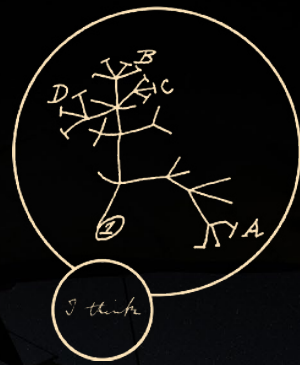


DARWIN'S MYSTERY OF MYSTERIES

# Natural Selection



## EDUCATION GUIDE

MIRAGE3D PRESENTS NATURAL SELECTION DARWIN'S MYSTERY OF MYSTERIES  
A FULLDOME IMMERSIVE CINEMATIC EXPERIENCE

WRITTEN/DIRECTED BY ROBIN SIP NARRATED BY TONY MAPLES  
MUSIC BY MARK SLATER PERFORMED BY THE BUDAPEST SYMPHONY ORCHESTRA

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“The voyage of the beagle has been by far the  
most important event in my life and has  
determined my whole career”

*-Charles Darwin*







# Charles Darwin

*"It is not the strongest of the species that survives, nor the most intelligent that survives. It is the one that is the most adaptable to change."*

*"A man who dares to waste one hour of time has not discovered the value of life."*

– Charles Darwin

Charles Darwin was born in Shrewsbury, England, on February 12, 1809. His mother died when he was only eight years old. His father was a medical doctor and his grandfather was a famous botanist, so science had always surrounded him. Charles was especially fond of exploring nature. He grew up with wealth and privilege.

In 1825, when he was only sixteen, Darwin enrolled at Edinburgh University. In 1827, he transferred to Christ's College in Cambridge. He planned to become a physician like his father until he discovered that he could not stand the sight of blood. His father suggested that he become a minister, but Darwin wanted to study natural history, which he did. In 1831, he obtained a Bachelor of Arts degree and his mentor, botany professor John Stevens Henslow, recommended Darwin for a position as a naturalist on the HMS Beagle. Initially, Darwin's father opposed the voyage and since he was expected to pay for Darwin's supplies (microscopes, glassware, preserving papers, etc.) and his passage, he had the right to do so. However, he was finally persuaded to let Darwin go. And then there was another obstruction that almost caused him to miss being on the Beagle.

*"Afterwards on becoming very intimate with [Captain] Fitz-Roy, I heard that I had run a very narrow risk of being rejected, on account of the shape of my nose! He was an ardent disciple of [Johann Caspar] Lavater [a physiognomist], and was convinced that he could judge a man's character by the outline of his features; and he doubted whether anyone with my nose could possess sufficient energy and determination for the voyage. But I think he was afterwards well satisfied that my nose had spoken falsely."*

Finally, however, on December 27, 1831, the Beagle – with Darwin aboard – embarked from Plymouth, England. Although the trip was planned for two years, the Beagle took five years to circumnavigate South America, Australia, and Africa (see [aboutdarwin.com](http://aboutdarwin.com) for a map of the journey). The ship was about 90 feet by 24 feet and held 73 crewmen. With such tight quarters and because Darwin was seasick almost the entire journey, it is not surprising that Darwin said, "I abhor, I loathe the sea and all ships which sail on it." Fortunately, the majority of the time he was gone, he was on land rather than on sea.

*Natural Selection*



# Charles Darwin

Throughout the trip, Darwin collected many specimens. Some of his samples were living (birds, fish, snails, reptiles, and plants), and some were fossils. Darwin found giant fossils of nine different mammals including the Megatherium, an elephant-size ground sloth, in Punta Alta, Argentina; he also found smaller fossils of brachiopods (two-shelled organisms) in the Falkland Islands. He wondered about their age and why they were similar to, but different from, animals in his time.

In September and October of 1835, Darwin studied the creatures of the Galapagos Islands. He noticed that many of the animals had counterparts in other areas of the world, but that those on the Islands were slightly different: their coloration or the shape of a beak or a claw had changed. Through his hands-on study and research, he began to develop a theory about the origin of living beings that contradicted the commonly-held beliefs of the time.

## Information

A quick overview of Darwin's trip with interactive map

<http://www.nhm.ac.uk/nature-online/science-of-natural-history/expeditions-collecting/beagle-voyage/>

A 2-D map of Darwin's voyage

[http://www.aboutdarwin.com/voyage/voyage\\_01.html](http://www.aboutdarwin.com/voyage/voyage_01.html)

Great deal of information about Darwin

<http://www.aboutdarwin.com/index.html>

Darwin's diary

<http://www.pbs.org/wgbh/evolution/darwin/diary/>

Basic biographical information

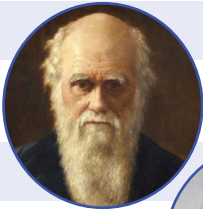
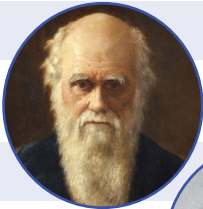
<http://www.biography.com/people/charles-darwin-9266433>

