Like evolution, all scientific theories are a work in progress

May 1 2018, by Paul Braterman

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Discussions about the nature of science and scientific theories are often confused by the outdated view that such theories are rendered false when anomalies arise. The notion of a scientific theory as a static object should be replaced with the more current view that it is part of a living research programme, which can broaden its scope into new areas.

For example, take the hypothesis that all swans are white, which seemed pretty good to Europeans until Dutch explorers found black swans in Australia in 1636. So what happens to our hypothesis? There are a number of options.

1. Redefine swan-ness to include whiteness. Then black swans aren't really swans, and the hypothesis remains true by definition.
2. It's been disproved. Discard it.
3. Compare different species of swan the world over, and see how well black swans fit in.

(1) is the least useful. Definitions can only tell us about how we are using words. They tell us nothing about the world that those words attempt to describe. (2) is based on the common-sense idea that hypotheses should be discarded when falsified by observation. This was the idea put forward by philosopher Karl Popper in the 1930s, to distinguish between science and pseudoscience.

He saw psychoanalysis, for example, as pseudoscience because disagreement with its findings can always be explained away as a result of repression. Popper's 1930s view has a great deal to commend it, but throws out a lot of babies with the bathwater. (3) is how science actually works, as Popper and his colleagues, who challenged traditional views of how science works, had realised by the 1970s.

In our example, the black swan was an anomaly, but any major scientific theory will have anomalies. Newton's theory of planetary motion could not explain the orbit of Mercury, an anomaly that was known for decades before Albert Einstein explained it with his general theory of relativity. Despite this anomaly, Newton's theory was retained because there is so much that it does explain. A theory is not meant to be a final statement of how things are, but just the latest stage of a research programme in continual progress.

Evolution as theory and research

In the 18th century, the existence of family relationships between different species was spelt out in the Swedish naturalist Carl Linnaeus's grouping of living things into species, genera, orders and so on, but there was no suggestion of how things got that way. By the 1820s, the French biologist Jean-Baptiste Lamarck was talking about inheritance of characteristics acquired as the result of striving (as the giraffe's ancestors strived to reach higher into the trees).

By 1859, naturalist-biologists Charles Darwin and Alfred Russel Wallace independently came up with the idea of natural selection as the primary driver of evolution. Natural selection, that is, operating on variation, but with no understanding of where the variants came from, or how that variation was inherited.

In the early 20th century came the discovery of mutations as a source of variants and the incorporation of the Austrian botanist Gregor Mendel's genetics into evolution science, but as yet without knowledge of the material basis of mutation and inheritance. This emerged in the 1940s, when DNA was recognised as the genetic material. Then from the 1950s onwards there was the determination of its structure and the cracking of the genetic code that revealed how it directs the formation of proteins.

Since then, we have recognised that evolution is governed by chance as well as by selection, that inheritance is complicated by things like gene duplication (where a chunk of DNA is copied twice and each copy can then evolve independently), horizontal gene transfer (where DNA is transferred between species), and even the incorporation of genetic material from viruses into our own genetic material. And of course there are plenty of other things that we still don't understand … Yet.

So at every stage, we have an imperfect theory, full of gaps and inconsistencies, but one that emerges all the stronger from scrutiny of its imperfections. Like atomic theory, it has developed in ways that its originators could not even have imagined, with growing understanding at all levels from individual molecules to the genetics of populations. And like atomic theory it is fundamental to our understanding of the science that has grown up around it. Biology without evolution is like chemistry without atoms.

The possibility of correction

Sometimes we tells students that "the scientific method" consists in gathering data, formulating hypotheses to explain them and then collecting more data to see if the hypotheses stand up. At other times, we tell them that it consists in formulating hypotheses, collecting data and rejecting the hypotheses if the data don't fit. Such views are much too simple and make scientific research sound like following a rather boring recipe.

The first step in any scientific enquiry is deciding that something is worth looking at. So the possible results must be worth having and the research programme must have some prospect of success. The next thing is continual dialogue between hypotheses and data. The hypotheses must be open to modification in the light of the data and must always remain open in principle to correction in the light of further knowledge. This commitment to the possibility of correction is known as fallibilism, and is one thing that all scientific endeavours have in common.

Beyond that, I see no point in pretending that science has a single method (it doesn't), or in trying to draw a hard and fast line between scientific knowledge and other kinds of knowledge about the world (there isn't one).

What about the swans?

Meantime, DNA evidence shows that the different white swan species whooper swan, tundra swan and mute swan are closely related, with the Australian black swan as their first cousin. Surprisingly, the black-necked swan of South America is a more distant relation.

Other questions suggest themselves. Is there any link between geographical distribution and closeness of relationship? When and where did the separate species arise? Do the differences in colour have any survival value, and if so, what?

So by now, our original swan hypothesis, based on appearance, has been greatly modified, and given rise to a whole range of new questions involving molecular similarities, adaptive evolution vs neutral drift, biogeography and the fossil record. That's science.

This article was originally published on The Conversation. Read the original article.

Provided by The Conversation

Citation: Like evolution, all scientific theories are a work in progress (2018, May 1) retrieved 29 April 2024 from https://phys.org/news/2018-05-evolution-scientific-theories.html