles and dinosaurs, mammals and eventually humans.

In the fishes' forward fins, the scientists found evidence of limbs in the making. There are the beginnings of digits, proto-wrists, elbows and shoulders. The fish also had a flat skull resembling a crocodile's, a neck, ribs and other parts that were similar to four-legged land animals known as tetrapods.

Other scientists said that in addition to confirming elements of a major transition in evolution, the fossils were a powerful rebuttal to religious creationists, who have long argued that the absence of such transitional creatures are a serious weakness in Darwin's theory.

The discovery team called the fossils the most compelling examples yet of an animal that was at the cusp of the fish-tetrapod transition. The fish has been named Tiktaalik roseae, at the suggestion of elders of Canada's Nunavut Territory. Tiktaalik (pronounced tic-TAH-lick) means "large shallow water fish."

"The origin of limbs," Dr. Shubin's team wrote, "probably involved the elaboration and proliferation of features already present in the fins of fish such as Tiktaalik."

In an interview, Dr. Shubin, an evolutionary biologist, let himself go. "It's a really amazing, remarkable intermediate fossil," he said. "It's like, holy cow."

Two other paleontologists, commenting on the find in a separate article in the journal, said that a few other transitional fish had been previously discovered from approximately the same Late Devonian time period, 385 million to 359 million years ago. But Tiktaalik is so clearly an intermediate "link between fishes and land vertebrates," they said, that it "might in time become as much an evolutionary icon as the proto-bird Archaeopteryx," which bridged the gap between reptiles (probably dinosaurs) and today's birds.

The writers, Erik Ahlberg of Uppsala University in Sweden and Jennifer A. Clack of the University of Cambridge in England, are often viewed as rivals to Dr. Shubin's team in the search for intermediate species in the evolution from fish to the first animals to colonize land.

H. Richard Lane, director of paleobiology at the National Science Foundation, said in a statement, "These exciting

discoveries are providing fossil 'Rosetta Stones' for a deeper understanding of this evolutionary milestone — fish to land-roaming tetrapods."

The science foundation and the National Geographic Society were among the financial supporters of the research. Besides Dr. Shubin, the principal discoverers were Edward B. Daeschler of the Academy of Natural Sciences in Philadelphia and Farish A. Jenkins Jr., aHarvard evolutionary biologist. Casts of the fossils will be on view at the Science Museum of London.

Michael J. Novacek, a paleontologist at the American Museum of Natural History in Manhattan, who was not involved in the research, said: "Based on what we already know, we have a very strong reason to think tetrapods evolved from lineages of fishes. This may be a critical phase in that transition that we haven't had before. A good fossil cuts through a lot of scientific argument."

Dr. Shubin's team played down the fossil's significance in the raging debate over Darwinian theory, which is opposed mainly by some conservative Christians in this country, but other scientists were not so reticent. They said this should undercut the argument that there is no evidence in the fossil record of one kind of creature becoming another kind.

One creationist site on the Web (emporium.turnpike.net/C/cs/evid1.htm) declares that "there are no transitional forms," adding: "For example, not a single fossil with part fins, part feet has been found. And this is true between every major plant and animal kind."

Dr. Novacek responded: "We've got Archaeopteryx, an early whale that lived on land, and now this animal showing the transition from fish to tetrapod. What more do we need from the fossil record to show that the creationists are flatly wrong?"

Duane T. Gish, a retired official of the Institute for Creation Research in San Diego, said, "This alleged transitional fish will have to be evaluated carefully." But he added that he still found evolution "questionable because paleontologists have yet to discover any transitional fossils between complex invertebrates and fish, and this destroys the whole evolutionary story."

Dr. Shubin and Dr. Daeschler began their search on Ellesmere Island in 1999. They were attracted by a map in a geology textbook showing an abundance of Devonian rocks exposed and relatively easy to explore. At that time, the land had a warm climate: it was part of a supercontinent straddling the Equator.

It was not until July 2004, Dr. Shubin said, that "we hit the jackpot." They found several of the fishes in a quarry, their skeletons largely intact and in three dimensions. The large skull had the sharp teeth of a predator. It was attached to a neck which allowed the fish the unfishlike ability to swivel its head.

