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**SOURCE MATERIAL BOOKLET  
FOR QUESTIONS 1, 2 AND 3**

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Property of Durban Girls' College

## SECTION A

### QUESTION 1

Read the information below. Refer to this information, as well as your own knowledge, to answer Question 1 in the question paper.

#### **A tiny marsupial is upending ideas about the origins of flying mammals**

**Flying squirrels, sugar gliders and bats haven't had a common ancestor in 160 million years, but they form their wing flaps using some of the same genetic ingredients.**

That's the intriguing finding from a Princeton-led team of biologists, detailed recently in the journal *Science Advances*. In other words, when the seven known flying mammals evolved flight, they recycled some of the same genetic parts that had been in their DNA since dinosaurs roamed the Earth.

The researchers investigated how wing flaps develop in two tiny mammals, the marsupial sugar glider (*Petaurus breviceps*) and a microbat: Seba's short-tailed bat (*Carollia perspicillata*). The biologists discovered a network of genes driving the formation of this flap in sugar gliders and bats, and likely other flying mammals as well.

"Among flying mammals, sugar gliders and bats are just about as distantly related as you can get," said Charles Feigin, first author on the new paper and a former postdoc in Ricardo Mallarino's lab at Princeton University. "They also have very different mechanisms of flying, plus all the other flying mammals are more closely related to one or the other, so we have pretty good reason to suspect that similar mechanisms are at play in all of them."

Mallarino's lab focuses on the origins of diversity. "If you go back to the to the days of Darwin, he was fascinated by how and why we have biodiversity," said Mallarino, an assistant professor of molecular biology who is associated with the faculty in ecology and evolutionary biology.

"Over the past decades, the biological community has done a good job understanding *why*: There's a very close relationship between the features of an animal or a plant and its environment.

Sugar gliders, small nocturnal flying marsupials native to New Guinea and Australia, are more closely related to kangaroos than to their lookalike, distant cousins' the flying squirrels. Like kangaroos, sugar gliders give birth to joeys that are still early in their development, presenting an extraordinary opportunity to watch development, said Feigin, who is now a research fellow specializing in marsupial development at the University of Melbourne. The Princeton-led team combined many techniques in their study, including DNA and RNA sequencing.

“Even 10 years ago, you couldn’t easily sequence a species like this; that was restricted to humans or mice, or else it cost a fortune,” said Mallarino. “Now, because these tools have advanced so much, we can sequence a genome — even a mammalian genome, which tends to be very large — pretty easily.”

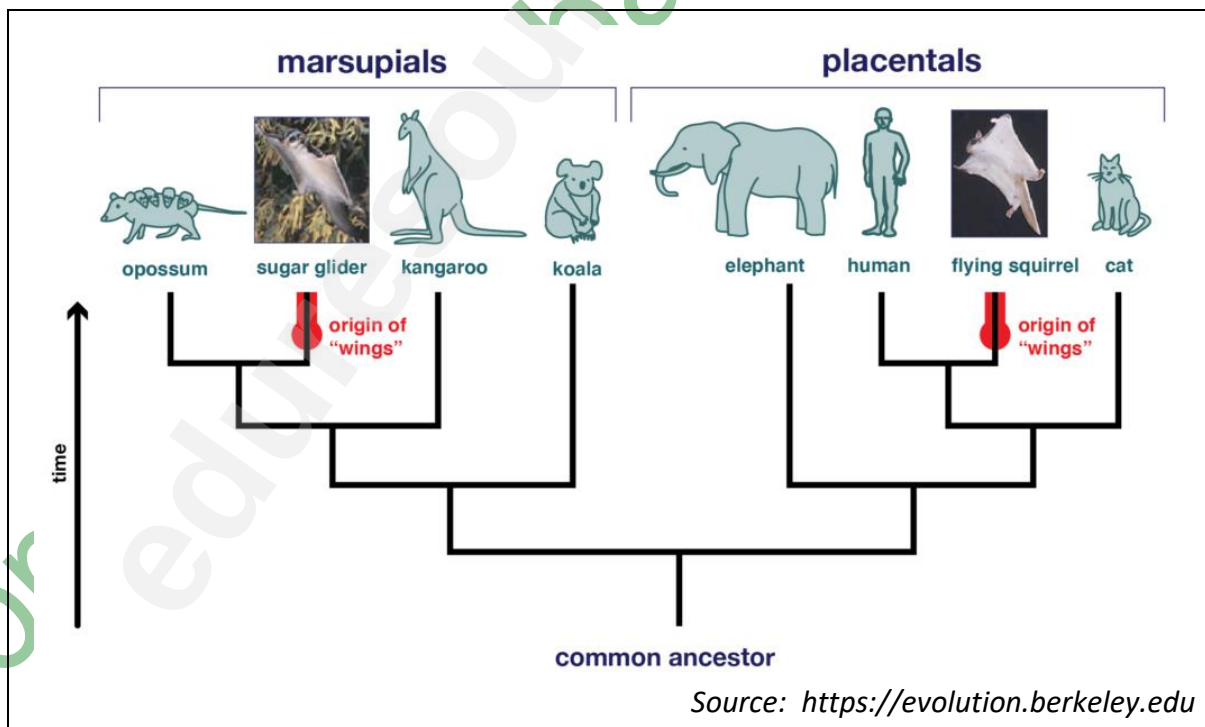
They found that a key gene in growing the patagium — *Wnt5a* — is also linked to skin thickening in mouse ears, suggesting that this genetic toolkit may have served other roles before being adapted for flight.