Primarily on Darwin's theory of evolution

<http://ngm.nationalgeographic.com/print/2009/02/darwin/quammen-text>

# Timeline



|            |                                                                                    |                                                                                       |
|------------|------------------------------------------------------------------------------------|---------------------------------------------------------------------------------------|
|            |                                                                                    |                                                                                       |
| 1665       | Robert Hooke is credited with the discovery of cells                               |    |
| 1766       | The first mosasaur is collected in Maastricht, Netherlands                         |                                                                                       |
| 1775       | James Watt invents steam engine                                                    |    |
| 1800       | Washington D.C. becomes the capital of the United States                           |                                                                                       |
| 1803       | The Louisiana Purchase is made                                                     |    |
| 1804       | Napoleon becomes emperor of France                                                 |                                                                                       |
| 1809-1882  | Charles Darwin's life                                                              |   |
| 1811       | Mary Anning discovers the first Ichthyosaurus fossil                               |                                                                                       |
| 1819-1901  | Queen Victoria rules the British Empire                                            |   |
| 1820       | Missouri Compromise                                                                |                                                                                       |
| 1826       | Pierre Turpin observes the division of cells                                       |  |
| 1828       | The London Zoo (the world's oldest scientific zoo) opens and includes an orangutan |                                                                                       |
| 1830       | Charles Lyell publishes Principles of Geology                                      |  |
| Feb. 1835  | Darwin feels an earthquake in Concepción, Chile                                    |                                                                                       |
| Sept. 1835 | The Beagle reaches the Galapagos Islands                                           |  |
| 1837       | Samuel Morse telegraph                                                             |                                                                                       |
| 1841       | Sir Richard Owen first uses the word "dinosaur", meaning terrifying lizard         |  |
| 1843       | Dickens publishes A Christmas Carol                                                |                                                                                       |
| 1845       | Edgar Allen Poe writes The Raven                                                   |                                                                                       |

# Timeline



|           |                                                                                                                                                |                                                                                       |
|-----------|------------------------------------------------------------------------------------------------------------------------------------------------|---------------------------------------------------------------------------------------|
| 1848      | Karl Marx and Friedrich Engels publish the Communist Manifesto                                                                                 |    |
| 1849      | The California gold rush begins                                                                                                                |                                                                                       |
| 1858      | Alfred Russell Wallace shares his ideas about evolution and natural selection with Darwin                                                      |                                                                                       |
| 1859      | On the Origin of Species by Means of Natural Selection by Charles Darwin was published                                                         |                                                                                       |
| 1861-1865 | The American Civil War                                                                                                                         |    |
| 1869      | Miescher discovers DNA                                                                                                                         |                                                                                       |
| 1871      | The Descent of Man, and Selection in Relation to Sex by Charles Darwin                                                                         |                                                                                       |
| 1874      | The first Impressionist exhibition takes place featuring Claude Monet, Edgar Degas, Pierre-Auguste Renoir, Camille Pissarro and Berthe Morisot |   |
| 1898      | Pierre and Marie Curie discover radium and polonium                                                                                            |                                                                                       |
| 1914-1918 | World War I                                                                                                                                    |  |
| 1939-1945 | World War II                                                                                                                                   |                                                                                       |
| 1953      | Watson and Crick describe the double helix of DNA                                                                                              |  |
| 1961      | Gagarin pilots the first manned space flight                                                                                                   |                                                                                       |
| 1969      | Apollo 11 – first men on the moon                                                                                                              |                                                                                       |
| 2012      | The rover Curiosity lands on Mars                                                                                                              |                                                                                       |





## I. Mary Anning

Mary Anning was born in 1799 in Lyme Regis, which is on the southern coast of Great Britain. Her father was a cabinet maker and enjoyed collecting fossils. He passed on his love of the ancient bones to his children. He died in 1810, leaving his family in poverty.

Mary turned her passion for fossil hunting into a job and her family desperately needed the income. She is credited with finding the first of many new species including an Ichthyosaurus (a marine reptile similar to a dolphin), a British Pterodactylus macronyx (a flying reptile), a Squaloraja (a fish that links sharks and rays), and a Plesiosaurus macrocephalus (a long-necked sea reptile). She sold her discoveries to many private collectors.

In 1817, Mary's family was befriended by Lieutenant-Colonel Thomas Birch, a fossil collector, who helped the Annings by giving them credit for many of the findings in their area and by donating the money made from selling the fossils he had bought.

As Mary's reputation as a fossil hunter increased, visitors came to Lyme to see this curiosity – a woman from the lower class who was knowledgeable in the new field of paleontology. The tourist trade brought in scientists along with other onlookers, and she won the respect of the scientific community with her familiarity of old bones. She was so admired that she was granted an annuity from the British Association for the Advancement of Science in 1838 and was named the first Honorary Member of the new Dorset County Museum. Although the Geological Society did not admit women to their organization until 1904, Mary's obituary was published in 1847 in their Quarterly Journal.

Mary's contributions are great. Not only did she help to get paleontology off the ground, she showed that women could be influential scientists in a time when men were considered to be the only beings capable of rational thought. We owe a great deal to Mary Anning.





Part One: Read this excerpt from All The Year Round, Volume 13, pp. 60-63, edited by Charles Dickens

MARY ANNING, THE FOSSIL FINDER

Everyone must have seen at least an engraving of that strange old-world monster the Plesiosaurus, of which Cuvier said, when the skeleton was sent to him from Lyme Regis, "Verily, this is altogether the most monstrous animal that has yet been found amid the ruins of a former world. It had a lizard's head, a crocodile's teeth, a trunk and tail like an ordinary quadruped, a chameleon's ribs, a whale's paddles, whilst its neck was of enormous length, like a serpent tacked on to the body". This 'classic, first cousin of all lizards,' was discovered by a self-taught geologist, the daughter of a Lyme carpenter.

Geology does not seem a pursuit likely to attract women, yet we have known several who had picked up a very fair knowledge of its outlines-some of them literally. There was a quaint old lady who used to go her "midland circuit," calling on all parsons and other supposed encouragers of science, carrying about with her boxes of "specimens", and begging to be allowed to enlighten the national school children at so much a head.