If the animal spent any time out of water, said Dr. Jenkins, of Harvard, it needed a true neck that allowed the head to move independently on the body.

Embedded in the pectoral fins were bones that compare to the upper arm, forearm and primitive parts of the hand of land-living animals. The joints of the fins appeared to be capable of functioning for movement on land, a case of a fish improvising with its evolved anatomy. In all likelihood, the scientists said, Tiktaalik flexed its proto-limbs mainly on the floor of streams and might have pulled itself up on the shore for brief stretches.

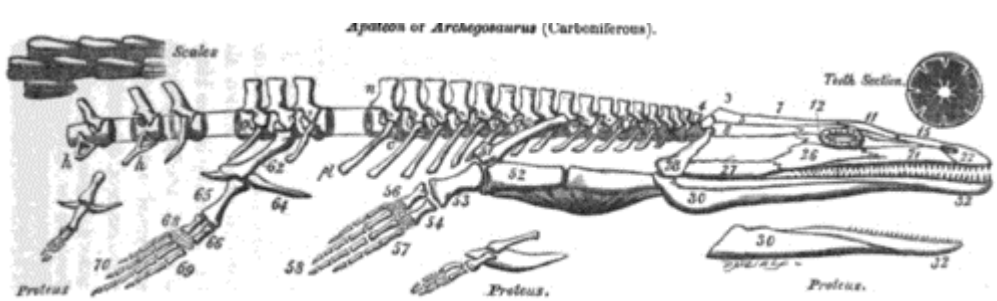
In their report, the scientists concluded that Tiktaalik was an intermediate between the fishes Eusthenopteron and Panderichthys, which lived 385 million years ago, and early tetrapods. The known early tetrapods are Acanthostega and Ichthyostega, about 365 million years ago.

Tiktaalik, Dr. Shubin said, is "both fish and tetrapod, which we sometimes call a fishapod."

Ancient Tracks Question Ideas About Tetrapod Origins

Tiktaalik is practically a household name. Since its description in 2006 the flat-headed "fishapod" has appeared in books, on t-shirts, and has even starred in its own music video. Hailed as a "missing link", *Tiktaalik* has become a poster ~~child~~fossil for evolution, but it is hardly the first such creature to be given this honor.

Way back in the 1840's, well over a decade before Charles Darwin's *On the Origin of Species* was published, the Victorian anatomist Richard Owen was mulling over the concept of transitional forms. He was not so much thinking about actual fossils as the way anatomical frameworks could be modified by natural laws, but even so the anatomy of several creatures Owen had examined appeared to throw credence to the idea that one form could be derived from another. The lungfish *Lepidosiren* and *Protopterus*, for example, were fish that had lungs and wispy fins supported by stacks of bone. These traits made the fish seem very similar to some amphibians, and a fossil creature approached the "fish/amphibian boundary" from the other side. The extinct crocodile-like amphibian *Archegosaurus* showed some close resemblances to *Lepidosiren*, and together Owen took the two forms to represent a divergent juncture in vertebrate forms. The anatomy of *Lepidosiren*, on the one hand, appeared capable of forming the basis for salamanders with gills such as the axolotl, while the *Archegosaurus*, on the other, could have been derived from a gar-like fish. Together they were "transitional types" that seemed to represent gradations along anatomical chains, but frustratingly, Owen was vague about just what he meant by all this.



A restoration of *Archegosaurus* in Owen's *Systematic Summary of Extinct Animals and Their Geological Relations*. Parts of its skeleton are compared to corresponding parts in the living amphibian *Proteus*, commonly called the olm.

It was Darwin's 1859 work, of course, that spurred a greater scientific interest in evolution, but he did not co-opt *Lepidosiren* and *Archegosaurus* as transitional forms. Perhaps this was a wise move. Clearly the first land-dwelling vertebrates (called "tetrapods" for their possession of four limbs) could not have evolved from a living fish, and as *Archegosaurus* became better understood it was moved further and further away from the origin of the first land-dwelling vertebrates. (Today we know *Archegosaurus* as a temnospondyl that lived tens of millions of years after the first tetrapods.)

