A biology educator's perspective on 'life'

Paul Davies

Abstract Defining what is meant by 'life' seems, on the face of it, straightforward. But, as this article explores, once you delve below the surface you find that providing a definition that everyone agrees upon is nearly impossible. By first considering how biologists and philosophers of science debate the issue of defining life, the article then goes onto explore the implications of this for the biology classroom. Finally, the debate is widened to include the 'meaning of life', suggesting that a cross-curricular approach to addressing questions of this type is a powerful approach for students to work with.

This article explores ideas about what biologists mean by 'life'. In doing so, I draw on my own experiences as a teacher of biology, as well as research in the fields of biological science and the philosophy of biology, to cast light on this trickiest of questions.

Biology *is* the branch of science that studies life. Therefore, having a definition of what constitutes life is important. In their day-to-day work, most biologists will not be thinking about what it means to say something is alive or has been alive, but the question remains important and is one that biologists and philosophers of science have struggled to pin down. In some respects, not having a well-accepted definition of 'what is life?' is not problematic; biology has developed into a fascinating science with important predictive powers and applications without one. But it is an intriguing and essential question and something that we expect students to grapple with through school, from ages 5 to18, and possibly beyond.

Defining life

Having a set of criteria about what it means to say something is 'alive' and something is 'no longer alive' or has 'never been alive' does have important implications about how we view the world and relationships with other living things. Biologists seek a definition (or set of definitions) about life because it frames biological thinking. Clearly, this is essential for a researcher trying to understand how life began or when looking for life on other planets, but it is also important in terms of framing the scope of biology as a discipline.

Reaching a consensus about what life means is not straightforward. Daniel Koshland (2002) gives a vivid example of how academics grappled with this point at a meeting that was attempting to produce a definition of life:

> *What is the definition of life? I remember a conference of the scientific elite that sought to answer that question. Is an enzyme alive? Is a virus alive? Is a cell alive? After many hours of launching promising balloons that defined life in a sentence, followed by equally conclusive punctures of these balloons, a solution seemed at hand: 'The ability to reproduce – that is the essential characteristic of life,' said one statesman of science. Everyone nodded in agreement that the essential of a life was the ability to reproduce, until one small voice was heard. 'Then one rabbit is dead. Two rabbits – a male and female – are alive but either one alone is dead.' At that point, we all became convinced that although everyone knows what life is there is no simple definition of life.*

As the quote demonstrates, everyone seems to know what it means to say something is alive, but defining this is difficult. In some senses it should be easy to identify when something is alive; young children have been shown to have a pretty good sense of this, although very young children tend to think that anything that moves, such as a motor vehicle but not a plant, is living (Akerson, Weiland and Fouad, 2015). Providing a universal definition of life is a challenge because, as soon as criteria are developed, exceptions to the rule are found and the definition breaks down. For example, as illustrated above, if 'replication' is central to identifying something as being alive, then organisms that cannot reproduce or do not show asexual reproduction should be classified as non-living. The problem is compounded when we consider entities that hover on the living/non-living boundary. The best examples of these are the viruses and prions, but it also includes the individual cells and molecules that make up multicellular organisms.

As biologists struggle with the challenge of defining life, it is profitable to consider how astrobiologists go about this, because without a working definition, they cannot focus their research in their quest to find life on other planets. Carl Sagan famously told a NASA committee that was discussing the possibility of life in the cosmos that biologists are asking the wrong question when considering what 'being alive' means and should focus their attention on the *concept* of 'life' (Joyce, 1994). This led to the NASA definition of life as being '*a self-sustaining chemical system capable of Darwinian evolution*'. The inclusion of the notion of a 'chemical system' introduces an important idea that parts of the system can be alive (e.g. a cell or a single rabbit) without individually providing a complete exemplification of 'life'. I think that this is a neat workaround to the problem that some biologists have had in trying to nail down the nature of life.