“Evolution is economical; it uses what it has,” said Mallarino. “Instead of evolving an entirely different pathway to make a flight structure, it uses the molecules that are at hand and are found across all mammals living on this planet. They work in different ways, and they’re integrated with other genes in different ways — the patagium\* in bats is quite different than the patagium in gliders — but you use the same gene because it’s what is at hand. I think this is the beauty of evolution.”

**\*Patagium - a membrane or fold of skin between the forelimbs and hindlimbs on each side of a bat or gliding mammal.**

Adapted from: <https://www.princeton.edu>

### Phylogeny of sugar gliders and flying squirrels



## Sugar glider

The sugar glider is characterised by its pair of gliding membranes, known as patagia, which extend from its forelegs to its hindlegs. Gliding serves as an efficient means of reaching food and evading predators. The animal is covered in soft, pale grey to light brown fur which is countershaded, being lighter in colour on its underside.

The flying squirrel can leap many times their own body length, and can have precision control of their landings. "Flights" (which are really glides), of nearly 91 meters, have been recorded. Flying squirrels can also turn nearly 180 degrees in mid-air. Their limbs, and their flat rudder-like tail, help them steer and control their leaps. They alight exactly like Batman: They reach toward their landing spot with strong, padded feet that land silently, before their front limbs come down to steady the landing.

They fly, and stay up at night, to avoid predators. Flying squirrels use their aerial abilities to evade predators, including arboreal snakes. But their folded patagia prevent them from being as nimble on their feet as non-flying squirrels, which makes them more vulnerable to predators including birds of prey, dogs, and cats. Being active at night helps them hide from those predators. Their enormous eyes help them see in the dark.

*Adapted from: <https://www.wikipedia.com> and <https://www.rewild.org/>*

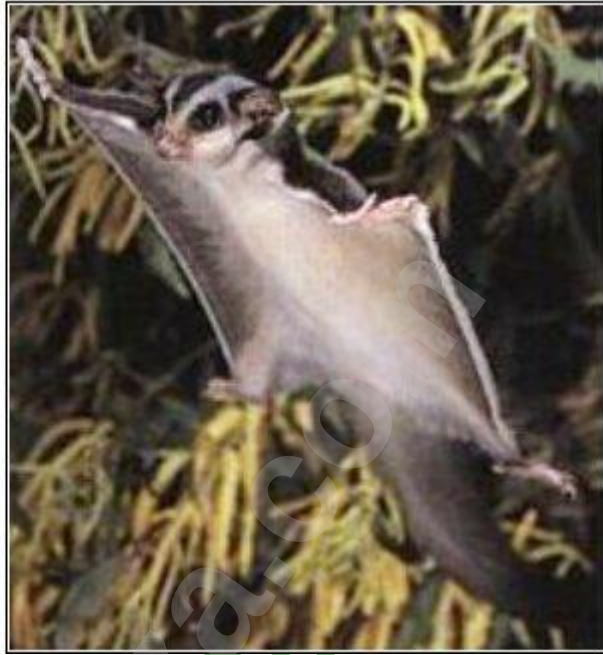
## Evolution of sugar gliders and flying squirrels

Sugar gliders and flying squirrels look amazingly similar. They are both furry animals of about the same size, with big eyes and a white belly. And they both glide from treetops using a thin piece of skin that is stretched between their legs. This piece of skin helps keep them stable while gliding.

However, these animals also have a range of differences:

- Sugar gliders have a pouch (like a kangaroo does), which provides shelter and safety for their tiny babies — at birth, a baby sugar glider is smaller than a peanut! In flying squirrels, on the other hand, most of the baby's development happens inside the mother's body, which supplies nourishment with a specialized organ called the placenta. Flying squirrels give birth to much larger babies and have no pouch.
- Sugar gliders have many more teeth than do flying squirrels.
- Sugar gliders have multiple holes in the bone that forms the top of the mouth and flying squirrels do not.

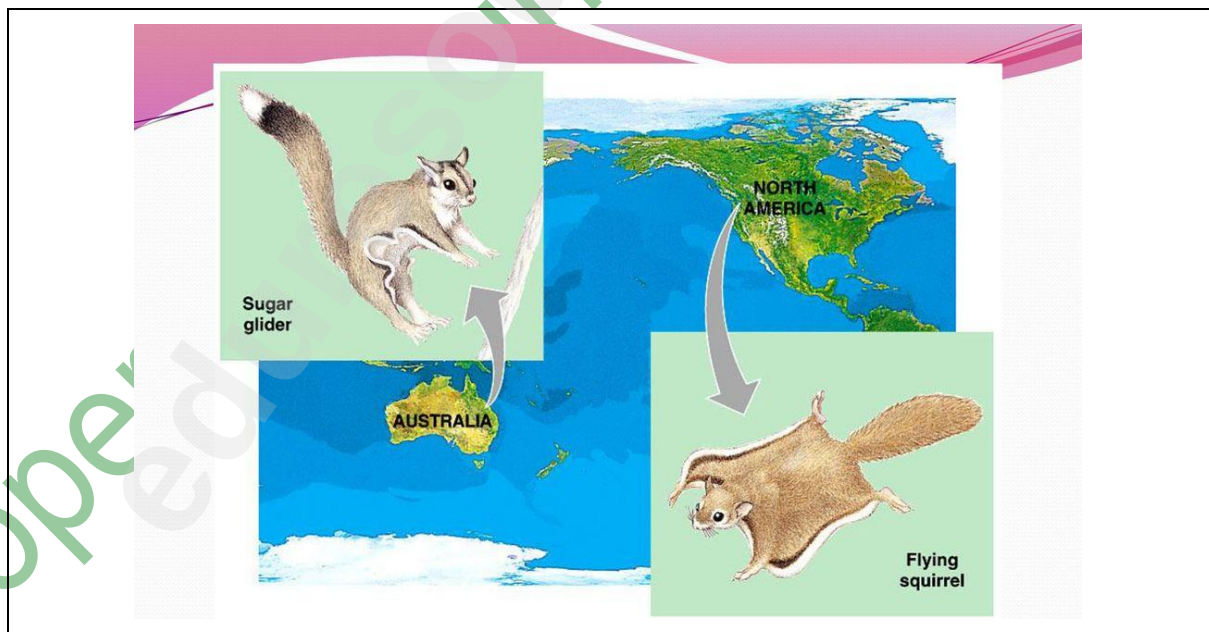
Sugar gliders are marsupial mammals and flying squirrels are placental mammals. They are not closely related to one another.