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With so few fossils mapping out the transition debates went on for decades about the details of how vertebrates became adapted to life on land. This was not helped by some delays in the description of important specimens. Many fossils of early tetrapods such as *Acanthostega* and *Ichthyostega*, had been found in the over 365 million year old rock of Greenland during the early part of the 20th century. Unfortunately, however, the description of these fossils was held up due to the death of one scientist, the almost glacial work pace of another, and the relegation of some specimens to museum basements where they gathered dust for years.

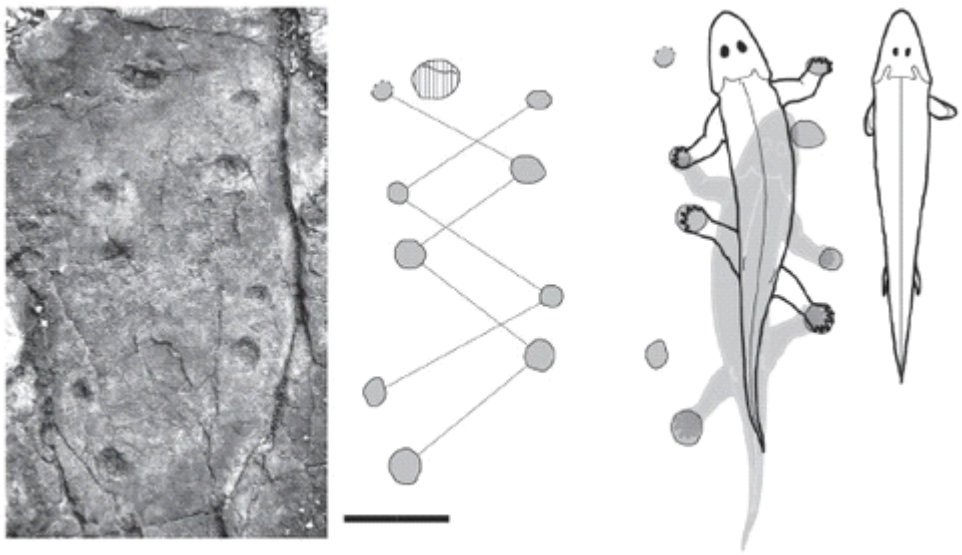
By 1990, though, our picture of tetrapod origins seemed a little more complete. The earliest tetrapods had evolved from "bony-finned" fish akin to *Eusthenopteron* (a long-time representative of the fish side of the transition) and had evolved through graded states into forms such as *Acanthostega* and *Ichthyostega*. Yet there was still a wide anatomical gap between the "fish

side" and the "tetrapod side" of the transition, a gap that *Tiktaalik* and its lesser-known relative *Panderichthys* would come to fi in.

Nor were these the only fossils relevant to questions about this transition. They became the most famous because they are the most complete, but there are plenty of other critters known from fragments that illustrate that the origin of tetrapods was not some straight-line march as is commonly seen in cartoons. What this all means is that even though *Tiktaalik* is a celebrity today there is still a lot out there to be discovered, and in a few years we very well may be celebrating some other tetrapodomorph with an anatomy that fits snugly between *Tiktaalik* and *Acanthostega*.

Indeed, since the 1980's scientific investigations into the origin of tetrapods has exploded, and new discoveries are being made all the time. One new finding, just published in *Nature*, may even cause us to revise what we thought we knew about the tempo and mode of tetrapod evolution. It is a collection of approximately 395 million year old tracks from Poland, tracks that predate *Tiktaalik* and its kind by several million years.

As described by Grzegorz Niedzwiedzki, Piotr Szrek, Katarzyna Narkiewicz, Marek Narkiewicz, and Per Ahlberg, the tracks were found in quarry in Poland. Rather than representing a shallow freshwater swamp or stream, however, these deposits were marine This is significant as the evolution of the first tetrapods has generally been thought that have occurred in brackish-to-freshwate environments. Instead the tracks appear to have been made in an area alternately covered and exposed by saltwater, such as a lagoon or shallow tidal area. Whatever the environment was like, though, the creatures walked all over it. While devoid of body fossils (as is often, and frustratingly the case with such sites) the deposit contains numerous tracks made by the animals.

