

Rap History of the World – Teaching Notes

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These notes are suggestions for how to use the RHW as a teaching resource to explore the subject matter and wider themes in Big History. Feel free to contact the author on contact@raphistoryoftheworld.com for help, advice with lesson plans, other materials, etc. See for example materials for a lesson on disease and World History [here](#).

Notes also available for Acts [II](#) and [III](#).

Act I – Evolution: Physical, Chemical, Biological, Human from the Big Bang to the Neolithic

Physical Universe to Planets	Questions for Students	Teacher's Notes
Big Bang Where it all began Deep time Beyond imagination First pure radiation		I haven't written much in terms of questions and notes about the very early universe (a fraction of a second) as it is highly technical. Note there is no mention here of antimatter and the subsequent great annihilation, or any detail on subatomic physics.
That expanded and stretched Cooled and condensed Get prepared For $E=mc^2$ Photons became protons Add electrons We got hydrogen The atomic spark But, most matter is Dark...	What exactly expanded? How do photons 'become' protons? What other great events of the early Universe are not mentioned in the first verses?	Space expanded. Which explains how radiation can 'cool', increasing its wavelength, while obeying the law of having a constant speed. As above, this is one for the physicists... but anti-matter and the great annihilation is one conspicuous absentee.
And even though we can't see We can feel it's gravity, The key to galaxies Spinning with obscene speed: 100 billion stretching far, Each, 100 billion stars	The speed at which galaxies spin is described as 'obscene' - is that just because it is really fast? Or something else unusual? We can 'feel' Dark Matter's gravity, but how does that help us observe its presence?	This is hinting at the fact that the observed rotational speed of inconsistent with their observed mass and known physical laws - galaxies spin impossibly fast. These observations led to the first suggestions about the existence of Dark Matter. Further to this, galaxies would not actually exist without Dark Matter, and stars would not exist without galaxies... Gravitational lensing is the effect of Dark Matter's gravity which allows us to observe it more directly. It is seen in both the still images and the video.

Now gravity attracts Anything with mass Like clouds, of dust and gas That shrink, until at last Getting denser under pressure Raise the temperature Great engines ignite Nuclear fusion makes bright The dark night Let there be light!	Why did gravity not just pull the Universe back into its original ball? Or fly apart forever? What made these separate clouds come together? Is this like nuclear power that we use on Earth? What is nuclear fusion?	Tricky one this - random imbalances in the early sphere of radiation caused by (I think) quantum fluctuations. Perhaps avoid! Is there a distant parallel to how our own weather clouds require 'seeding' by dust particles to start forming? Some of it no, some of it yes. Nuclear fission in power plants and early nuclear bombs consists of large atoms breaking up; hydrogen fusion is used in more power 'thermonuclear' weapons; controlled fusion is a scientific area currently being researched. https://en.wikipedia.org/wiki/Fusion_power
First hydrogen to helium Then boron and carbon, Nitrogen and oxygen, And on and on... The ancient stable Of the periodic table Everything you touch Everything you own Everything in you If you ask where it begun It was in the heart Of a long dead sun	Why does fusion not make stars explode and scatter all the nuclear 'fuel' again? What happens when the 'fuel' runs out? Is it literally true that <i>everything</i> in us has definitely been through the heart of a long dead sun? What might not have been?	The main point of this verse is to make clear the surprising fact that virtually all of the matter in and around us consists of 'large' atoms (compared to hydrogen), that were produced in stars. If those engines of complexity never existed, then neither would we. Ultimately, we are very reliant on Dark Matter, as we saw above. The expansive force produced by nuclear radiation balances out the attractive force of gravity, stopping the collapse; expansion then leads until it slows down the rate of fusion, i.e. it limits its own source in a process known as negative feedback. Lead the students towards the concept of stable equilibrium; hence a stable sphere. When the initial supply of fuel runs out, then gravity takes over again and gravity takes over again until eventually the next level of fusion occurs the output of the last round. The still image is good for visualising how a large star could comprise layers with multiple different shells of fusion occurring at the boundaries. Here you can also introduce the inevitable fate of the Sun and, therefore, of Earth.