Left, a flying squirrel. Right, a sugar glider. Flying squirrel photo courtesy of Mona Rutger, backtothewild.com; Sugar glider photo courtesy of The Mouses House, Queensland, Australia

Source: <https://evolution.berkeley.edu>

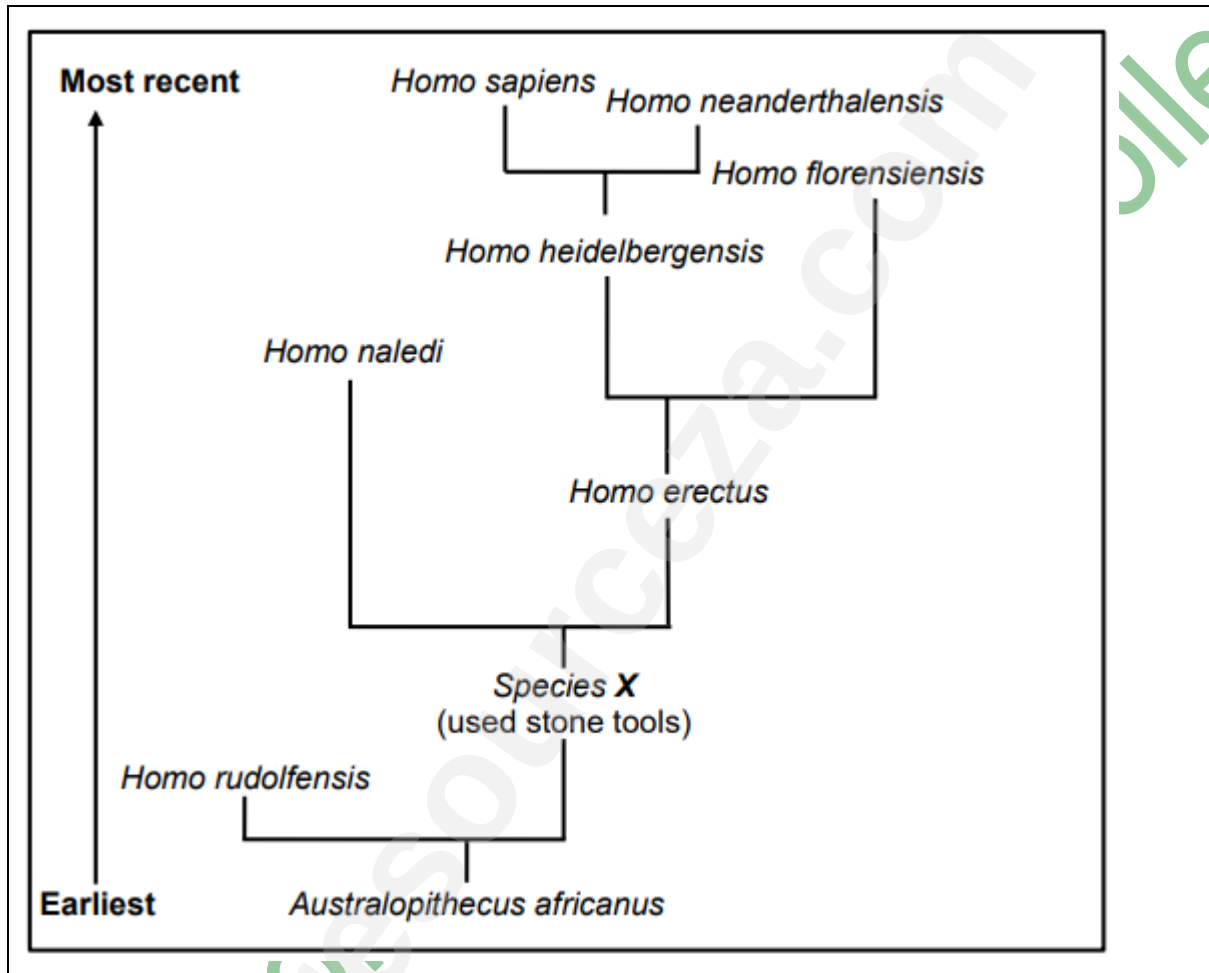
### Distribution of sugar gliders and flying squirrels



## QUESTION 2

Read the information below. Refer to this information, as well as your own knowledge, to answer Question 2 in the question paper.

### A model of the evolution of some hominins



### Who were the Neanderthals?

Human evolution expert Prof Chris Stringer has studied Neanderthals his entire career. Here, he tells us what scientists have uncovered about the lifestyle of these hominins, their distinctive characteristics and what they were like.