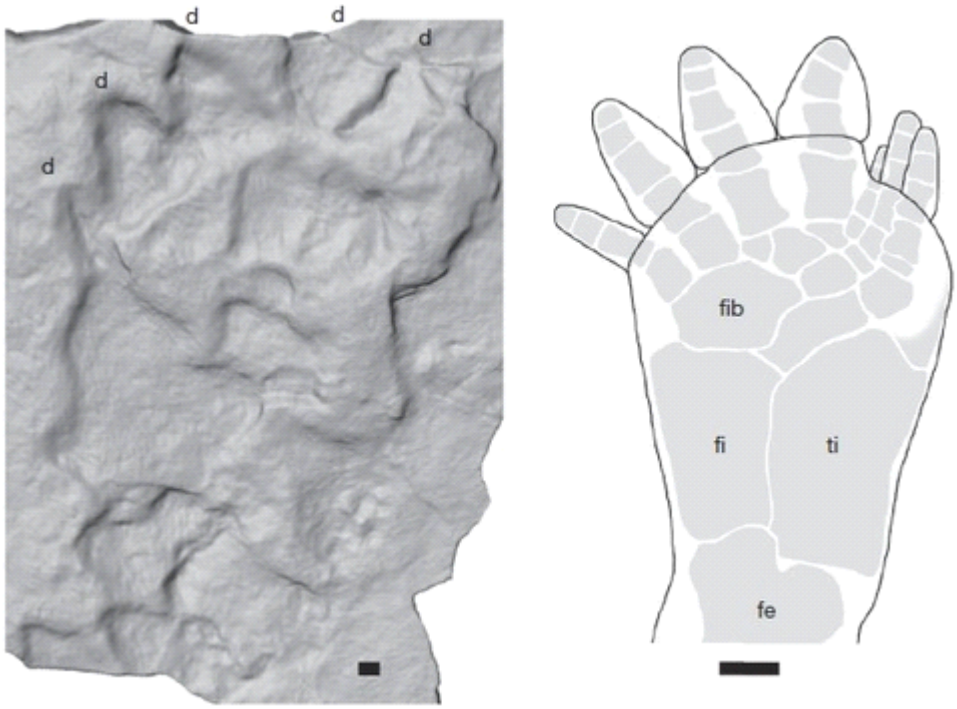


A short trackway representing the steps of what may have been an early tetrapod. To the left is a photo of the trackway, in the middle is an illustration of the track pattern, and to the right are restorations of two tetrapods. The one on the left is based on *Ichthyostega* and the one on the right represents *Tiktaalik*. (From Niedzwiedzki et al, 2010)

Among the most impressive of the specimens is a short trackway left by one of the animals. It preserves the hand and footprints of an animal moving in a straight line, and there are no body drag marks. Think about that for a second. *Tiktaalik*, which lived about 10 million years or so *after* the tracks were made, had short, stubby arms and even less-well-developed legs that would no have allowed it to do this. No doubt that it could have raised its body to move, but it could not have moved it all the way off the bottom and hence would have left a drag mark between the footprints. The creatures described by Niedzwiedzki and colleagues however, appear to have raised their bodies higher off the bottom, although they may have also floated their bodies in the wate and moving themselves about with their limbs (thus removing some of the weight-bearing stress from their arms and legs).

What is especially interesting, though, is that this trackway appears to show that this animal, which was larger than *Ichthyostega* moved in a side-to-side manner similar to that of living salamanders. This might not have been possible for some of the earlies tetrapods known from complete skeletons such as *Ichthyostega*. In fact, just a few years ago Ahlberg and colleagues published a

reexamination of *Ichthyostega* in *Nature* in which they proposed that its overlapping ribs would have hindered its ability to move its body from side-to-side. Instead the restrictions of its skeleton made it seem more likely that it would have moved in a way similar to a seal or an inchworm by flexing its body up-and-down. Clearly the animals whose tracks were preserved in the quarry in Poland were moving more like living amphibians, making them unlike *Tiktaalik* and (presumably) *Ichthyostega*.



Specimen Muz. PGI 1728.II.1 compared to the restored left hind limb of *Ichthyostega*. (From Niedzwiedzki et al, 2010)

Some of the individual tracks are also of great interest. If the scientists are correct, they represent the earliest animals yet known with differentiated toes. Toes are a key tetrapod trait, *Tiktaalik* did not have them, and one of the best-preserved representations of a foot with toes is specimen Muz. PGI 1728.II.1. Altogether it seems to be an impression of almost the entire lower left hindlimb exhibiting at least five toes (there may be more, though, given the track is smudged). It looks akin to what you would expect the foot of something like *Ichthyostega* to make, but it is not an exact match.

