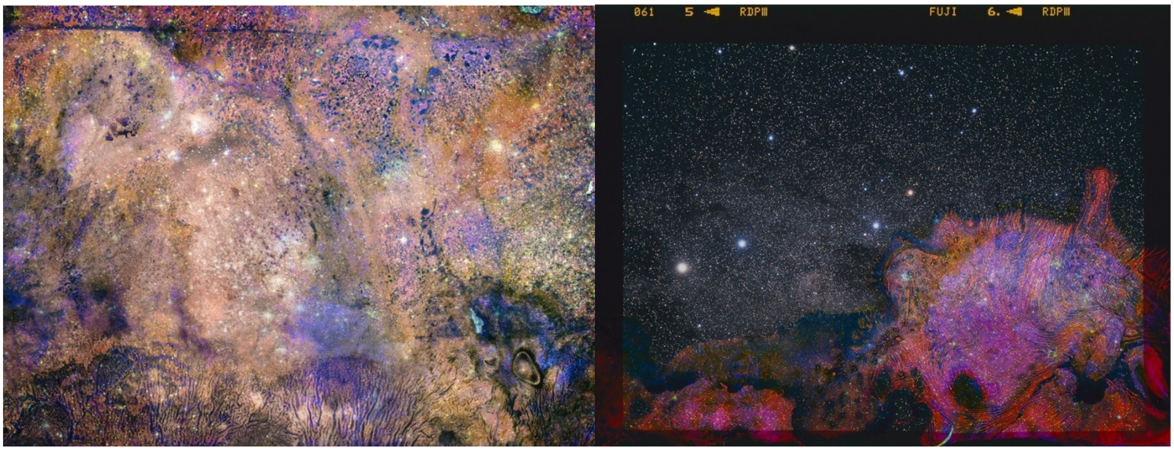
A CHILD-CENTRIC MICROBIOLOGY EDUCATION FRAMEWORK
This chapter is part of a book that is a component of the International Microbiology Literacy Initiative: https://sfamjournals.onlinelibrary.wiley.com/doi/epdf/10.1111/1462-2920.14611)

Thinking Philosophically About Microbiology

Mum: what am I if I am only 50% human and the rest is microbial?



These images, part of the 'Cosmos' series by artist Marcus DeSieno, show growths of microbial communities consuming photographs of galaxies. These representations symbolize the micro-macro aspects of microbiology that philosophy of microbiology tries to capture. Images used with kind permission of the artist. Copyright: Marcus DeSieno. https://www.marcusdesieno.com/cosmos
Left-hand image: **A Photograph of a Barred Lenticular Galaxy Eaten by Bacteria Found in My Belly Button** (archival pigment print of bacteria grown on photographic film, 2014). Right-hand image: **A Photograph of the Milky Way Eaten by Bacteria Found in Unpasteurized Milk**
(archival pigment print of bacteria grown on photographic film, 2014)

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How does philosophy relate to microbiology?

Surely philosophy is about humans, for humans, and by humans. Philosophy is deep and abstract, and microbes are thoughtless chunks of biological material. How do the two come together? And why would anyone want to think philosophically about microbes, and the science of microbes, microbiology?

Let's break down some possible answers to these basic questions. First, we need to think generally about the nature of philosophy and what it does. Second, we should reflect more generally on microbes and microbiology, and – because we are human-centric creatures – we should focus on the relationship between microbes and ourselves. Having done that, we can turn to a third task: showing the connections between the two themes such that 'philosophy of microbiology' sounds like something that is worth thinking about for ourselves.

1. What is philosophy? Philosophy is the old term for any enquiry into the nature of things and how we know stuff. In fact, right up until the 18th-century, science was known as philosophy: 'experimental philosophy' was the 17th-century term for any research based on observations (including experiments). Later, language such as 'natural philosophy' and 'natural history' began to be used, even though the term 'science' was increasingly overtaking these older terms in the 19th century. But right into the 20th century, universities in Germany, for example, still housed science departments in a 'Philosophy' faculty, because of the shared idea that rigorous and deep inquiry is central to all such studies and research. That legacy continues even today, when science graduate students obtain their doctorate – including those doing research in microbiology – their title is Doctor of Philosophy, Ph.D.