We know more facts about Neanderthals than any other extinct hominins. Many thousands of their artefacts and fossils have been found, including several nearly complete skeletons. We also know about their genetic make-up, as several Neanderthal genomes have now been reconstructed from ancient DNA obtained from their fossils.

Neanderthals were humans like us, but they were a distinct species called *Homo neanderthalensis*.

Together with an Asian people known as Denisovans, Neanderthals are our closest ancient human relatives. Scientific evidence suggests our two species shared a common ancestor. Current evidence from both fossils and DNA suggests that Neanderthal and modern human lineages separated at least 500,000 years ago. Some genetic calibrations place their divergence at about 650,000 years ago.

Neanderthals lived alongside early modern humans for at least part of their existence. We now know that some encounters were very intimate - some of us have inherited around 2% Neanderthal DNA.

The Neanderthals have a long evolutionary history. The earliest known examples of Neanderthal-like fossils are around 430,000 years old. The best-known Neanderthals lived between about 130,000 and 40,000 years ago, after which all physical evidence of them vanishes.

Neanderthals evolved in Europe and Asia while modern humans - our species, *Homo sapiens* - were evolving in Africa. Judging from fossil evidence from Sima de los Huesos in northern Spain and Swanscombe in Kent, the Neanderthal lineage was already well-established in Europe by 400 000 years ago. The species ranged widely in Eurasia, from Portugal and Wales in the west across to the Altai Mountains of Siberia in the east.

Despite their reputation as being primitive 'cavemen', Neanderthals were actually very intelligent and accomplished hominins. These were no 'ape-men'. The brain size of late Neanderthals ranged from at least 1 200cm<sup>3</sup> to 1 750cm<sup>3</sup>. This is larger than the modern average, but in proportion to their body size, *Homo sapiens* skulls from around 30 000 years ago also had larger brains on average than people today.

Neanderthals were skilled tool makers, as evidenced by excavated objects such as spears and flint hand axes. Around 300,000 years ago Neanderthals developed an innovative stone technology known as the Levallois technique. This involved making pre-shaped stone cores that could be modified into a finished tool at a later time. It meant Neanderthals were free to travel away from sources of raw material and yet be able to make tools when needed.

Archaeological evidence shows that some Neanderthals looked after their sick and buried their dead, which suggests they were social and even compassionate beings.

The most recent fossil and archaeological evidence of Neanderthals is from about 40,000 years ago in Europe. After that point they appear to have gone physically extinct, although part of them lives on in the DNA of humans alive today.

Ancient DNA began to be recovered from Neanderthal fossils in 1997, and this has led on to the reconstruction of several complete genomes. These indicate that Neanderthals ranging from Spain to Siberia were relatively low in numbers and diversity during their last 20,000 years.

The genome of one female individual from the Altai Mountains also shows signs of long-term inbreeding in her population, a further indication of low numbers and isolation. It seems that regular and sometimes extreme climatic fluctuations continually fragmented Neanderthal groups during the last 100,000 years, preventing them from building up large populations and continuous distributions across their range.

Neanderthals did not all become extinct at the same time. Their disappearance may have been staggered, suggesting that they were replaced by early modern humans as a result of local population extinctions, rather than being quickly overrun. Rapid and dramatic climate change may have been another major factor that contributed to Neanderthals' extinction. When severe changes in temperature happened rapidly, the plants and animals Neanderthals relied on were also affected. Faced with such conditions, only the most resourceful and adaptable could survive.

*Adapted from: <https://www.nhm.ac.uk/discover/who-were-the-neanderthals.html>*

**Comparison of Neanderthal (left) and modern human (right) skulls, from a display in Cleveland Museum of Natural History**



## Neanderthal MtDNA

The first analysis of any Neanderthal DNA was mitochondrial DNA (mtDNA), published in 1997. The sample was taken from the first Neanderthal fossil discovered, found in Feldhofer Cave in the Neander Valley in Germany. A small sample of bone was ground up to extract mtDNA, which was then replicated and analyzed.

Researchers compared the Neanderthal mtDNA to modern human and chimpanzee mtDNA sequences and found that the Neanderthal mtDNA sequences were substantially different from both. Most human sequences differ from each other by an average of 8.0 substitutions, while the human and chimpanzee sequences differ by about 55.0 substitutions. The Neanderthal and modern human sequences differed by approximately 27.2 substitutions. Using this mtDNA information, the last common ancestor of Neanderthals and modern humans dates to approximately 550,000 to 690,000 years ago, which is about four times older than the modern human mtDNA pool. Since this study was completed, many more samples of Neanderthal mtDNA have been replicated and studied.

After successfully sequencing large amounts of mtDNA, a team led by Svante Pääbo from the Max Planck Institute reported the first complete mitochondrial DNA (mtDNA) sequence for a Neanderthal. The sample was taken from a 38 000 year old Neanderthal from Vindija Cave, Croatia. The complete mtDNA sequence allowed researchers to compare this Neanderthal mtDNA to modern human mtDNA to see if any modern humans carried the mtDNA from a related group to the Neanderthal group.

Later, Svante Pääbo's lab sequenced the entire mitochondrial genome of five more Neanderthals. Sequences came from two individuals from the Neander Valley in Germany and one each from Mezmaiskaya Cave in Russia, El Sidrón Cave in Spain, and Vindija Cave in Croatia. Though the Neanderthal samples came from a wide geographic area, the Neanderthal mtDNA sequences were not particularly genetically diverse. The most divergent Neanderthal sequence came from the Mezmaiskaya Cave Neanderthal from Russia, which the oldest and eastern-most specimen. Further analysis and sampling of more individuals has led researchers to believe that this diversity was more closely related to age than it was to population-wide variance. On average, Neanderthal mtDNA genomes differ from each other by 20.4 bases and are only 1/3 as diverse as modern humans. The low diversity might signal a small population size.