But are those really toes? It looks like the outlines of toes, but could the same impressions have been made by a modified fin? How can we tell whether or not those notches really represent the ends of fingers or something else entirely? As it stands now we can't. The tracks appear to be consistent with what an early tetrapod could make but the trouble with tracks is that the animals that much such prints almost never die in their tracks. We need bones to be sure, and in lieu of bones we need to try to reconstruct how those kind of tracks could have been made.

These tracks very well might be the earliest traces of tetrapods on record, but that is a hypothesis, not a fact. The fact is that some marine vertebrate with limb-like appendages made these tracks about 395 million years ago, but just what that vertebrate was and what it looked like will require further evidence to determine. I am comfortable saying that the tracks were made by a tetrapod in the vernacular sense (i.e. a four-footed vertebrate), but what is truly a creature related to the common ancestor of all land-dwelling vertebrates?

Here is another, hypothetical, example that might help explain some of my reservations about these tracks. Bipedalism has long been treasured as the defining trait of humans (=hominins). Find something "ape-like" between 6 and 4 million years ago that exhibits evidence of bipedalism and you have yourself a hominin, right? But lets say you find what appears to be a track made by a bipedal ape in sediments 10 million years old. Does this mean that "Ardi" is suddenly irrelevant? Of course not! It is entirely possible, for example, that another group of apes, as yet unknown, independently evolved bipedalism before going extinct. Then again, such a track could mean that our previous hypotheses were wrong and require revision according to new evidence. Without body fossils, bones to compare to what has already been collected, it is impossible to know which scenario is correct.

We are faced with a similar situation here. The hypothesis that the tracks were made by tetrapods seems pretty reasonable, but i is going to take more evidence to support. I am in no way trying to downplay this study. Instead I think it is wonderful because i brings up so many new questions! If the scientists behind this new research are correct then tetrapods evolved much earlier than we previously supposed, and what we have taken up till now as the general evolutionary sequence of forms in early tetrapod evolution are actually disparate forms which are part of a more complex radiation of early tetrapods. In this case, as the authors note, creatures like *Tiktaalik* did not quickly give way to early tetrapods but lived alongside them for 10 million years or more. This does not mean that *Tiktaalik*, *Acanthostega*, and the rest are irrelevant to tetrapods origins, but rather that we need to revise our hypotheses about how they relate to one another.

Some people might consider my uncertain admissions here to be something of a downer, but I cannot agree. In science uncertainty is exciting. The authors of this new paper have proposed an interesting hypothesis that could rearrange what we thought we know about the origins of tetrapods and a lot of work, both in the lab and the field, will need to be done to sort this all out. We should not feel compelled to throw all our weight behind one hypothesis or another without more evidence. We have been presented with some really intriguing questions, and I look forward to reading the future reports of how scientists went about trying to find some answers.

Lecture 4:

Jack Horner's Plan to Bring Dinosaurs Back to Life

Hans Larsson is a fast walker and a fast talker. You need to be fit to keep up with him on the hills of the McGill University neighborhood in Montreal, let alone on the remote islands of the Canadian Arctic where he searches for fossils in summer fieldwork. He talks the way he walks, in a freely swinging fast-paced lope that ranges from the philosophy of science to genetic probes to the rich Cretaceous ecosystem he is exploring at another field site in Alberta.

Larsson is at the forefront of merging paleontology and molecular biology in an effort to connect major evolutionary changes—the development of new species and new characteristics, new shapes and structures, new kinds of animals—to changes in specific genes and in how those genes are regulated. He is interested in reactivating dormant genes or changing the regulation of active genes in embryos to bring back ancestral traits that have been lost in evolution.

Scientists can do this now because we have the fossils. We have the lessons of developmental biology. And we have the tools of molecular biology. All of these are being merged in the study of the history of life in evolutionary developmental biology, or evo devo.