		Anything larger than helium was manufactured in a star - so that's pretty much everything in your body except hydrogen. Your hydrogen might have existed in the outer layer of a star without ever engaging in fusion - or it might have always been in interstellar clouds. One other idea here would be to introduce Joni Mitchell https://www.youtube.com/watch?v=26LYjMww0GY
And when a supernova flashes Scattering the ashes The next generation of stars Can have planets, like Mars And with the perfect size and distance – The Goldilocks Conditions – Maybe there'd be water, for an instant...	Do all stars become supernovae? What conditions are required? Will the Sun explode? Can you work it out from its size and brightness? How long will it last? What are the 'ashes' and why are they important? What is the earliest time in the Universe's history that rocky planets could have appeared? Why might water appear only for an 'instant'?	Only stars of a certain size will explode. This would be an opportunity to introduce the life pathways of stars ('standard path' + deviations), and also how this was a good example of the matching of theory and evidence in physics. Students will hopefully be curious as to what will happen to their own Sun - give them the relevant size + brightness numbers and see if they can identify it on the chart. Then tell them how old it is and they can estimate how long we have left. The 'ashes' are larger, more complex atoms and we will see why they are essential to greater complexity, including rocky planets, chemistry, and life. The earliest rocky dust could have appeared as soon as the first supernovae had run their courses - very large ones can have relatively short lifespans. Would the dust from the first explosions, scattered in all directions, have been enough to allow rocky planets to form? Or would it have taken several generations of supernovae? (Perhaps it would have taken 2 generations of supernovae: 1 to seed interstellar space with large atomic dust, then the 2nd to supply the the shockwaves that help compact and trigger the gravitational collapse of existing gas/dust clouds; the 3rd generation of solar systems might have rocky planets). I don't know, but interesting to speculate. In 2014, scientists discovered proof that water once existed on the surface of Mars, but it is not there now. It actually lasted several billion years (we think) until

		relatively recently, and probably vanished through gradual evaporation. So this raises the question why water remained on Earth... it is only very tenuously hinted at in the next section, but possibly because of the ozone layer, which can only persist because of life. So life is essential for water, as well as vice versa. If I remember Lovelock's arguments correctly.
Emergence of Life and Bacterial Evolution And so it came to be That on one of these... Amid the primal seas A dash of energy Linked C-H-N-O-S and P Making Amino acids, RNA, DNA The base of everything alive today	Why do we think life began in water? Why do we think water is important for life? Where did the 'dash' of energy come from? What different theories are there? What do these letters mean and why are they important? What does 'base' mean? All this sounds a bit like magic - how do we know this is happened?	Don't necessarily need to answer these questions now, but keep them in mind... Note there are multiple theories, traditionally lightning was thought to be responsible but today mid-ocean alkali vents seem to be the leading candidates. Here you can introduce the names of the elements if not known, and observe that most of life's constituent parts are made from just these six elements (although trace elements are vital too). Ask them why carbon is so important? (Because of its ability to form long chains - but why is that important? In the next section we will introduce 'information store'. Hopefully anyone familiar with 'base pairs' in DNA will spot the double-meaning. You could chose to introduce how DNA works here to younger groups. Well, we have known it is possible since the Miller-Urey experiments in the 1950s, which created amino acids from Ammonia, Hydrogen, Water, and Methane + electricity. Amino acids have been found in meteors and comets from outside the Earth, so they must be able to form spontaneously elsewhere.
Trapped in a membrane Forming long chains Information store And self-replicator	What does 'membrane' refer to?	Make sure the students understand we are talking about cells from here on. Why are cells important? We take it for granted that life is cellular, but why do we think it is? probably (a) intimate proximity of varied carbon chains to