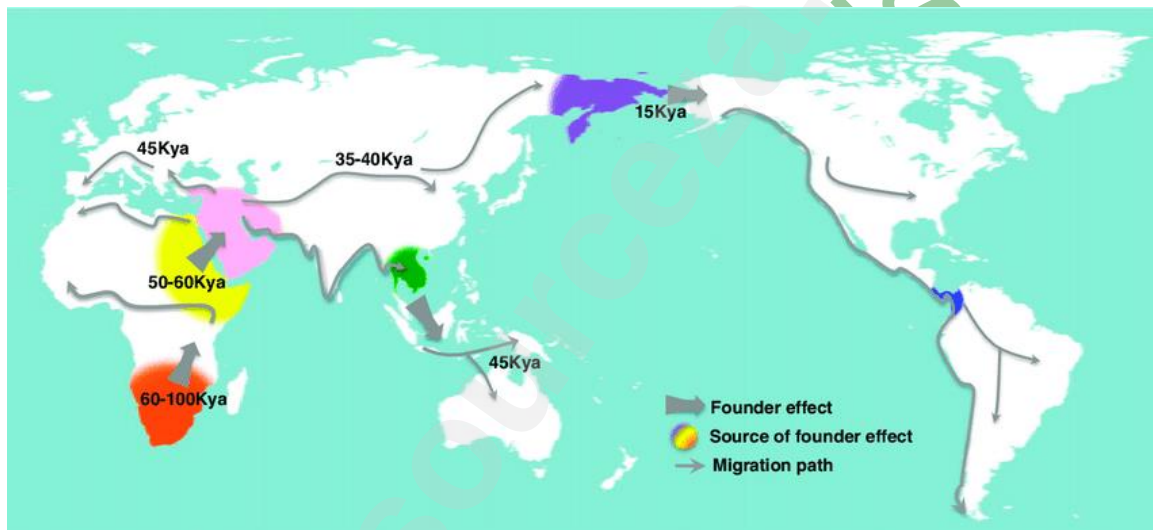
There is evidence that some other hominin contributed to the Neanderthal mtDNA gene pool around 270,000 years ago. A femur discovered in Germany had its mtDNA genotyped and it was found that there was introgression\* from a non-Neanderthal African hominin, either *Homo sapiens* or closely related to us, around 270,000 years ago. This mitochondrial genome is also highly divergent from the Neanderthal average discussed previously, indicating that Neanderthals may have been much more genetically diverse in their more distant past.

As for Neanderthal introgression into the modern human mtDNA genome, it is possible that the evidence of such a mixture is obscured for a variety of reasons. Primary among these reasons is sample size: There are to date only a dozen or so Neanderthal mtDNA sequences that have been sampled. Because the current sample of Neanderthal mtDNA is so small, it is possible that researchers simply have not yet found the mtDNA in Neanderthals that corresponds to that of modern humans.

**\* Introgression – the transfer of genetic material between species following hybridization and backcrossing to the parental species.**

*Adapted from: <https://humanorigins.si.edu/>*

**Ancient dispersal patterns of modern humans during the past 100,000 y.**



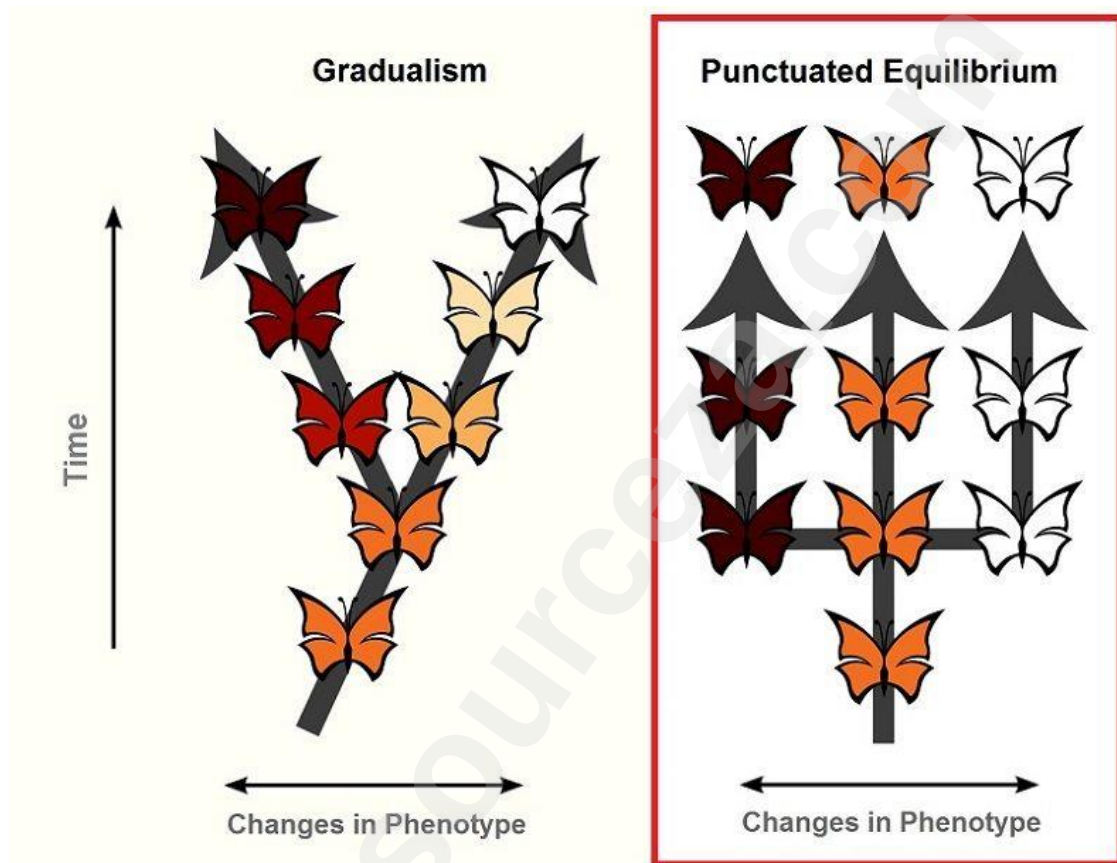
*Source: <https://www.researchgate.net/>*