But Mary Anning was something more than a mere village celebrity, interesting to those who like to study character, and are fond of seeing good stubborn English perseverance make way even where there is nothing in its favor. She acquired, if not an English, certainly a European, reputation. Professor Owen thought so highly of her usefulness, that he moved the authorities of the British Museum to grant her a pension of forty pounds a year, which she enjoyed for some little time before her early death.

Her father used to employ the church holidays in picking up along the beach pretty pebbles and shells, fossil and recent, and "verteberberries", and "John Dory's bones", and "ladies' fingers", and other "curies", as they were called. Lyme and its neighbour, Charmouth, were then on the old coach-road, and the passengers mostly liked to take away a specimen or two, which they got either from Anning or from a Charmouth "fossiler", called the Cury-man, or "Captain Cury", from his trade in curiosities. In August, 1800, little Mary Anning was taken to see some horse-riding in the Rack field. A thunderstorm came on; those in charge of her hurried her under a tree; a flash of lightning struck the party, killing two women on the spot, and making the child insensible. A warm bath restored her to consciousness, and, strangely enough, she who had been a very dull girl before, now grew up lively and intelligent. She soon got to accompany her father in his rambles. "Fossiling", however, does not appear to have paid so well as steady carpentry, for the family went down the hill. The father died of consumption, and Mary, at ten years of age, was left very badly off. Just then a lady gave her half-a-crown for a very choice ammonite. This encouraged her to take to collecting as a regular means of life. But she soon proved something more than a mere "fossiler".





In 1811, she saw some bones sticking out of a cliff, and, hammer in hand, she traced the position of the whole creature, and then hired men to dig out for her the lime block in which it was embedded. Thus was brought to light the first Ichthyosaurus (fish-lizard), a monster some thirty feet long, with jaws nearly a fathom in length, and huge saucer eyes, some of which have been found so perfect, that the petrified lens (the sclerotica, of which it had thirteen coats) have been split off and used as magnifiers. People then called it a crocodile. Mr. Henley, the lord of the manor, bought it off the enterprising young girl for twenty-three pounds. It is now in the British Museum. Then came the Plesiosaurus, which was the occasion of a sharper, though shorter, battle. Miss Anning's business, of course, was not to take sides, but to furnish the combatants with munitions of war—now a paddle, then a jaw, then a stomach full of half-digested fish. She had in a high degree that sort of intuition without which it is hopeless for anyone to think of becoming a good collector of fossils.

Here, as in everything else, field and chamber practice are widely different; you may be well up in the latest theories, and able to argue perfectly on the specimen when it is laid before you, and you may totally lack that instinct which will lead your brother-collector right to the place where the "specimen" is to be found, and will direct him in following up the track, until from finding a fragment of a claw he succeeds in ferreting out the whole skeleton. Our heroine would have been able, for instance, out of fifty "nodules", all looking to you much of a muchness, to pick without hesitation the one which, being cleft with a dexterous blow, should show a perfect fish imbedded in what was once soft clay. Scenting out valuable specimens in this way, she enabled the savants to fix four kinds of ichthyosauri, besides two plesiosauri, and the extraordinary pterodactyle (discovered in 1828) which made Cuvier retract what he had said of the lizard's cousin, and award the palm of strangeness to a monster half vampire, half woodcock, with crocodile's teeth along its tapering bill, and scale armour over its lizard-shaped body. If you have never seen the creature delineated, take Dr. Buckland's wonderful plate, *Duria antiquior*, wherein "the dragons of the prime, which tear each other in the slime", are shown, swimming, flying, biting, fighting, as 'twas their nature to; and aloft in the corner of the picture, those things that look like Japanese kites, are nature's first attempts at anything in the bird line. Gruesome beasts they seem to be.

One more discovery Miss Anning helped to bring about: the ladies' fingers were at last judged from their surroundings to be the bony processes of pre-chaotic cuttle-fish, belemnites they are now named, because they are long and dart-like, instead of flat like our present cuttlefish's inside. Some of them are so perfect that, the ink-bag has been found and "utilized". Dr. Carus, who went with the King of Saxony through England and Scotland, in 1844, and wrote an account of his majesty's journey, speaks of visiting her collection, and securing six feet of reptile for fifteen pounds. The doctor says, "Wishing to preserve the name of this devoted servant of science, I made her write it in my pocket-book; she said, with unaffected pride, as she gave me back the book, 'My name is well known throughout Europe'".



Better known indeed abroad than at home! In her own neighbourhood, Miss Anning was far from being a prophetess. Those who had derided her when she began her researches, now turned and laughed at her as an uneducated assuming person, who had made one good chance hit. Dr. Buckland and Professor Owen and others knew her worth, and valued her accordingly; but she met with little sympathy in her own town, and the highest tribute which that magniloquent guide-book, *The Beauties of Lyme Regis*, can offer her, is to assure us that “her death was, in a pecuniary point, a great loss to the place, as her presence attracted a large number of distinguished visitors”. Quick returns are the thing at Lyme. We need not wonder that Miss Anning was chiefly valued as a bait for tourists, when we find that the museum is now entirely broken up, and the specimens returned to those who had lent them. No one had public spirit enough to take charge of a non-paying concern, when the early geological furor had calmed down, and people came to bathe and not to chop rocks. You may now visit the old abode of saurians without being able to see a single tolerable specimen.

Miss Anning wrote sadly enough to a young girl in London, “I beg your pardon for distrusting your friendship. The world has used me so unkindly, I fear it has made me suspicious of every one”.

Her history shows what humble people may do, if they have just purpose and courage enough, towards promoting the cause of science. The inscription under her memorial window commemorates “her usefulness in furthering the science of geology” (it was not a science when she began to discover, and so helped to make it one), “and also her benevolence of heart and integrity of life”. The carpenter’s daughter has won a name for herself, and has deserved to win it”.