Mutate, replicate: Innovations can accumulate At a rate that fascinates Ribosomes, chromosomes Meiosis, osmosis A million chemical tricks Turning rocks, water, air Into trees, lungs and hair	How can something be an information store and self replicator? DNA needs cellular machinery to replicate itself... What causes mutations? What is life?	give rise to diverse interactions and (b) group selection, although this is probably too large and tangential a topic to go into here. Point (a) might help answer the question above about why life emerged in water: water provides <i>liquidity</i>, a medium which facilitates exchange. On the question of self-replicating information stores, lead the discussion towards the possibility that original life was not DNA-based. Ask the students to find out what ribosomes are made of hopefully they might postulate an RNA world. See this or this or this (very technical). On the question of what is life, students will hopefully disagree with each other and discover that it is not a simple question. Ask them to list the features they think define what life is, and what features we have seen so far in the RHW, i.e.: self replication, information store, processes chemicals (matter), requires energy, is composed of amino acids. Are all of these essential for life?
Diversification Follows descent with modification And non-random elimination Of all but the best adapted I just rapped that	Who famously first wrote this algorithm? Is this algorithm complete as presented here? What terms do we use today? When did the author write and what was his book called? What was his inspiration? Was he a genius?	This is called the 'Darwinian algorithm'; the phrase 'descent with modification' was used by Charles Darwin in his original argument, not 'evolution'. We call this process 'evolution' and the preferential survival mechanism is known as 'natural selection'. We need to add that the modified feature which permits the organism to survive elimination is hereditary. This is not quite clear in this verse. The last questions are more general knowledge. Darwin wrote <i>The Origin of the Species</i> in 1859. His inspirations were (a) the diversity he saw on his voyage on H.M.S Beagle 15 years earlier, especially the famous Galapagos finches, and (b) Thomas Malthus' <i>Essay on the Principle of Population</i> (1798).

		On the question of genius, Darwin was not the only person to have the same idea for similar reasons; he co-published the arguments with Alfred Wallace who came up with the ideas independently (but slightly later). But Darwin also later introduced important ideas on sexual selection and group selection, which were neglected by mainstream biology until the second half of the 20th Century but are generally regarded favourably today.
Producers and consumers Symbiotic communities Tectonics cycle minerals While life's building chemicals Forming Mechanisms of feedback, A global thermostat They began to stabilise What's in the seas and skies And gave rise To the blue marble that we marvel at Lovelock called it Gaia, These rhymes are on fire!	What is being produced and consumed? By what? What does 'symbiotic' mean? Can you think of examples? Tectonics involves the movement of continental plates in the Earth's crust - how does this cycle minerals? How does a thermostat work? How does a global thermostat work? What else is being 'stabilised'? Why is the blue marble famous? Where did the picture come from?	In these opening lines you might encourage the students to consider conceptual links between biology and economics. Classic examples of symbiosis include mitochondria and chloroplasts in the eukaryotic cell (more below), gut bacteria (including our own, which is increasingly in the news currently, but the four stomachs of cows might be a better known example), or bacterial mats. At this stage we only have single-celled life and are talking about microbial communities. Students will hopefully be aware that tectonic plate movements are linked to mineral cycling via processes such as subduction, volcanism, etc., driven by mantle plumes. But did they know tectonics also cycle water and CO₂ (on much longer timescales than the carbon cycle traditionally taught in the classroom), how, and why this is important? (The short answer is CaCO₃ in sea shells, and tectonic carbon cycle helps regulate climate on very long timescales.) Which leads us to the next set of questions on the basic functions of Gaia... Earth Systems Science is the academic field spawned by Lovelock's original theory, and it considers the processes which maintain the chemical composition and temperature levels of the atmosphere and oceans (and possibly atmospheric pressure). Note the careful wording of the penultimate