Collecting and cataloging fossil bones, the heart of vertebrate paleontology, has been primarily a historical enterprise, one of unearthing ancient information and looking for patterns. Laboratory science has been conducted in a different fashion. You could suspect, say, that a gene that controls a particular growth factor is important in how five-fingered hands develop at the ends of arms. So the hypothesis might be that if that gene were absent or nonfunctional, the hand would not develop. You can engineer mice so that the gene is absent or silenced and see what happens to the development of the embryo. If the hand develops perfectly, your hypothesis is false. If the hand does not develop, you have good evidence that the gene in question does what you thought it did.

What about a significant change in form? What happens that allows something new to be introduced that hasn't been seen before in evolution, something like the appearance of limbs, or hair, or feathers, or lactation? We can see it happening on a gross anatomical level throughout the fossil record, but how can we test in the laboratory our ideas about what went on at the molecular level?

There is a way that these ideas can be tested, but it takes us to the very edge of science. The trick is to run the tape of evolution over again: to intervene in the development of a chicken embryo, for instance, to reverse evolution, rolling back the clock to manifest earlier patterns of gene expression. This is a profound advance in the kind of experiment available to test evolutionary theory, and it depends entirely on the progress that has been made in evolutionary developmental biology. It is only because we can match developmental events to evolutionary events, only because we now have both the fossil record, which shows us the path that evolution has taken, and the developmental record of modern animals in extraordinary detail, that we can begin to link the two.

With birds, for instance, the absence of a tail, the difference between wings and grasping forearms, and the absence of teeth are all subtle evolutionary changes on a basic dinosaur plan. Why not rerun an ancient developmental process in a bird embryo, this time triggering the signals to produce a grasping forelimb or a long tail?

At last, we would have a truly experimental way of studying macroevolution, the kind of changes that lead to the creation of new species. If we think a particular process is responsible for the origin of feathers, we could rerun that process, changing the developmental pathway in the bird embryo as a way to test our proposed evolutionary pathway.

But why stop at one developmental process? Why not grow an entire dinosaur? At least that's the thought that came to my mind. It seemed so obvious that if fairly small changes in development, which adjusted the timing and concentrations of growth and signaling factors, could have led to the evolution of birds from nonavian dinosaurs, we could readjust those changes in development and get a dinosaur from a chick embryo. Dinosaurs and chickens share a very similar skeleton. In the grand scheme the differences between the two creatures are just adjustments to a basic body plan, and such adjustments, we are assured by evo devo, are the result of changes in gene regulation, not a complete new suite of genes. Once I got the idea in my head that it could be done, I started talking to researchers who were truly fluent in the language, ideas, and techniques of both paleontology and molecular biology. That's how I ended up talking to Larsson.

He was already researching how the tail in birds first got shorter and then disappeared over the course of evolution. I thought, why not look at it from the other direction? Suppose we were going to try to bring back the tail—what would we do then? I gave about 40 thousand dollars to pay for a postdoctoral researcher to work on this problem in Larsson's lab. Larsson is continuing to pursue the research on his own now.

A very few experimental attempts to achieve this kind of thing have been done. Chicken embryos have been induced to grow teeth without any transplant of tissue from another organism. Changes in the presence of growth factors produced the teeth, which were consistent with those of archosaurs (the group that includes birds, nonavian dinosaurs, and crocodilians).

Primitive birds, like *Archaeopteryx*, had tails, but modern birds don't. It seems a good bet that this was a simple evolutionary change at the molecular level, a turning off of the growth program that was keeping the tail going. Find the chemical switch, flip it the other way in embryonic development, and the result would be a bird with a tail. Larsson determined that in chicken embryos, a tail does begin to grow in the normal course of events. But then, he said, "I found that at a particular stage of development everything comes crashing to a halt."

Larsson and his postdoctoral assistant began to try to make an embryo's tail continue growing. They began snipping off the tip of a growing tail at one stage and stapling it, with fine tungsten wire, to a later stage, to see if the growth factors in action during early tail growth could override the stopping signals. The next step was to add retinoic acid, a compound that stimulates the release of a protein called sonic hedgehog, which is important in promoting growth during development.

Transplanting completely failed to keep the chick embryo's tail growing, but the retinoic acid, Larsson said, "pushed tail growth to the upper range of normal development. It had some effect, but it didn't break it out of the cycle." The tail was a far more complex system than he or anyone else had imagined.