SECTION B

QUESTION 3

SOURCE A

Punctuated Equilibrium vs Gradualism



Source: <https://biologydictionary.net/punctuated-equilibrium/>

SOURCE B

**Yes, the Punctuated Equilibrium Model Was Developed to Explain the Lack of Transitional Fossils**

Casey Luskin

January 5, 2022, 6:30 AM

Punctuated equilibrium is a model of evolution that was first developed in the 1970s by palaeontologists Stephen Jay Gould and Niles Eldredge. By proposing reduced transitional population sizes and time spans, punctuated equilibrium drastically limits the expected number of transitional organisms. Since most individuals do not fossilize, the likelihood of finding transitional forms is decreased.

Central to the punctuated equilibrium model is the concept of allopatric speciation. Because the “daughter population” may be small, it could potentially change rapidly in response to new selection pressures in its environment.

Eldredge and Gould tried to justify why palaeontologists should not expect to find series of transitional forms, and should instead expect “breaks” in the fossil record where new species arise without leaving fossils of transitional forms.

According to Gould, the speciation process takes place in such a geologically short amount of time, it would not lead to fossilized transitional forms. The National Academy of Sciences (1998) explained it this way: “changes in populations might occur too rapidly to leave many transitional fossils.”

Gould and Eldredge readily admitted the commonality of abrupt appearances of new species and the lack of transitional forms in the fossil record. And they admitted this pattern with respect to the fossil record as a whole. They recognized the problem for gradualistic accounts of evolution *across the board*. Their model therefore sought to explain why abrupt change was the dominant pattern in the fossil record.

Gould and Eldredge could make their case for punctuated equilibrium – they had to address a different common explanation for the lack of transitional forms: the imperfection of the fossil record. Darwin attempted to save his theory of gradual evolution by maintaining that intermediate fossils are not found because of “the extreme imperfection of the geological record.” Even Gould noted that Darwin’s argument that the fossil record is imperfect “persists as the favoured escape of most palaeontologists from the embarrassment of a record that seems to show so little of evolution directly.” Palaeontologists today generally recognize that while the fossil record is imperfect, it is still adequate to assess questions about evolution. Palaeontologists now frequently recognize that “jumps” between species, without intermediates, are not simply the result of an incomplete record. “The record jumps, and all the evidence shows that the record is real: the gaps we see reflect real events in life’s history — not the artifact of a poor fossil record.”

Once palaeontologists overcame “imperfection” as the favoured excuse for the lack of transitional forms, they were able to start taking the fossil record at face value and seek explanations for what they saw.

*Adapted from: <https://evolutionnews.org/2022/01/yes-the-punctuated-equilibrium-model-was-developed-to-explain-the-lack-of-transitional-fossils/>*

**SOURCE C**

Due to the development of various concepts in evolutionary theory, there is an extensive discussion on basic problems related to the graduality or discontinuity of evolution. American palaeontologists Niles Eldredge and Stephen Gould (1993) found a lack of gradual transition between successive forms. The species, which existed for millions of years without any significant changes, suddenly disappeared, and replaced a new one with a completely different characteristics compared to the main structural feature.

The supporters of the punctuated equilibrium theory are based on extensive fossil records and have quite strong theoretical justifications. The species is a relatively stable self-supporting system. For a new system or species to occur, the old system(species) must be destroyed. Against punctuated equilibrium, it can be argued that the species' geographical movements can explain the differences in fossils that formed the basis for the theory. However, there is evidence of a sharp change in conditions or intensive selection, such as in animal domestication experiments. Changes do not result in a smooth and gradual shift in the population's structural characteristics, but a sharp increase in variability. Later, a new species may arise from this deteriorated population.

**How does punctuated equilibrium compare with gradualism?**

Eldredge and Gould showed the contrast between the lengths of time involved in stasis (when a species remains unchanged) and speciation and raised the question of the structure of the evolutionary process. The existence of stasis does not imply the existence of the continuous evolution of life forms. It is essential to note that the authors of punctuated equilibrium do not consider the stasis as passive stability that corresponds to the environment staying the same, they see it as the genetically active state of the species.

**Which one of the theories gradualism or punctuated equilibrium makes the most sense?**

Although at first the disputes between the representatives of gradualism and punctuated equilibrium were quite vigorous, today, these two concepts can coexist within a single developing evolutionary theory. They may not contradict but complement each other to understand progression better. Most experts recognize that evolution can sometimes follow a punctuated, sometimes a gradualistic scenario. Moreover, there is a study proving the possibility of both scenarios of evolution. Scientists concluded that 22% of DNA differences occur during brief periods of intensive speciation, and the remaining 78% gradually accumulate during long gradualistic periods. The leaps of evolution are more characteristic for plants and fungi, and less characteristic for animals.