### Part Two: Questions about the reading selection

Answers in Appendix I Answer sheet

1. Describe Mary Anning’s socioeconomic status.
2. What originally drove Mary Anning to collect fossils?
3. Describe 3 different species of animals collected by Mary Anning.
4. How did these fossils disturb the prevailing view of the development of life on Earth?
5. How was Mary Anning treated by her peers in Lyme Regis? How was she regarded by the International Scientific Community of her time?
6. Who is Charles Dickens? Describe briefly his more common claims to fame.
7. What does Mary Anning’s work contribute to the study of evolution?

### Part Three: Interview a female scientist. Choose a female scientist that you know locally, if possible. Find out the following

1. What drew her to pursue her chosen field?
2. What obstacles did she need to overcome in order to be successful?
3. Has she now, or did she at some point in her pursuit of career, experienced discrimination?





## II: Principles of Geology: Superposition

This excerpt from a Geology textbook written by Lyell (who also wrote *Principles of Geology*, which Darwin read while aboard the HMS Beagle), gives a good introduction to one of the key geological ideas that sets the geological clock, and allows time for evolution to occur.

Part One: Read the following selection from Charles Lyell's *The Student's Elements of Geology*, (Chapter VIII, paragraph 9) a text written in 1878 for geology students

Answers in Appendix I Answer sheet

### SUPERPOSITION

The first and principal test of the age of one aqueous deposit, as compared to another, is relative position. It has been already stated, that, where strata are horizontal, the bed which lies uppermost is the newest of the whole, and that which lies at the bottom the most ancient. So, of a series of sedimentary formations, they are like volumes of history, in which each writer has recorded the annals of his own times, and then laid down the book, with the last written page uppermost, upon the volume in which the events of the era immediately preceding were commemorated. In this manner a lofty pile of chronicles is at length accumulated; and they are so arranged as to indicate, by their position alone, the order in which the events recorded in them have occurred.

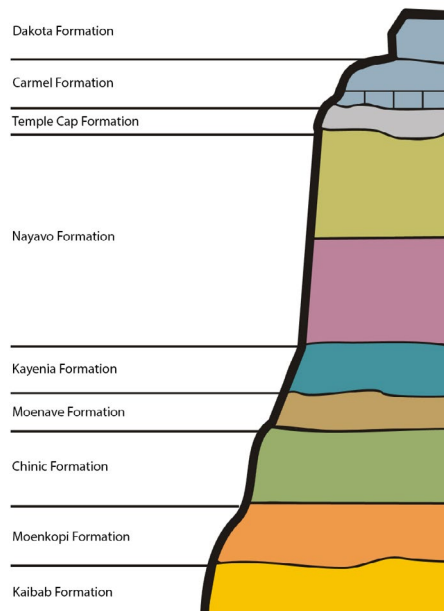
Part Two: Restate the previous paragraph in your own words

Part Three: Superposition in your own experience

1. Find at least two examples of either short or long-term superposition occurring in your environment.
2. Make your own geological column at home. You'll need flour, sand, potting soil, gravel, and a glass container. Gently pour in one ingredient at a time, and shake the container gently until you get a series of flat layers. Write down the order in which you added the layers. Do the layers pile up in the order they were laid down?
3. Locate a diary, journal, or photo album. Open it up to the latest entry. Is this entry, or collection of images, the last chronologically?
4. As you proceed back into it, are all of the pages and images sequential?

### III: Interpreting a Geological Column

One technique geologists use to determine the setting and order of rock layers in a given location. These layers and the borders between them can be very useful in determining the geological history of the area. Was there an ocean here? Did they have volcanoes? Was there a long period of erosion between depositional events (other layers atop the previous ones)?



This geological map demonstrates how a set of rock layers can be categorized. This example is occurring in a rock column in Zion National Park in Utah, USA. Note: the surface is at the top of the image.

#### Part One: Identifying the order

Answers in Appendix I Answer sheet

Arrange the layers in the map above in order, oldest to youngest:

#### Part Two: Limits of Information

Given this diagram alone, can you make any inferences about the amount of time it took to generate these layers?  
Why or why not?

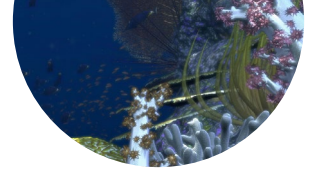
#### Part Three: Unconformities

One of the problems geologists face is a curved or jagged line or interrupted break in the column, called an unconformity.

1. Which layer(s) have an unconformity between them?
2. What are the chief agents responsible for unconformities?
3. What process has occurred during the deposition of this column?
4. Is there a way to figure out how long this process took?

*Natural Selection*





## IV. Charles Lyell: Uniformitarianism and Time

*Charles Lyell was born in 1797 in Scotland. His father was a naturalist. He became a barrister (a trial lawyer), but spent most of his time indulging in his love for the study of geology. Over time, he became a professional geologist by observing different land forms, developing theories about the Earth, and experimenting to test those ideas. He studied the work of James Hutton, the father of geology, who refuted the popular idea of the time that only a major catastrophe could change the surface features of the Earth. Hutton believed in uniformitarianism, the idea that slow, constant adjustments had been and continued to be made on the Earth, and that earthquakes, floods, and other disasters were part of the cycle of change. Lyell, however, communicated these ideas much more coherently than Hutton and it was Lyell's persuasive arguments led to the now commonly accepted view that the Earth's features have altered over long periods of time because of their physical, chemical, and biological aspects, Lyell also was one of the first to suggest that the world was much older than was commonly thought; he believed that the world was more than 300 million years old. For his work in science, Lyell was knighted in 1848. One of the most important features in Charles Lyell's book, *Principles of Geology*, is the notion of deep time. At the time of Lyell's book being published, the prevailing view was that the Earth was approximately 6,000 years old. We will perform a simple calculation based on actual earthquake data to see if this claim has merit.*