		line, which neatly sidesteps the weak Gaia/strong Gaia controversy! The 'blue marble' is the famous 'Earthrise' photo, taken by astronauts in 1970, the first colour photograph of the Earth taken from outside the Earth. (Earth's first 'selfie' if you like). Both the astronauts and the people looking at this photo were moved by how precious the Earth's biosphere appears, contrasted against the forbidding backdrop of uninhabitable space, and is said to have inspired the Environmentalism movement. (It also inspired UvA's Professor Fred Spier's academic career.)
3 billion years Of the single cell They'd done well But life went further: When bacterial merger Made the eukaryote Of historical note Horizons opened far We're multi-cellular	Earlier we mentioned symbiotic communities among single-celled life; what is different about true multi-cellularity? How do bacteria merge? What are the noteworthy features of a eukaryote? Why is this historically significant?	Note the timings here are a little ambiguous. Single-celled life dominated for c. 3 billion years before multi-celled life took off (c. 600m years ago), but the origin of the eukaryote is estimated to be much earlier, at 1.5-2bn years ago. 'True multi-cellularity' is probably an amorphous concept, but we might argue that the organism has a more clear distinction between reproductive (germ) and normal (soma) cells, is less able to function when not in multi-cellular form (e.g. the reproductive phase, but some sponges can separate their cells and reform). How bacteria merged historically is complicated and uncertain! It might have begun as incomplete reproduction or predation, or two types of bacteria who consumed each other's wastes as inputs for their own metabolism became locked in an increasingly intimate relationship. Eukaryotes have a large nucleus of DNA, protected from the rest of the cell, which permits the storage of much more information in a more stable format (like how the CD was an upgrade on the floppy disk, etc.). The division of labour with chloroplasts producing and mitochondria processing energy allowed consumption of much higher levels of energy, i.e. a more powerful cell.

		Historical significance because the eukaryotic cell is larger and more powerful than bacterial cells, and multi-cellular life can become much larger, more powerful, more complex and more diverse, eventually leading to large animals and intelligence.
Evolution of Macroscopic Life About half a billion years ago... Deep in the oceans The Cambrian explosion Set in motion A great radiation Of prey and predation Things to help swim Like fins and branching limbs Teeth, claws, grasping jaws Sensory perception Evasion and deception The arms race continues at pace Forever. For <i>ever</i>? For <i>ever</i> ever.	How old was the Universe half a billion years ago? Compare this to the other major milestones so far... what do you notice about time? What was special about the Cambrian explosion? What is special about 'branching limbs' in the ocean? What animal is that in the video? What is meant by an 'arms race'? How is biological evolution like human warfare? How is it different?	Universe was c. 13.3 billion years old at the Cambrian explosion. The earth was c. 3.5bn years old at this stage, life c. 3bn, eukaryotes c. 1.5-2bn years old and multi-cellular life possibly as little as 100 million years old. Change appears to be accelerating. The Cambrian explosion was a very narrow period in time (a few 10s of millions of years) which saw an enormous diversification of animal species, including the innovation of most of the phyla (plural of phylum) that have ever existed (including several that are extinct). A phylum is a major high-level category usually linked to a type of body plan e.g. <i>chordata</i> is the phylum of all chordates, which are mostly vertebrates. Many creatures that appear very strange compared to later animals appeared at this time, e.g. the trilobites (pictured). The size of organisms greatly increased. The Cambrian explosion roughly coincided with the first hard-bodied fossils which are more likely to leave an impression in ocean sediment (as opposed to sponges, jellyfish etc. which are less likely to leave a trace); from now on ancient life left much more abundant and detailed evidence for future investigators. If all that was ultimately made possibly by multi-cellularity, what is going on? Is this like how a great invention like the internet creates space for many other inventions. Branching limbs... the video is of a Coelacanth, a currently living fish which belongs to a group from which we believe the first land animals descended; it's 'lobe-fins' have joints which are thought to be precursors