**Do Gould and Eldredge make a convincing argument that punctuated equilibrium is the only process that occurs?**

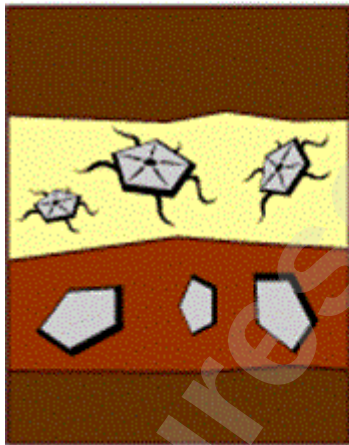
The authors of the theory do not argue that punctuated evolution is the only possible process. Firstly, in their article, they talk about research that can cause concern for their approach, despite their strong faith in it. Secondly, each scientist, even if he or she is confident in specific ideas and concepts, should allow the possibility of its disproof and the appearance of alternative options. In the opposite case, the development of science will stop, and scientific debate will be meaningless.

*Adapted from: <https://ivypanda.com/essays/punctuated-equilibrium-arguments-for-and-against/>*

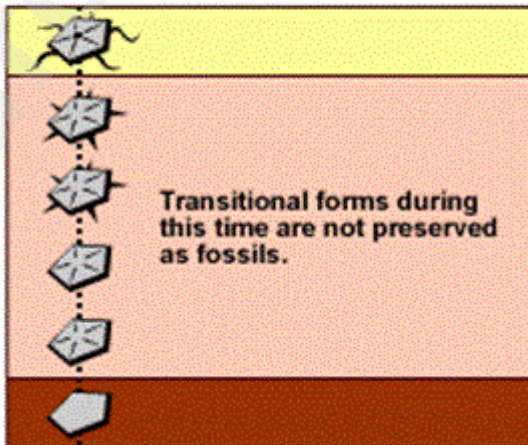
## SOURCE D

**Does evolution occur in rapid bursts or gradually?**

The observed fossil record seems to show rapid evolution...



...but this pattern can also be explained by transitional forms not fossilising in time.



Source: <https://kaiserscience.wordpress.com/biology-the-living-environment/evolution/gradualism-vs-punctuated-equilibrium/>

## SOURCE E

**Punctuated Equilibrium is Now Old Hat**

***The rapid changes seen in the fossil record can be accounted for by traditional explanations from population genetics, according to two recent mathematical models***

There is an old saying about the reception of a new idea, which goes as follows. At first it is dismissed as being wrong, then it is characterised as being against religion, and finally it is said to be something everyone knew all along. So it is with the notion of punctuated equilibrium, which has been the subject of much lively debate among evolutionary biologists for a decade and a half. This hypothesis, once rejected as being wrong or at least anti-Darwin, now appears to have entered the last of these three stages.

Using similar mathematical models of population genetics theory, two research groups independently report that the evolutionary pattern that is the basis of punctuated equilibrium can, after all, be explained by classical Neo-Darwinian mechanisms, including selection. There is, therefore, no need to suggest that other mechanisms are important in influencing the pattern of change in the fossil record.

Classical Neo-Darwinism\* viewed organisms as being closely adapted to their environments. It therefore followed that, when environmental conditions shifted, so too did a species' adaptations, sometimes to the point of generating a distinctly new species. There was no reason to expect – and Darwin and the Neo-Darwinians were explicit about this – that change would for the most part be other than a steady accumulation of small modifications. In other words, the pattern of change would be gradual. The fact that the fossil record does not show this – instead, it typically reveals long periods of stasis and bursts of change – has long been explained as the result of the fossil record's woeful incompleteness. Capturing just brief glimpses of the past, it has been argued, the smoot, gradual transitions are mostly invisible in the record.

When, in 1972, Niles Eldredge, of the American Museum of Natural History, New York, and Stephen Jay Gould, of Harvard University, proposed the hypothesis of punctuated equilibrium, they were giving two main messages. First, that the pattern of stasis and abrupt change apparent in the fossil record is real, and not an artifact of its incompleteness. In other words, once a species has arisen it remains essentially unchanged for most of its history, but when change occurs it does so swiftly.

And second, that the long periods of stasis in individual species through periods of environmental change were not predicted by classical Neo-Darwinian theory and required another explanation. Eldredge and Gould suggested that the very conservative mechanisms of embryological development imposed constraints on the evolutionary change of a species, even in the face of some shift in environmental conditions.

Their hypothesis was unpopular among classical evolutionary biologists, and was dismissed as being wrong. However, there ensued an enthusiastic search through the fossil record, focusing on organisms as small as microscopic marine species and ones as large as terrestrial vertebrates. The upshot of it all was that a complete spectrum of patterns of change could be identified, from gradual to essentially instantaneous change. It also became clear that stasis was a real phenomenon, which required explanation.

**\* Neo-Darwinism - a modern version of Darwin's theory of evolution by natural selection, incorporating the findings of genetics.**

*Adapted from: <https://www.science.org/doi/10.1126/science.231.4739.672>*

## SOURCE F

### **Biases of the fossil record**

Posted on October 1, 2022 by Allison Nelson

The fossil record is inherently biased. Not everything that dies becomes a fossil. Not every fossil has been found. Not every fossil stays intact well enough to study. These biases in the fossil record come in many forms.