### Part One: Calculating the average rate of uplifting events in Chile

Answers in Appendix I Answer sheet

Some Earthquakes which produced uplift in Chile are recorded below.

| Year | Average Meters of uplift |
|------|--------------------------|
| 2010 | 0.24                     |
| 1960 | 0.34                     |
| 1835 | 0.29                     |

1. What is the average length of time between uplift events?
2. What is the average uplift, in meters?

Lyell used methods like this to calculate an age of the Earth as roughly 100 million years old.

3. The average height of the Andes mountain chain is 4,000 meters. So using our generated figures, roughly how old are the Andes Mountains, using these figures?



## Part Two: Research questions

1. What is the actual age of this mountain range?
2. What sort of plate tectonics is going on in this area?
3. Are the Andes an old or young mountain range? How can you tell visually?
4. What is the age of the Appalachian mountain chain in the Eastern USA?
5. Look at an image of the Appalachian Mountains. How can you tell that they are much older than the Andes?
6. Where are the oldest rocks on Earth found? How does this age compare with other rocks found elsewhere in the solar system?
7. Suggest two reasons why Moon rocks are older than Earth rocks.

## Part Three: Evaluating the evidence and drawing conclusions

1. How old is the Earth? List 3 lines of evidence that lead to this conclusion.
2. How do astronomers know the age of the solar system?
3. Does astronomical evidence support Lyell's notion of geologic time?
4. Does natural selection have the time required to operate as described by Darwin here on Earth?





## V. Missions of Exploration: Then and Now

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*The HMS Beagle was a ship designed to explore. Here are some links to help you learn about the Beagle, and another great ship of exploration, the Mars Rover Curiosity.*

### Part One: Learn about the ships

Answers in Appendix I Answer sheet

Visit the following websites and read about these two ships of exploration.

<http://www.rmg.co.uk/explore/sea-and-ships/facts/explorers-and-leaders/charles-darwin-and-hms-beagle>

<http://www.nhm.ac.uk/nature-online/science-of-natural-history/expeditions-collecting/beagle-voyage/>

<http://www.rmg.co.uk/whats-on/exhibitions/past/the-beagle-voyages>

<http://mars.jpl.nasa.gov/msl/>

### Part Two: List similarities

List 5 similarities between these two missions.

### Part Three: List Differences

List 5 differences between these missions.

### Part Four: Developing a Mission Image Portfolio

Select 5 images from the Mars Rover Curiosity taken so far.

For each image, suggest why it's a good image to represent the aims and objectives of this mission.



## VI. Gathering evidence for the Anthropocene

*Anthropocene is a term coined by Dutch chemist Paul Crutzen and was first seen in print in 2000. It is an expression for a new geologic epoch which refers to man's impact on the planet. It comes from anthropo- meaning pertaining to human beings and -cene meaning new. The Holocene Epoch began at the end of the last ice age (about 11,500 years ago) and, until recently, was considered to continue through the present day. However, with about seven billion people on the planet, our existence alone has a huge impact on Earth, enough of an impact to warrant its own term. When looking at other epochs, stratigraphers (those who study rock layers) have had many tiers of the Earth's features to examine. The Anthropocene layer is not yet complete, so will the mark we leave be significant? Generally, the science community says yes. People are leaving their mark by building cities, farming, denuding our forests, and probably most importantly, changing the amount of various gases in our atmosphere. Although scientists do not agree when the Anthropocene Epoch began (some say as long as 8,000 years ago), they do agree that because we have increased the amount of carbon dioxide in our atmosphere, causing it to heat up, our impact is noteworthy. The big question now is if the consequences of our impact will have horrific results or merely be a change worth mentioning.*

Most geoscientists have accepted the new term, Anthropocene, to describe the time since the industrial revolution began (set at the invention of James Watt's Stream Engine, according to one source). What does "anthropocene" mean?

Websites for information:

<http://www.uc.edu/orgs/qarg/about/the-anthropocene.html>

[http://globaia.org/en/anthropocene/the\\_anthropocene\\_igbp\\_globaia.jpg](http://globaia.org/en/anthropocene/the_anthropocene_igbp_globaia.jpg)

<http://amazingstuff.co.uk/humanity/the-anthropocene/#.UhEEyWQacwI>

<http://www.anthropocene.info/en/home>

### Part One: Argument in the Affirmative

Answers in Appendix I Answer sheet

List 5 lines of evidence you've discovered in learning about the Anthropocene Epoch that support renaming this geological epoch. At least one line of evidence must come

### Part Two: Speculation

What will the next geological epoch look like? Select some images that you feel portray the "post-anthropocene" epoch.





