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If Darwin were brought back to life, given only three minutes, what would you tell him about what has happened in biology since his day?

Undergraduate winning entry (Zoltan Soltesz, Trinity College)

"It is such an honour to have been chosen to give this presentation to you, Mr Darwin. I understand you've already heard about the new technologies, so I hope it's not too much of a problem that we have to talk by phone."

"Security concerns prevented me from being there in person, unfortunately – the decision to bring a great scientist back to life was obviously quite contentious, and the experiment itself was risky as well. Also, you've become something of a controversial figure yourself recently, as I'm sure you're aware. Now, I'd like to quickly explain the most important discoveries that have happened in biology in the last century – I'm told I only have a few minutes to do this, so I'll try to hurry."

"There are some things you didn't exactly get right, but for the most part, your theories were correct. For example, you were wrong about the mechanism of heredity: it's not *gemmules*, but so-called *genes* that are the basic units responsible for passing on traits. Actually, it was a few of your contemporaries who made some important early discoveries about heredity: August Weismann realized that only sex cells can pass on genetic information, which body cells typically can't do – unlike in gemmule theory –, while Gregor Mendel found that *alleles*, specific variants of genes, can be inherited independently of each other. Mendel also proposed that each individual has two alleles for the same trait; one from each parent, because each sex cell receives only one particular copy of a gene."

"Limb regeneration is explained by the fact that the entire *genome* – all inheritable information required for building and maintaining the cells of an organism – is normally present in all cells."

"The reason why not all cells are functioning the same way in multicellular organisms is that deoxyribonucleic acid – or *DNA* - sequences, which contain the genetic information needed for the development and functioning of cells also contain so-called *non-coding sequences*, which can regulate when or where genes are active."

"DNA is a weak acid composed of repeating units, which is present in all living organisms. Typically they are in the shape of a double helix and are organized into large structures called *chromosomes*. Information is stored in the sequence of nucleotide molecules on the DNA strands, and, using a cellular mechanism, this information is copied and passed on to new cells during division. This copying process has very high fidelity, but due to the enormous amount of information that needs to be copied, errors do occur. It is now thought that most such errors do not affect the individuals' chances of survival, but some of them could prove to be either beneficial or detrimental. These errors, called *mutations*, provide a constant source of new variation on which natural selection may act."

"The way DNA can affect how a cell works is though a multi-step biological process, in which *enzymes* – usually protein molecules – catalyse biochemical reactions that ultimately result in the production of specific proteins, which can serve a wide variety of functions. DNA information is *transcribed* into so-called messenger ribonucleic acid – or *mRNA* – molecules, which are then used as blueprints for building proteins in a process known as *translation*. This one-way flow of information – the fact that information from protein cannot be transferred back to RNA or DNA – is called the *central dogma of molecular biology*. This also means that the similarity of DNA or RNA from different species can be used to analyse their evolutionary relationships: more closely related species tend to have more similar genetic makeup."

"There is no clear consensus yet on how life itself developed on Earth. There are a number of competing theories, but one theme that seems central is that at some stage a primitive

replicator emerged. A replicator is a biological - or maybe even a chemical - unit that is capable of producing additional copies of itself. Even though the spontaneous appearance of a replicator could be very improbable, it has to arise only once: once a single replicator exists, it will mass-produce a large number of copies of itself, and if the self-copying mechanism is not perfect, and slightly different versions of the replicator have different success rates of producing further copies, evolution by natural selection has to occur. So even if the emergence of the first replicator was improbable, millions of years were available for a single successful event to happen, and once a single replicator came into existence, evolution, and life, inevitably had to occur."

"The first living organisms were probably primitive single-celled ones called *prokaryotes*, which lack *cell nuclei* – meaning that their genetic material is not organized in a membrane-enclosed "control centre" like eukaryotes', but is held instead in an irregularly-shaped complex called the *nucleoid*. At the most fundamental level, life is sometimes categorized into three domains: archaea, bacteria and eukarya. However, this classification highlights a recently recognized difficulty in trying to reproduce the tree of life this far back in history: *horizontal gene transfer*."

"Normally genetic information is only transferred from one generation to the next, but sometimes genes can be transferred within the same generation. For example, *conjugation* allows bacteria to exchange genes through direct contact, while the *mitochondrion*, a eukaryotic organelle involved in generating a source of biochemical energy, is thought to have originated as a separate prokaryote, which was taken inside a eukaryote cell in a symbiotic relationship. Horizontal gene transfer appears to be a particularly significant confounding factor when trying to resolve the relationships between early bacteria, because the fact that different species could exchange genes with each other means that standard DNA-based techniques for reconstructing the tree of life are going to be inaccurate – indeed, at this level it's probably better to visualize it as a web, rather than a tree."

"You were mostly right about humans too. We do share a common ancestor with great apes, proof for which comes for example from looking at the human chromosome 2, which appears to be almost identical with DNA sequences in, for example, the bonobo and chimpanzee genomes, except that in great apes the sequence is found on two different chromosomes. The properties of chromosome 2 strongly suggest that it was formed by a fusion of two ancestral chromosomes, which are still present as separate chromosomes in great apes.

Experiments have also found that some animals display signs of intelligence, and even self-awareness: for example, elephants can recognize themselves in the mirror, New Caledonian Crows display purposeful *metatool use* – the use of tools to make other tools –, and some bonobos seem to be able to acquire at least a limited form of understanding of language."

"*Altruism*, helping other individuals at one's own expense, can also be seen in nature. A *gene-centred view of evolution* helps to understand why this could be even selectively advantageous: genes are the fundamental units on which selection works, and genes only "care" about passing on more copies of themselves to the next generation. However, identical copies are also likely to be present in other individuals – most probably in close kin, who could share as much as 50% of their genes – so it's advantageous for genes to promote altruism when the costs of doing so is less than the expected benefits of helping other copies of themselves propagate to the next generation using other individuals."

"*Culture* could also contribute to the behaviour of some animals. There is evidence that chimpanzees can imitate and learn from other members of their species, and can therefore learn cultural traditions, such as tool use, and pass on the knowledge in a non-genetic way. There could be, then, slight variations in the way different groups use tools, and the more efficient ways of using tools would be more likely to be spread successfully. Therefore something similar to evolution could act on units of "ideas", which is what "*memetics*" aims to investigate."

“Your theories also contributed to modern medicine. Bacterial infections have been treated with agents that kill them or inhibit their growth, and in response, due to a strong natural selection acting on a pre-existing variation in bacterial resistance, *antibiotic-resistant* microorganisms have evolved. Understanding how and why this happens allows better treatments to be developed.”

“I'm afraid my time is up now. As you can see, a very large number of advancements have been made in biology since your day, and your ideas have contributed to many of them. I hope this quick talk has been useful in explaining the basics of at least a few of the new developments.”

“Thank you.”

“Goodbye.”