However, with increasing academic and research specialism as the 20th century continued, this common ground was fragmented. If we look now at universities and broader society, we can see a clear split between the activities of science and philosophy. But even so, there is a thriving area of philosophy called 'philosophy of science', and it has lots of sub-disciplines, including philosophy of biology, which in turn has a sub-discipline, philosophy of microbiology, that is our focus here. But the main thing to bear in mind is the basic idea that all science has philosophical underpinnings. Whether these are about concepts or the nature of explanations, or the status of models and theories, all scientists grapple philosophically with their subject matter, and bringing this philosophy out into the open can often be very useful as well as intellectually rewarding.

More broadly, philosophy likes to ask big questions: what is the nature of being human? How do we know the world? What are the values that guide us? It may be a surprise to some readers, but microbiology itself has some very philosophical answers to give on these topics. In particular, microbiology poses some very interesting questions about the contribution of microbes to human bodies and minds, and to our understandings of the world around us and the extent to which our world is in fact a microbial world. Moreover, microbiology can even at a very fundamental level raise issues about values, such as whether we need to appreciate microbes to have the sort of world we want, and why this might be the case.

But so far, this is talking in very abstract terms, and what we need to do is get a bit more down to earth with some microbiological facts, before we join broad philosophy with particular microbiological findings, so that we can get back to our aim of justifying 'philosophy of microbiology'.

2. What is microbiology and what are microbes? Although philosophers tend to like tight definitions with no ambiguity, many terms used in science and the everyday world do not work like this. 'Microbe' is one such word. Even though there is a whole science based on whatever microbes are, the term is loose and imprecise. It certainly should include all unicellular lifeforms, most of which are the small and prolific bacteria and archaea, but also larger protists. But does it include viruses of any kind, when these entities don't have cells at all? Some casual uses of 'microbe' are comfortable with that.

And what about unicellular fungi and algae? Well, why not call them microbes, if they are unicellular? Then, however, we have a conundrum: some multicellular filamentous fungi can actually exist as unicellular yeast forms. These are the dimorphic fungi, which switch between multicellular and unicellular forms according to the temperature. Where do they fit? And then there is a broader complicating issue: many unicellular organisms (both smaller and large unicells) prefer to live in large groups, sometimes of one species, other times of many mixed species. When they live most of their lives in social groups, individual microbes tend to function as part of a group, and that group can be thought of as multicellular. If unicellularity is the single criterion defining microbes, then living as part of a multicellular entity doesn't seem quite consistent with that definition.

What if we were to say microbes are simply living entities that have to be observed with microscopes? Viruses are again a problem if we want to include them (not 'living' by most accounts), and much more problematically for this definition, all kinds of cells, even human cells, need microscopy to be observed properly. And if animal cells, for example, live in groups and need microscopes to be visible, then what is the difference between them and microbes? Even if we say that microbes at least have a starting point of unicellularity before they get together in groups, that is also the case for animal cells, which also have a brief existence in a unicellular state as fertilized eggs.

Perhaps a less troublesome way to define microbes is simply to state that they are the subject matter of microbiology. We have existing and historical groups of scientists studying various phenomena, and by examining this research, we will get a good idea of what fits and what doesn't. And it certainly becomes clear that bacteria, archaea, protists and unicellular fungi and algae are the subject matter of microbiology, along with viruses even though there is a closely linked field called virology. Because there are many types of viruses that interact intimately with the microbial world, this degree of interaction makes it hard to keep viruses completely separate.

Being open to including viruses has a corollary with larger organisms. Although microbiologists tend not to focus on, for example, animals and trees, it often happens that because of the way microbes live their lives in very close associations with larger organisms (including animals and trees), then a microbiologist might also have to pay quite a bit of attention to those hosts and their biology. And it is these sorts of relationships that are probably stimulating some of the most interesting philosophical reflections of microbes and microbiology in recent years.

3. Living in a microbial world. Microbes are everywhere! In the ground, in the air, on everything, including our bodies and food. Not only are they omnipresent, but they are doing a vast number of chemical transformations every second of the planet's existence. Some of these transformations produce the chemical cycles that sustain the Earth: nitrogen, oxygen, carbon, and many other vital elements. Microbes may not be exclusively involved in these cycles (e.g., plants do a lot with carbon and oxygen), but they play vital roles in all these processes, and these roles cannot be filled by larger organisms. This is because of the metabolic versatility of microbes, and their dedication to making a living in even the most extreme and low-energy situations.