Animals are more likely to fossilize if their bodies are made of hard material (such as calcium carbonate or bone) than if they're a soft-bodied organism, such as a slug. When a slug dies it decomposes and leaves nothing behind. Therefore, nothing is left to fossilize.

These animals only get preserved in rare environments. One example of this are conodonts – basically aquatic slugs with teeth from the Paleozoic Era (498-298 million years ago). Paleontologists found the teeth but could not figure out what they were from—until an imprint of the animal was found, with its teeth in place. The fossils were found in what used to be a quiet lake where the mud at the bottom of the lake encased the animals and preserved impressions of their bodies.

The animal's location upon dying affects fossilization likelihood as well. Fossilization is more likely if the area has lots of sedimentation and the animal can be rapidly buried (not affected by scavengers). If the animal cannot be quickly buried, the likelihood of fossilization is low, unless the area lacks organisms that will eat/decompose the dead animal. These organisms tend to separate and spread-out animal's bones and shell parts. In addition, there are regions with low sedimentation where sedimentary rocks aren't created because sediment isn't being created or transported there. For instance, rocks aren't being created on top of the ice in Antarctica. So, the animals who live in Antarctica tend not to fossilize when they die, unless their bodies end up in the water.

Assuming the animal does become a fossil, there are still more potential biases introduced before its discovery. If the fossil is in a tectonically active area, then it could be destroyed by lava or magma. If the fossil is not affected by lava or magma, but instead is in an area where the volcanic ash deposits, then it would be covered by great amounts of

volcanic ash rock (tuff). This means that it will take longer for overlying rock to erode and expose the fossil, as there is more rock to erode. Researchers often don't find fossils until they are on the earth surface or have already eroded out of the casing rock and there are fossil pieces on the ground.

A fossil could easily be destroyed or damaged when two blocks of rock slide past each other. Maybe one rock goes down, or right, and the other rock stays in place. If the fossil is caught between these blocks of rock, it is destroyed or damaged at the very least.

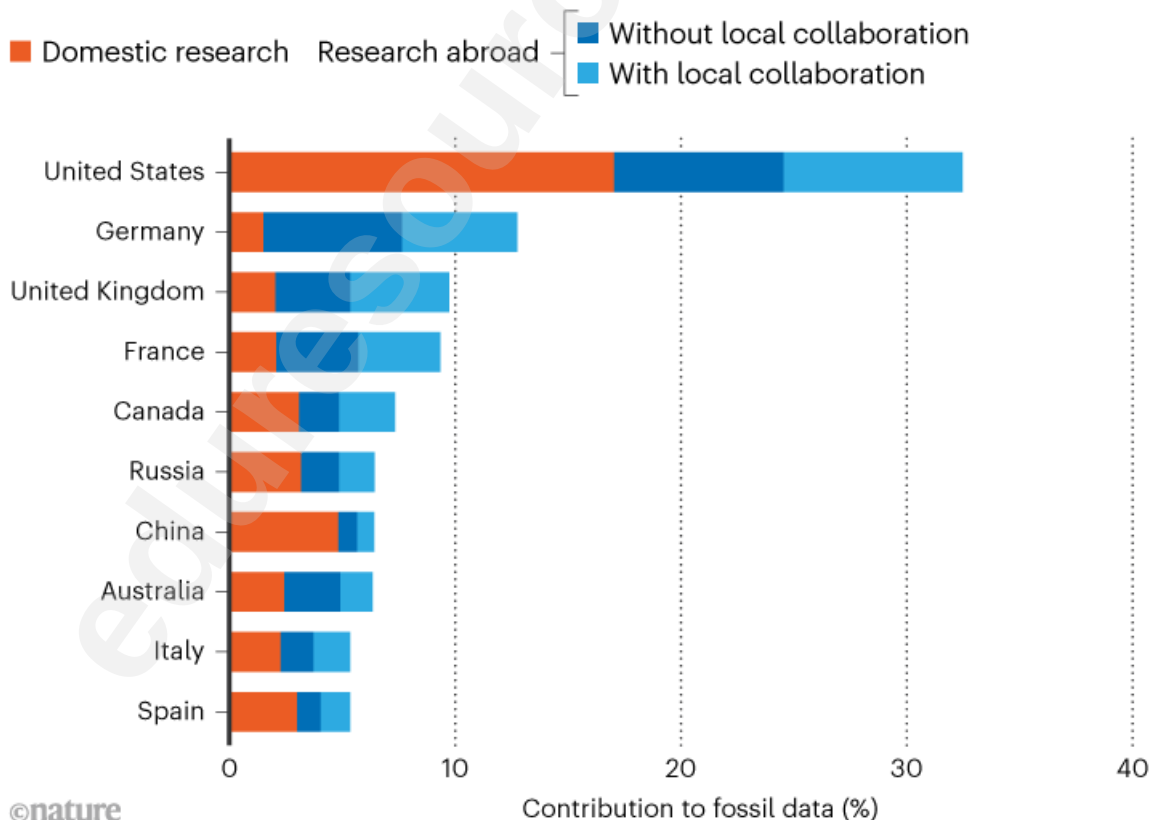
If the fossil stays intact in the ground, over time erosion will uncover the specimen. Hopefully at this stage, the fossil is found, removed, and placed into a museum setting. Otherwise, it is susceptible to erosion on the surface.

*Adapted from: <https://blogs.iu.edu/sciu/2022/10/01/biases-of-the-fossil-record/>*

## SOURCE G

### GLOBAL IMBALANCE

The majority of palaeontological data come from researchers in high- and upper-middle-income countries.



Source: <https://www.nature.com/articles/d41586-022-00103-9>