		to the limbs of land animals. The Coelacanth evolved into its current form some 400m years ago; the discovery that it was still living in the 1930s was met with incredulity by scientists. Re: arms race, ask the students to discuss parallels between biological evolution and human warfare. What aspects are hinted at here? (Armour, weaponry, camouflage, military intelligence/espionage, mobility). How is it different? Pace of change: many generations in biology vs individual lifetimes in warfare; natural selection vs conscious innovation; genetic coding vs learning / writing... this could digress into cultural evolution because e.g. some patterns of warfare become fossilised until eliminated on the battlefield; there are restrictions on human innovation and adaptability (more accurately: trade offs against the value of replicating proven, successful strategies).
Life passed with distinction Five mega-extinctions From without or within The atmosphere is <i>thin</i> Volcanic eruptions Asteroid interruptions Once or twice Earth's been covered in ice But after adversity Comes fresh diversity Other branches of the tree Leading the recovery	What does 'thin' remind you of from earlier in this act? When were the five great extinctions and what happened? Note that (a) these are the 'big five' which occurred after the Cambrian explosion, causing mass extinctions of animals as witnessed in the fossil record, but there were also plenty of catastrophes for the biosphere before the Cambrian explosion, not least the 'Snowball Earth' episodes which happened slightly earlier. What is the significance of 'other branches... leading the recovery'?	'Other branches... leading the recovery' hints at the fact that a dominant caste often holds sway until swept aside in some catastrophe, allowing different types to rise in their place. Famously, mammalian evolution did not take off until after the extinction of the dinosaurs, even though they had been around for a long time at this point.

And so it came to be That creatures of the sea Ventured onto land And would quickly expand From amphibians to simians And lots between we've seen Colossal among the fossils Are dinosaurs Once ruled the world Today they survive Only as birds While mammals rised late To dominate	What are 'simians'? Are they the most 'advanced' form of animals? Are mammals more 'advanced' than other types of animals? (are humans?) What is special about mammals? Winged dinosaurs were the ancestors of modern birds, the only dinosaurs which did not disappear in the great extinction event c. 60 million years ago... Did they 'survive', or achieve immortality?	There are several slightly contradictory teaching points here: (1) 'advanced' is a problematic word because it might imply there is some sort of 'goal' of evolution when there is not; more importantly, all organisms are selectively optimised for their niche (subject perhaps to constraints relating to their historic nature); (2) on the other hand, there are long-term trends such as increasing power consumption, brain-to-body mass ratios, intelligence, etc. Mammals have several special features, but the main one is possibly their endogenous (internal) production of heat, which allows them to be active effectively at any time of day or night (as opposed to reptiles which rely on warmth from the sun to be able to move vigorously). This increases the foraging/hunting opportunities available to mammals and increases their energy consumption. The question about survival vs immortality of the dinosaurs is partly philosophical. They're winged branch certainly survived - but why? This is the key to thinking about whether they have achieved immortality - flight gives far greater flexibility to live off widely scattered food resources in times of crisis, or find sheltered oases of life, and arguably places birds in the best place to survive future crisis. (Of course in the long run, they are trapped on Earth and an ageing, expanding Sun will kill off the entire biosphere.) Finally, it is amusing to note tha the chicken is the closest living relative of the T-Rex.
Reflection: Cosmic Evolution We've seen the creation From random generation Of new entities, even whole environments Driven by selection Against the direction Of entropy So it grows: life's magic tree.	Is the use of 'creation' ironic? What is entropy and what is its direction? How does life counteract it?	Life counteracts entropy by harnessing free energy flows, in Eric Chaisson's terminology.