## VII. Colored Toothpicks: A Natural Selection

*Several examples of how natural selection pressures work are explained in the film Natural Selection. This activity is a simple, fun, engaging, hands-on, and kinesthetic that can be used to demonstrate selection pressures, competition for limited resources, predation, warning coloration, and camouflage. This activity should be done in 3 'runs' or trials, each time making the simulation more complicated, and thereby more realistic.*

*Materials needed: Colored toothpicks (note: any multicolored item that is toothpick-sized will do), comfortable outdoor shoes, a large field like a football pitch, and a timing device.*

*Before the hunt: spread toothpicks around the play area randomly. Students are birds; toothpicks are bird prey items (worms).*

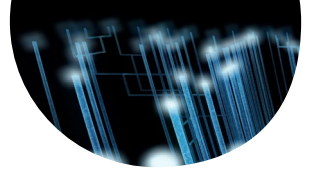
### First Run

1. Divide students into groups of two; these are a nesting pair
2. Students should select a nest site on the perimeter of the play area
3. Students have 5 minutes to collect as many toothpicks as possible.
4. All students with at least 20 toothpicks per pair "survive".
5. Brief discussion: what were some successful hunting strategies?
6. Are your toothpicks more than one color? Is there a color that you found more of? Less of? Suggest some reasons for this.

### Second Run: Warning colors and prey adaptation

In nature, many species of insect have bright areas of red, yellow, and orange prominently displayed. These are called warning colors, and are meant to ward off predators, usually because the insect is poisonous or foul-tasting.

1. Re-spread out the toothpicks, as before
2. Warn the nesting pair that all red and yellow toothpicks are lethal: collect them and die immediately.
3. Reset the 5 minute timer and begin collecting toothpicks.
4. All nesting pairs with at least 20 toothpicks survive-as long as the toothpicks aren't red or yellow.
5. Discuss why warning colors represent a successful adaptation for the prey.

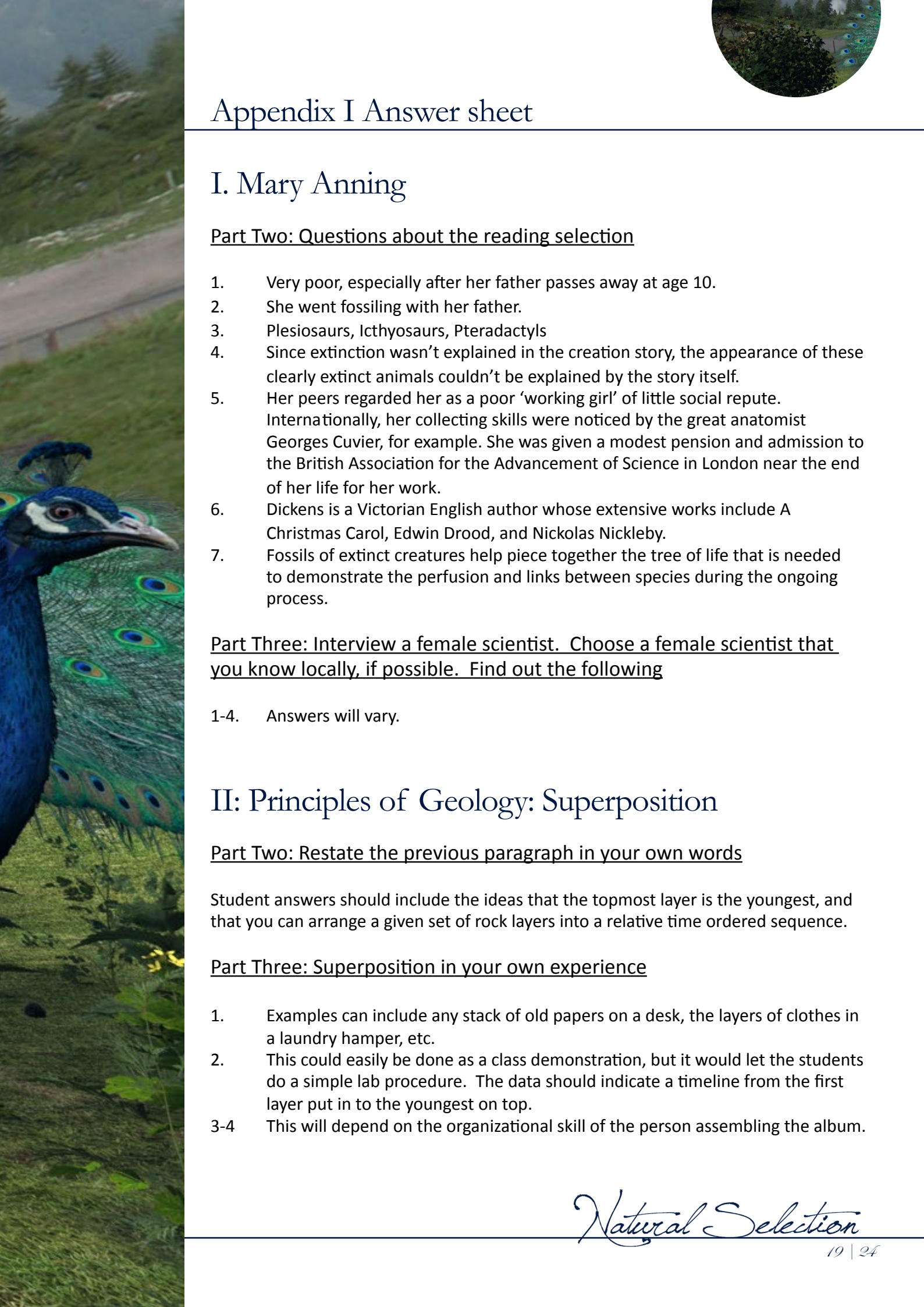


### Third Run: Introducing another predator

1. *In nature, there are also those who prey on other predators-in this case, a hawk.*
2. *Select two volunteers, and brief them before the hunt begins.*
3. *Distribute toothpicks as before.*
4. *Two relatively swift students are selected to be the hawks, and are allowed to select their nesting site on the perimeter of the play area. Note: do not let other “birds” change nesting sites.*
5. *Start the timer. Every time you say t word “feed” (every 30 seconds) the hawks run out and attempt to catch feeding birds (tap them lightly on the shoulder). If tapped, the bird “dies”, and must sit down in that spot.*
6. *At the end of the 5 minutes, each nest should have at least 20 toothpicks.*
7. *Discuss: what happened to your odds of success if a partner was taken by a hawk?*
8. *Are more birds dead in a particular area of the field? Why?*
9. *What adaptations do you think real birds employ to not get eaten by hawks? List some successful adaptations that you employed, such as evasive maneuvering, using a lookout system, etc.*
10. *For all successful nesting couples: you are awarded 2 eggs, to put in your nest (use crumpled up paper to represent these). Repeat the activity as often as desired.*