The initial hint of growth from the retinoic acid was encouraging, but Larsson needed to know much more. In particular he needed to avoid creating something that looked like a longer tail but was simply an embryologist's trick, a growth that occurred without utilizing an ancestral pathway. Unless he knew the normal pathway of development in detail, all he would have achieved with a tailed chicken would be a circus attraction.

Unfortunately, there was no foundation of basic research describing how a tail grows. Studies had been done on how embryos initiated tail growth, but not on how they maintained that growth and what genes might be involved. Larsson had to start from scratch and do fundamental developmental research.

Larsson is now working on a model of how the tail grows. This will involve labeling cells in the growing embryo tail and using microinjections of dye to follow the pathways that these cells take as the tail develops. His goal is to see how zones of growth and organization move as the embryo grows and to probe what is going on biochemically. He has been able to piggyback on previous work on the development of the chick embryo: When researchers interested in some process use a stain to show gene activity, the stain affects the whole embryo, providing clues about which genes are active in tail growth.

Although the growth of the tail is very complicated once begun, the action that turns that growth off may be quite simple. Larsson compares the situation to a mechanical one. "It's kind of like the key to a car. You could turn the key on and the motor will run and produce all these patterns and rhythms. Once you turn the key off, it stops. The key is relatively simple, compared with the rest of the car. I think that's the kind of system we're dealing with. Or I'm hoping."

But building a dinosaur requires more than just a tail. "The experiment I'm envisioning is that you have a single embryo developing in the egg with multiple injection sites and multiple kinds of molecules to be really fine-tuning the regulation of genes," Larsson says. "We'll be able to inject different parts of the embryo at different times of development with different things. If we do that, if the timing and position are correct, we should be able to manipulate lots of different kinds of morphologies—feathers, wings, teeth, tails.

> **We don't have to give an embryo new genes, just adjust the growth factors and other chemicals that direct development. It would be the first step in growing a dinosaur.**

"It would take just a little bit of time to work out each one of those systems in very great detail, which we're now doing for the tail. Other people are doing it for the limbs for clinical work. And teeth are being worked out by other people for mammals and such, and then we can just sit down and play with all these in concert, which has never been done before."

The goal, in the end, would be to steer the embryo down the path it would have gone if it were something like a very early coelurosaur, a dinosaur grouping that counts tyrannosaurs and velociraptors among its members. If the genes in the chick embryo are very close to those of an ancestral,

nonavian dinosaur—and if the changes, over more than 150 million years, have been almost all in regulation of the genes—then we could reactivate the old pattern of regulation.

We don't have to give the embryo new genes, just adjust the growth factors and other chemicals that direct development. And by doing that we can see what must have changed during evolution, and what the old pattern of regulation was. If we learn enough, this will give us enormous insight into the fundamentals of biology, development, and evolution. It will also be the first step in growing a dinosaur.

In the end, there is an image that keeps popping into my mind. I give an awful lot of lectures. I don't read from notes; I prefer to use slides, each of which fits with a topic that I want to talk about. I don't need to memorize a speech or make it formal. I can stay conversational, which is what I find most comfortable.

So the image I have is that I walk onstage with a dinosaur on a leash. It's small, but bigger than a chicken. Let's say it's the size of a turkey, one day maybe even the size of an emu. The dinosaur, or chickenosaur, or dino-chicken, the emu-size version of a dinosaur (that one might have a muzzle or a couple of handlers) is the ultimate slide. Instead of a lecture, this would be a public science class with questions and challenges about how it was done, what its skin feels like, does it have teeth, what does it eat, how close is it really to a dinosaur? What would inevitably follow would be a discussion about the nature of dinosaurs, of birds, of evolution and development, of the relationship of molecular biology to big changes in evolution, of how we know what we know, and whether we were justified in doing what we did.

That would be the most satisfying lecture I could possibly give. I don't like providing answers. I never have. I like questions. I like asking them, trying to figure out answers, trying to figure out what we are really asking, and seeing what new questions come up. For this event I won't have to prepare any speech at all. My entire prepared text will consist of one simple question from which everything else will follow.

I'll walk to the edge of the stage, point to the creature on the leash, look at the audience, and say, "Can anyone here tell me what this is?"

Lecture 5/6: my island life.pdf