However, the problem is not so easily solved. According to Cleland (2012), trying to agree on a shared definition of life is a flawed approach for both scientists and philosophers of science. She builds an interesting case that trying to define something that cannot be tested but that is part of a scientific theory is not possible. Instead, she suggests a better approach would be to consider providing *examples of life*. This solves the issue of using categories and lists, with the inevitable examples that do not fit taking us back to square one. But even this approach is not without problems. In many ways, Cleland's ideas echo Wittgenstein's discussions about family resemblances (Wittgenstein, 2009). Wittgenstein's theory argues that grouping similar things can appear to be easy, but that actually there is not one feature which connects them all together. Using 'games' as an example, he shows how everyone can agree on what a game is, but providing a definition that encompasses all games is not at all straightforward.

So where does this leave us? I think that the NASA definition is useful because at its heart is the point that life is 'Darwinian evolution'. This phrase encapsulates much, including molecular genetics, mutations, inherited change and differential fitness. At its heart is the ability for replication with errors, which are then passed onto subsequent generations. This is key to defining life and, for me, is where the most profitable thinking can be done. Inheritance of this type is unique to living things. Benner (2010) provides two useful examples that help to explain this. The first is concerned with crystal growth, where one crystal seeds the formation of others. Here the crystals are reproducing and passing on features (e.g. chirality) to the 'offspring' crystals. In some cases, the 'parent' crystal might show a defect that is observed in the offspring crystals, but the information in these defects is not itself inheritable. The second example is fire: fire consumes food, produces waste, moves and grows and reproduces by seeding new fires. But the new fires do not pass on their features through entities (in living things these would be genes) that can be selected for or against. These means that fires cannot evolve through the principles of Darwinian evolution and are therefore excluded from being classified as living things.

So maybe that is it: living things can be defined as entities that are chemical systems that have the ability to evolve. While, as a biologist, that feels like familiar territory, I suspect that to many people it would seem pretty meaningless. Yet this question is at the heart of biology and biology education. What then can we learn from defining life by considering what is happening in school biology?

Life in the school curriculum

School biology, at least until the latter parts of GCSE and A-level, tries to see life as a thing rather than a system. As discussed, this *descriptive* definition of life is flawed because it relies on lists, the most common being the specific characteristics of life processes embodied within the acronym MRS H GREN (see Table 1). Presenting students with this definition immediately poses the problem that a thing that is clearly alive does not fit the definition; for example, the single rabbit quoted above or the sterile offspring of hybridisation. Another problem that students might face is that this approach to defining life suggests that living things must exhibit these characteristics all of the time. Take, for example, an acorn; this might spend long periods of time in a state of dormancy where life processes are almost completely suspended. Acorns do still respire but are doing this so slowly that it very hard to detect. So, from a student's point of view, it might seem that the life cycle of an oak tree involves a stage (the acorn) when it is apparently dead and then comes back to life. Despite there being no shared consensus on a definition of life, biologists all agree that dead things cannot come back to life, so that would present a major problem for the acorn example.

Why then does school biology insist on a definition that is based on descriptive characteristics and why does this model become more complex as students move through school? The MRS GREN idea is introduced to students in primary school, and is often taught through grouping things into 'alive', 'never alive' and 'once alive but now dead'. Some objects are easy to group, such as most animals, but others are trickier, such as a twig of a tree or a wind-up toy. This definition of life does prove useful for helping students to consider what life means, and so begin their journey of a formal education in biology. As students move through school, the MRS GREN acronym becomes enhanced with an H (for homeostasis). This is an important addition because it introduces the idea that living things also maintain some sort of control over their internal environment and it links well with the idea of the 'chemical system'. The 'H' of MRS H GREN is probably best left until secondary school to allow students time to learn something about these processes (e.g. osmoregulation and temperature control in humans).

Increasing the sophistication of the definition of life in this way is similar to how a chemistry teacher might first introduce elements as metals and non-metals, moving on to consider elements that are metalloid in character at some later point once students have grasped the central concepts of measuring characteristics. This also opens up opportunities to discuss how science sometimes imposes order on nature and that, inevitably, not everything fits into neat organisation systems in this way. This also asks questions about why scientists (and, in many cases, biologists in particular) seek to organise nature like this. A criticism that students often level at biology is that there is a lot of content to learn and remember for examinations. This is true and there is an important argument that until one knows the language of biology one cannot understand biology. Beyond this, however, naming and classifying things in biology is very important for two reasons. One is that it often helps explain the evolution of living things and relationships between them. Take, for example, the embryonic development of organs: tracing these back, and seeing how structures that appear very different in adult organisms share common routes, helps understanding of evolutionary family trees (phylogenies) and shared ancestry. A good example here would be the thyroid gland in humans, which is homologous to the endostyle, part of the feeding apparatus, of the sea squirt (a marine organism that resembles an immobile jellyfish). A shared language here is essential for biologists to understand what things they are talking about, and what those things mean.