### Some concluding questions

1. *What elements in this simulation were hardest to adapt to?*
2. *What advantages did the green toothpicks have? Suggest two examples in nature that exemplify this phenomenon.*
3. *What was good or bad about where the hawks selected their nesting site?*
4. *Do predators look for these kinds of advantages over their prey?*



# Appendix I Answer sheet

## I. Mary Anning

### Part Two: Questions about the reading selection

1. Very poor, especially after her father passes away at age 10.
2. She went fossiling with her father.
3. Plesiosaurs, Ichthyosaurs, Pteradactyls
4. Since extinction wasn't explained in the creation story, the appearance of these clearly extinct animals couldn't be explained by the story itself.
5. Her peers regarded her as a poor 'working girl' of little social repute. Internationally, her collecting skills were noticed by the great anatomist Georges Cuvier, for example. She was given a modest pension and admission to the British Association for the Advancement of Science in London near the end of her life for her work.
6. Dickens is a Victorian English author whose extensive works include A Christmas Carol, Edwin Drood, and Nickolas Nickleby.
7. Fossils of extinct creatures help piece together the tree of life that is needed to demonstrate the perfusion and links between species during the ongoing process.

### Part Three: Interview a female scientist. Choose a female scientist that you know locally, if possible. Find out the following

- 1-4. Answers will vary.

## II: Principles of Geology: Superposition

### Part Two: Restate the previous paragraph in your own words

Student answers should include the ideas that the topmost layer is the youngest, and that you can arrange a given set of rock layers into a relative time ordered sequence.

### Part Three: Superposition in your own experience

1. Examples can include any stack of old papers on a desk, the layers of clothes in a laundry hamper, etc.
2. This could easily be done as a class demonstration, but it would let the students do a simple lab procedure. The data should indicate a timeline from the first layer put in to the youngest on top.
- 3-4 This will depend on the organizational skill of the person assembling the album.





### III: Interpreting a Geological Column

#### Part One: Identifying the order

Kaibob , Mocakopi , Chinle , Mocnave, Kayenia, Navaho sandstone, Temple cap, Carmel, Dakota

#### Part Two: Limits of Information

No, although the Navaho sandstone is by far the thickest layer.

We don't know how long it takes layers to deposit in a column without much more information.

#### Part Three: Unconformities

One of the problems geologists face is a curved or jagged line or interrupted break in the column, called an unconformity.

1. Kaibob-Mocakopi, Navaho sandstone-temple cap
2. Wind and water: erosion
3. Deposition.
4. Not without much more detail.

### IV. Charles Lyell: Uniformitarianism and Time

#### Part One: Calculating the average rate of uplifting events in Chile

1. 87.5 years
2. .29 meters
3.  $(4,000 \text{ m} / .29 \text{ m}) \times 87.5 \text{ yrs} = 1,207,000 \text{ years old}$



## Part Two: Research questions

1. 25-30 ma
2. Subduction of the nazca plate beneath the south american plate.
3. They are young, given their jagged peaks that haven't been subjected to much erosion.
4. 480-300 my, depending on location.
5. The mountains are not as tall, and they are rounded peaks, which have been eroded for a long time.
6. Northwest territories, Canada. These rocks are 4 billion years old, and the oldest rock returned from the moon by Apollo astronauts is 4.5 billion years old.
7. The moon doesn't have erosion and weathering, which break down rock here. It also doesn't have plate tectonics or vulcanism which can melt rocks.

## Part Three: Evaluating the evidence and drawing conclusions

1. 4.6 billion years. Stratigraphy (order of and length of time of deposits of rock layers), radiometric dating (comparing radioactive 'parent' elements to their decay 'daughter' elements), and the ages of meteorites and moon rocks.
2. Meteorite and moon rocks radiometric dating, and the spectra of the sun compared to other g-class stars.
3. Yes. Since the solar system and Earth are both 4.5 (rounded to the nearest half billion) years old, the types of processes Lyell discusses had time to operate.
4. Yes, again, since Darwin was using a 100 million year old age of earth in his initial work, the work of astronomers and geologists have given natural selection much more time in which to operate.



## V. Missions of Exploration: Then and Now

### Part Two: List similarities

Both were/are supposed to last 2 years  
Both have means of acquiring samples  
Both were sent for exploration reasons only  
Both have many people working on them/with them all the time  
Both are scientific enterprises  
Both provided evidence supporting the primary purposes of their mission

### Part Three: List Differences

Differences will include Earth-B, Mars-C; Curiosity is unhumanned; sails-B, wheels-C; relative sizes, sample return-B, sample analysis on site-C; technology used.

### Part Four: Developing a Mission Image Portfolio

Answers will vary, depending on images chosen and student descriptions of same.

## VI. Gathering evidence for the Anthropocene Epoch.

### Part One: Argument in the Affirmative

There will be numerous possibilities here, but they will most likely fall into these general bins: Mega cities; accelerated global warming effects: sea level rise, increases in average temperatures, seasonal changes, and polar ice melt, among others; exponential population growth; land use changes; and light pollution.