The many ways in which microbes transform the chemical resources of our planet are of immense importance to our own lives as humans. This is not just about our broader environment (e.g., having oxygen to breathe, and nutrients to sustain us) but also about our own roles as environments for microbes. Living on and in us are vast numbers of microbes, many of them affecting our body's processes and perhaps even our minds. Whether on our skin or in our intestines, microbes are just as busy converting chemical resources in those more intimate locations as they are out in the wider world. We cannot opt out of these interactions: microbes' size and ability to disperse, plus their rapid generation time, makes them highly effective colonizers of large nutritious objects like ourselves.

This is a mixed relationship. It is not that microbes are out to harm us, and nor is it the case that they have evolved to help us. They are exploiting us, just as we are exploiting our environments for our own benefit. But it so happens that certain exploitations turn out to be beneficial, or at least, we have adjusted so well to certain exploiters and not others that when new invaders arrive, we experience negative effects. A lot of medical microbiology deals with the negative effects of the internal microbial world, just as much broader fields, of microbial ecology and environmental microbiology, deal with the positive and negative effects of the external microbial world. All the preceding chapters in this collection deal with the details of the science looking at the internal and external microbial worlds. How do we get from these details to a philosophical view?

4. Philosophical implications of living in a microbial world. Perhaps the first thing we should be thinking about are the implications of seeing humans as ecosystems. Although we cherish ideas of our autonomy, and identify ourselves as uniquely human, microbiology casts new light on these older ideas. By suggesting that we are enmeshed in a complex process of microbial interactions, many of which are central to each of us staying alive, we might want to relax our sense of a hard boundary between ourselves and other forms of life. This is not to deny that humans are a particular life form with certain characteristics, but it is often useful to take a broader, more integrated view of how we fit into Nature. Historically, there has been tendency to place humans at the top of a hierarchy of living forms, but if we pay more heed to our external and internal microbial worlds, both in the present and in the longer view provided by an evolutionary perspective, we might have a more modest view of where we fit.

Why is this a good thing? First, it is more realistic and pays more attention to a great mass of microbiological, biomedical and environmental science, but second, it might have moral implications. Recall that the first section talked about what philosophy does broadly: inquire into the nature of things, and how knowledge is produced, and thirdly, think about values and our moral responses to various situations. If we think of ourselves as at the top of a hierarchy, with rights over everything below us, then we might feel morally justified in caring only about ourselves and our immediate benefits. If, however, we see ourselves as just another species node (a small node) in a complex and dynamic network of relationships, even if motivated by pure selfishness, we might feel more pressure to behave in ways that do not lead to the destruction of the network we are part of. We might feel it is morally important to sustain that wider network, just for our own sakes (including future generations). But one response to that way of thinking could be: 'ecology already told us that, even before recognizing the importance of microbes'. Granted, but thinking about pandas and orchids and redwoods might still allow some sense of separation and hierarchy, whereas once we tie everything together with microbiology and microbial processes, it might be harder to avoid a different view of the world.

Does thinking about the microbial world mean that there is no such thing as individual species like ourselves? Should we always consider particular organisms, whether kangaroos or cactuses, as microbial worlds? For some purposes, singling out individual organismal groups (including the large visible ones) is appropriate, because there are many questions we might want to ask, both scientifically and philosophically. Certain questions might mean we can for practical purposes ignore microbes for a while. But the broader reality always takes over again, and that reality (as so many chapters in this volume reveal) is microbial.

Environmental ethics is a large and growing approach that informs conservation, and it covers a range of different views, from ecosystems-first to human-centred perspectives. Few if any of these perspectives would normally consider microbes, perhaps because they might be seen as part of the environmental background rather than foreground features. It is well worth thinking about whether bringing microbes to the foreground makes a difference to how we consider our human responsibilities in the world. One question we might consider asking is whether we need to think ethically about microbes themselves (rather than our place in a microbial world). Should we try and protect microbes in the same way we might other species? Do we have obligations not to cause microbes to go extinct, or is it ridiculous even to think of microbes in these ways?