But is the point mutation The Lord of All Creation What about Epigenetic methylation Chromosome hybrids Bacterial plasmids A lotta what's inside Got here by virus Maybe part of the answer Lies in horizontal gene transfer And what's this I'm hearing Genomes rearranging Is it natural and normal? Genetic engineering	What is a 'point mutation'? Could the eukaryotic cell have evolved from a single lineage of bacterial ancestors, by accumulating point mutations? Look at the diagrams again. (Note the irony here again, but less subtle.) The word 'Maybe' hints at the fact that this is still a fringe (although rapidly growing) area of science. Why did it take scientists so long to begin to let go of the point mutation as the main source of innovation? Was the evidence difficult?	There is no definitive answer to this question - it is 'what if' history (and hopefully the students will observe that), but it seems virtually impossible that the eukaryotic cell, with all its internal chambers and organelles, and in particular the mitochondria and chloroplasts which closely resemble free-living bacteria, could have evolved only by point mutations in the central genome. There are lots of exciting new evidence for the role of viral transfer in evolution, including our own - the human genome is full of DNA (mostly non-coding) which originated from viruses. This sort of evidence has only been available since DNA sequencing technology advanced in the late 20th Century (the first Human Genome Projects were completed c. 2000); but Lynn Margulis has been arguing for bacterial merger as the origin of the eukaryote (and the importance of other forms of symbiosis) since the 1960s. My personal theory is that science had insisted for so long, in arguments against Creationism etc, that incremental point mutations were indeed capable of producing the complexity and diversity visible in the world, that it was awkward to admit that other processes might have been as or more important. As an aside here, note that 'what's this I'm hearing' implies a later addition to the original lyrics; indeed I read Jonathan Shapiro's <i>Evolution: A View from the 21st Century</i> (2012), which surveys the evidence for natural genetic engineering as a major contributor to genomic innovation, a couple of years after the original lyrics were written. The lines on horizontal gene transfer had also been added in the meantime. Now look at the lines before and after this verse: '...of entropy/ so it grows/ life's magic tree', 'Note the propensity/ To increase complexity,/ And energy-flow density'. Originally they flowed in a single verse, with the same rhyming sound and similar rhythm. There is a loose analogy here with how we can see evidence for insertions and rearrangements in patterns of genetic code.
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Note the propensity To increase complexity, And energy-flow density: Evolution can operate On systems small and great Particles, chemicals Cells, plants and animals The trends transcend Different realms Will they hold true For human worlds too?		
Human Evolution So how did a Great Ape Lead to people who jape? Swinging from jungle to concrete jungle Playing bunga bunga on the drums Tapping keyboards with our thumbs: From where, did Homo Sapiens come?	How many of the classic 'distinct' human features are referenced here? How many of them are actually distinct? '...jungle to concrete jungle' reminds us of which argument about the human mind and behaviour? To what does 'bunga bunga' refer?	Humour (orangutans), manual dexterity, music (birds), tool use (chimpanzees, caledonian crows), complex communication (ants), dense populations, urbanity (ants, termites). Symbolic language is truly unique, as is synchronised rhythmic music/dance (drums). This is the argument for the 'Pleistocene mind', or in less technical terms, that much of our behaviour, particularly the competitive tendencies, stems from. 'Bunga bunga parties' was a topical term a few years ago that referred to alleged sex parties hosted by then-Italian Prime Minister Silvio Berlusconi. Margaret Cook has argued that promiscuous behaviour is typical of men in power throughout history.
So we had chimpanzees, up trees Or walking on hands and knees But great mountains rised The land dried, forests broke Grasslands encroached We stood up to see And, hands freed, Picked up sticks and rocks And made tools we need	Summarise the argument here in your own words. What are the 'great mountains' in question and where are they in the world? How did they have an effect on forests and grasslands.	This verse is literal so ask the students to summarise in their own worlds. The mountains are those in East Africa, which arose c. 10 million years ago, casting a 'rain shadow' across the lands to the east, causing reduced rainfall and a replacement of jungle with mixed forest and grassland. To get more detailed, the 'Rift Valley' which also emerged in the region, is thought to have lead to large lakes and variable micro-climates