### Part Two: Speculation

Answers will vary, depending on the nature of the Utopia/dystopia the students select.





## VII. Colored Toothpicks: A Natural Selection Game

7. Success level decreases, more likely to die of starvation.
8. Yes. Answers should include death due to proximity to the hawk's nest, less toothpicks in a particular location, slowness/lack of hunting ability of the birds, etc.
9. Answers will include warning calls/songs, being able to 'outfly' the hawk, hunting when the hawk is on the other side of the field, etc.

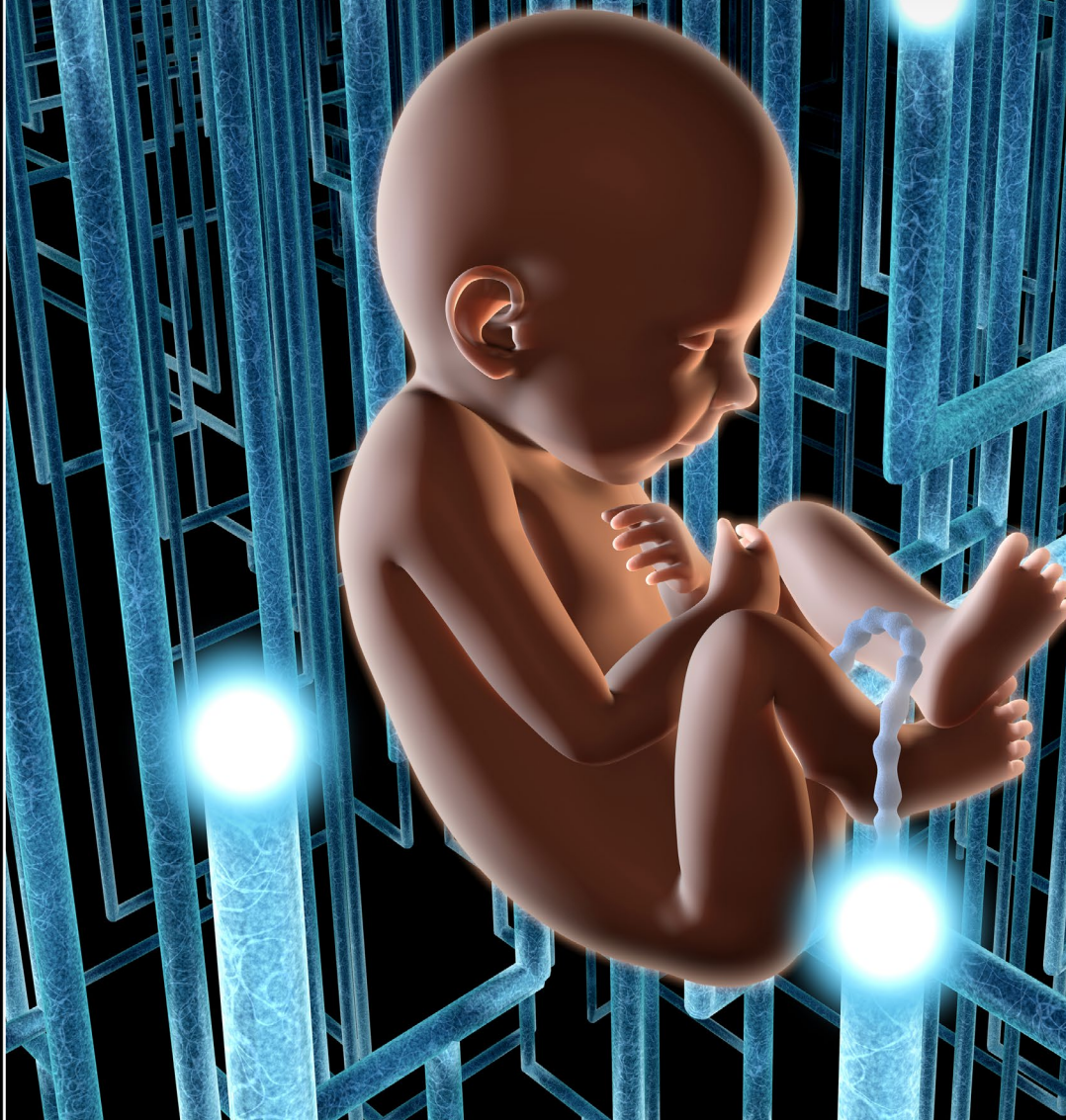
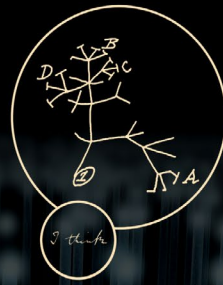
### Some concluding questions

1. Answers will depend on the particular challenges faced by each 'bird'. They will include being near the hawks, warning color non-recognition, physical inability of the 'birds', etc.
2. Camouflage on a green field. Green caterpillars, chameleons, sharks, etc.
3. Depends on where you were as a 'bird'.
4. Yes, good examples include sea lions nesting near penguins, etc.



DARWIN'S MYSTERY OF MYSTERIES

# Natural Selection



MIRAGE3D PRESENTS **NATURAL SELECTION** DARWIN'S MYSTERY OF MYSTERIES  
A **FULLDOME** IMMERSIVE CINEMATIC EXPERIENCE

WRITTEN/DIRECTED BY **ROBIN SIP** NARRATED BY **TONY MAPLES**

MUSIC BY **MARK SLATER** PERFORMED BY **THE BUDAPEST SYMPHONY ORCHESTRA**

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