The second reason for biology focusing much effort on classifying things is that it underpins what biology is actually studying, and so distinguishes it from other branches of science and, more broadly, from other areas of scholarship. This type of demarcation is important at organisational levels, for example knowing what work might take place in a university biology department as opposed to a geology department. It is here, though, that problems may arise, with subjects becoming silos of knowledge with little overlap or communication between them. This is something certainly true of the secondary curriculum and organisation of secondary schools, but if viewed as an opportunity rather than a problem, teachers can seize the opportunity of working across subject/curriculum boundaries to consider why defining life is a challenge, and the importance of biology as a discipline.

Students could be asked to consider whether a more useful definition of life might focus on thermodynamics and so, ultimately, on physical explanations. In this definition, life is seen as a thermodynamic system, maintaining itself against physical changes in its external environment (e.g. temperature or oxygen). As well as this, students are well placed to consider how much is gained by including Darwinian evolution as part of their explanations of life. Considering life in this way is probably closest to how biologists interested in the origin of life consider what 'life' actually means.

The boundaries between areas of knowledge are constructed, permeable and contentious, but at the same time can seem to students to be firm and simple. A broader landscape that includes philosophical ideas about what being alive means to a living thing (particularly a person) gives students the opportunity to make a deliberate step into the aims and practices of biology – to sort entities that are alive from those that are not. Most students will not proceed to study A-level biology and so their formal biology education will end with the 'MRS H GREN' model of life. The 'list' approach to defining life isn't just a problem because it is limited in its application, it is also a somewhat reductive view of what life means. It is here that the biology teacher can explore how science (and beyond this, school science) approaches topics and how this might differ in other disciplines (and in biology as a scholarly profession).

Moving between fields that seem to have some similarities – such as biology and technology – can also give insight into the natures of the key questions in each field and why they consider these questions and not some others. A useful starting point might be to consider whether human-made things could be classified as being living. Take the example of a computer virus. A biological virus is on the boundary of life. In a somewhat similar sense, a computer virus is a piece of computer code (a series of 0s and 1s) that, like a biological virus, needs to be inside a 'host' (in this case, a computer) or it cannot exist. As a thought experiment, students could be asked to consider how the 'life definition list' of MRS H GREN maps onto a computer virus (see Table 1 for an example of the types of ideas students might come up with). Once mapped, does this analysis reveal anything that might be useful for technologists seeking to limit the damage that computer viruses can wreak?

Conclusion

There is obviously a lot to explore in these ideas, and teachers may not feel confident enough or have time to develop more than a couple in any detail. Even so, planning and providing occasional opportunities for students to consider how and why definitions operate within and across disciplinary boundaries is really important. Opening out discussion across curriculum subjects can reveal ways in which insights in one discipline can inform scholars working in another. It can also build students' understanding about how knowledge is constructed and the different ways in which it is used. Thirdly, and of course not least, it gives students a glimpse into the complexity of trying to understand one of the most fundamental questions that humans ask: what is life?

Table 1 Possible student responses to the question: 'Does a computer virus meet the criteria of MRS H GREN?'

MRS H GREN classification	Ways that computer virus meet the MRS H GREN criteria
Movement	The virus moves between computers, for example via an email, or appearing as an animated image
Reproduction	Viral copies are made within and between computers
Sensitivity	The virus can be programmed to detect things inside its computer host
Homeostasis	The virus could show control of the internal environment if programmed to check the computer 'world' it lives in and then respond accordingly (e.g. if the virus detects virus-checking software it could change the software)
Growth	The virus numbers grow in size as the virus replicates
Respiration/Nutrition	The virus uses computer resources (electricity) to carry out its activities
Excretion	The virus might produce waste code that the computer needs to remove

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Paul Davies is Head of Science and Director of Teaching and Learning at Queen's College, London.
Email: pdavies@qcl.org.uk