		http://www.sciencedirect.com/science/article/pii/S0277379114002418
But before I proceed And you learn by rote We should note Another approach That we diverged on an ancient beach Diving to reach Seafood and all that's good On the shores of yore Do scientists agree? Maybe. Nearly. Check it out, The Aquatic Ape Theory.	What is 'rote learning'? Check out the Aquatic Ape Theory - what are its arguments? Why do you like going to the beach so much?	This is a reference to how the argument of the previous verse had become the orthodox position for a long time. Recently it has become increasingly questioned, not least by the Aquatic Ape Theory. The AAT has been heavily criticised but still has its champions and was, for the first time, the subject of a major academic conference in May 2013. http://www.palaeodeserts.com/wp-content/uploads/2012/10/Human-Evolution-Past-present-and-future.pdf It is possible that this verse has overstated the case for AAT - it has hard to find much publicly available, high-quality writing on the topic since the May 2013 conference. There are some ideas posted here, e.g. the riverine hypothesis: http://waterside-hypotheses.com/ The question about the beach should be arresting because it makes a (hopefully correct) assumption about the reader's behaviour. How can the question make that assumption with confidence? Are your preferences examples of universal human behaviour? Why are we so interested in beaches?
Whatever the divergence Soon came the emergence Of long-lost cousins, among them Australopithecus and Home Erectus Now Homo Habilis got his hands on this: The use of tools Learning, like in school But where selection rules Scrape meat from the bone Don't dine alone	What is meant by 'cousins'? What exactly is our relationship with the other species mentioned here? What is similar and different about the learning referred to here and the learning you are used to in school? What is the significance of the last line?	This is designed to provoke discussion about how evolution takes the shape of a branching tree, rather than a series of linear successors. Both involve deliberate learning (as opposed to gradual genomic change), but in evolution, your lineage goes extinct if you get it wrong; in fact, you might die quickly. Note what was probably most important was being able to crack open bones (using rocks) to access the marrow inside; for a long time our ancestors were possibly scavengers.

		The last line reminds us we are a social animal, and 'dine' suggests some sort of food preparation and communal eating, which perhaps became more important later.
And I haven't even mentioned Sexual selection Trying to get a mate's attention If you like this song, Have a dance and sing along That's how we bond	What does 'mate' mean here? Who's attention is being sought? What about 'we bond'? Can you find a current or historical human society which does not practice communal dancing? What value might social dancing bring to a group? How is this relevant to human evolution?	This verse mixes up several different ideas: • It is probably mainstream science nowadays that music, performance art etc. is a form of sexual display, and that sexual selection is an important driver of evolution in general and the human brain in particular (e.g. Geoffrey Miller, <i>The Mating Mind</i>, 2000) • Rhythmic dance as a form of social bond is hard to avoid as it is utterly ubiquitous and something the student can recognise from their own experience; its importance in human evolution might relate to practicing co-ordination for hunting, or for facilitating co-operation among larger groups (50+, e.g. William H. McNeill, <i>Keeping Together in Time: Dance and Drill in Human History</i>, 1995, or Stephen Mithen, <i>The Singing Neanderthals</i>, 2005) • My own thoughts that such activity is a form of social display as much as sexual display aimed at individuals of the opposite sex; successful social display could attract improved social status, important in its own right for survival and prosperity, but also indirectly as a source of sexual attraction So 'mate' is deliberately ambiguous - sexual mate or social friend. 'We bond' could be a courting pair, or a social group. The first-person reference and 'this song' insinuate that author is aware of his/her own performance as a form of display (credit to Baba Brinkman for first making this joke in his own show). Co-operation among larger groups offers a highly competitive edge to the members of that group, when they encounter and displace rival, smaller groups. (This

		is one theory for the eclipse of Neanderthals by Homo Sapiens c. 30,000 years ago).
And as our groups grow It gets harder to know Who knows who, Who's high and who's low, Who I should know... It's getting so complex I need more neocortex	What problem of larger groups is suggested here? How does it scale with group size? What is the value of solving it to the individual? What is the value of solving it to the group? What is the connection to intelligence and brain growth? Is there a limit to how well we can navigate social worlds today?	The larger a group, the more complex and confusing the interactions and relationships among its members become. For a group of n individuals, there are $n^2 - 1$ relationships. The better an individual can navigate the increasingly complex social world of larger groups, the better they can prosper by utilising alliances, recognising social power, etc. This is well documented among e.g. chimpanzees, dolphins etc., who are known to form 2nd-order alliances (alliances of allied groups) to achieve short-term goals. The better individuals can map and make work larger social worlds, the larger stable societies can become, giving them a competitive edge against smaller rivals, as discussed above. It might be surprising that some evolutionists regard this type of social intelligence as a critical driver of the growth of the human brain. It is thought today that we can successfully manage groups of c. 150 people, i.e. the biggest groups size in which everyone knows everyone, and knows how everyone relates to everyone else. This figure is recognised in diverse fields, including cultural anthropology and business theory. https://en.wikipedia.org/wiki/Dunbar's_number
Soon the grunts we heard Became nouns and verbs String together words With the art of language We can manage Many more techniques Shared by speech I can hear new pages turning:	Lots of animals making grunts and other noises with varying degrees of complexity and pattern - what is special about human communication? To help answer, what are the 'high points' of animal communication?	Mithen (I think) calls it 'true language'; it is orders of magnitude more complex than any other animal language; it can be recombined and can create an infinite amount of meanings; it is linked to the recognition of objects as independent things, which it is not clear animals can do. The most exhaustively-trained chimpanzees cannot get past the sophistication of a 3- or 4-year old human.

The rise and thrive Of collective learning	What other ways might we describe the phenomenon of 'collective learning'?...	Animal communication 'high points' include: • Extensive vocabulary; information-rich signals • Explicit functional signals (e.g. Vervet Monkeys) • Emotional communication • Regional 'accents' (Orcas) • Mimicry (parrots etc) 'Collective learning' is arguably the same thing as 'cultural evolution', or a component of it; the advent of this phenomenon is known as the 'Cognitive Revolution', or perhaps the climax of it, if we include the earlier phases of brain development discussed above.
What this will mean For genes Remains to be seen But in the meantime...	... and why is it so significant? Are we still evolving? What else is alluded to here? What are the implications for biological evolution?	Collective learning offers a new medium for information storage - the distributed 'cloud' of human brains in a society (and their connections beyond, as we shall see next). The key here is probably not so much the rate of innovation as the fact that innovations can be discovered in the lifetime of an individual, stored forever, and built upon. This is a mechanism of accumulating information and innovation several orders of magnitude faster than genetic evolution. 'Remains to be seen' alludes to (1) the fact that it is debated to what extent humans have been genetically evolving in say the last 10,000 years; certainly many of our traditional selection pressures have been removed in modern times; (2) the natural world has no defence, as per the next verse, exceptions to be discussed, and has been causing mass extinctions for tens of millennia; (3) human collective learning has gone so far today that it can directly manipulate genetic material.
Unfazed by Ice Ages We wandered and wandered Hunted and gathered Learnt to make a living In every climate On every continent In every environment	The phenomena described here began no later than c. 70,000 years ago - what has Homo Sapiens become? What has it achieved as a species that has never been achieved before.	We are now a super-predator - an apex predator in every environment we exist in; further, we exist <i>in every environment</i>. Emphasise that this is long before we have invented agriculture, never mind civilization or modern industrial technology and weapons.

Much to the detriment Of large animals That we'd find, and eradicated By now, humans already dominated What would become of them? What would be their fate?	Repeat the previous questions in the light of this verse: what is the significance of 'collective learning' for the rest of biology? How did we do it? Recap the themes in human evolution. What else is missing in the RHW? What parts of the natural world have 'fought back', survived or thrived?	Survey the megafauna holocausts - not just the Americas or Australia, but northern Eurasia too, and much more than the woolly mammoth. Survival in and domination of diverse environments is dependent on tool use, innovation (even things like needles for sewn clothes), and group co-operation for defense/hunting. Going back to how our intelligence evolved, we have seen bipedality, manual dexterity, tool use, sexual selection, artistic display, social navigation and complex language. All these would have co-evolved interactively with brain power - i.e. an increase in one would have facilitated development of the other. Many smaller events are missing, probably the most important omissions are controlled fire and cooking. It would be an interesting digression here, beyond the scope of the RHW, to discuss why surviving African megafauna is so diverse and rich compared to the rest of the world - why did they survive (co-evolved so had time to develop fear, plus disease inhibiting human population size)? Do not try this at home, but wild lions will typically run away from humans! The final question shades into Act II and beyond - domestication is one response, weed species is another, and disease too. Only in very recent times (c. 100 years) have we scored large victories over disease organisms, perhaps because microbes' rate of reproduction and therefore evolution is so fast; today disease is making strong comebacks and it is an open question whether cultural evolution will defeat it definitively via say genetic engineering.
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