Traditionally, microbes are considered evolutionary survivors. They've been around for far longer in planetary history than large organisms, and there is every indication they will continue even when the various crises mentioned earlier in the volume have wiped out much of the non-microbial biodiversity on the planet. And because microbes are so tiny and can disperse great distances, it has often been thought that wherever the right conditions exist, the microbes that like those conditions will be found. Even where there is pollution or major environmental devastation, microbes with particular characteristics will thrive there. While it is true that vaccination might wipe out one or two species of microbe, and while it's also the case that the destruction of rare environmental conditions might cause larger microbes in particular to disappear, by and large extinction is not an issue for microbes on an ecological timescale. However, on longer geological timescales, especially when the planet undergoes major transformations, such as with the oxygenation of the atmosphere and oceans, then microbial extinctions are a very likely possibility. We might want to think a bit more about ongoing human-driven havoc being wrought on the Earth, and how this may impact on the microbial nature of the world.

Conservation issues basically come down to ourselves and any roles we might play in the maintenance of the planet with our microbial partners. If we want coral reefs and their crucial symbiotic microbes to persist, we'll need to act on global warming. If we want to avoid runaway greenhouse effects from gases such as methane, we will have to work out ways to enlist both methane-producing and methane-consuming organisms in constructive ways. If we want to use pollution-consuming microbes as environmental custodians, we'll have to sort out the conditions in which that can be done safely. Even though the inevitable future of the planet is microbial, we can work with microbes to prolong the conditions in which large organisms can thrive together.

One important way in which this could happen is by joining forces with microbes via synthetic biology. Synthetic biology is a form of biological engineering that redesigns microbes to do even more remarkable things. Although some synthetic biologists dream of creating new organisms 'from scratch', in practice they base their engineering on microbial cells and the myriad capabilities of microbes. Although this needs to be done very carefully and with appropriate ethical reflections (about risk, unintended consequences, public concerns, and motivation), there are many hopes that synthetically altered microbes can be used to engineer a better future for the planet, in the same ways microbes have engineered via evolutionary processes a habitable planet that we are now able to take advantage of.

Concluding thoughts

Thinking philosophically about microbes and microbiology is one way of taking a big view of the world we live in. This might sound contradictory, because of course, microbes are the smallest living things in this world. But given the impact of microbes on the planet's chemistry, and on the internal workings of many large organisms, these tiny creatures add up to a huge force. And that leads us to a major philosophical decision: about whether to work with them, and how. Much contemporary microbiology as showcased in this currriculum shows the means and ways of following through on that decision.

Relevance for Sustainable Development Goals and Grand Challenges

The microbial dimension of acquisition of a companion dog relates to several SDGs (*microbial aspects in italics*), including

- **Goal 2. End hunger, achieve food security and improved nutrition and promote sustainable agriculture** (*end hunger and malnutrition, increase agricultural productivity).* Taking a broad philosophical view about microbes is likely to make us more aware of and more committed to making the innovations necessary to achieve these goals. Our gut microbiome extracts nutrients from the food we eat, and then the many trillions of microbes produce various products that interact with our physiology. For children experiencing malnutrition, it is clear that recovery is not just a matter of more food or even good food, but of having a microbiome that is conducive to health. Externally, agriculture is dependent on microbial interactions above and below the soil. Enhancing these interactions is likely to allow greater productivity with less environmental damage.
- **Goal 3. Ensure healthy lives and promote well-being for all at all ages** (i*mprove health, reduce preventable disease and premature deaths).* There are many ways in which microbes in the gut and elsewhere might contribute to physical and mental well-being. Although the science is still at an early stage with regard to which interventions are the most effective, a philosophical outlook in which microbes are recognized as important and worth knowing more about will steer microbiology more rapidly to the most applicable findings.
- **Goal 6. Ensure availability and sustainable management of water and sanitation for all** (a*ssure safe drinking water, improve water quality, reduce pollution, protect water-related ecosystems, improve water and sanitation management).* If we recognize the involvement of humans in a global microbe-mediated network of interactions, this allows us to connect the macro-micro aspects of everyday living more effectively. Philosophy of microbiology also reminds us that it's not a matter of detecting enemy microbes – the ones that might cause disease – but of living effectively with microbes. We can then apply this mindset to services such as water supply and sanitation.
- **Goal 7. Ensure access to affordable, reliable, sustainable and modern energy for all** (e*nsure access to clean, renewable and sustainable energy, and increase energy use efficiency).* Sustainability requires understanding our world better and how we fit into that world. Thinking philosophically about microbiology can give us deeper motivations and insights into how to do that.
- **Goal 8. Promote sustained, inclusive and sustainable economic growth, full and productive employment and decent work for all** (p*romote economic growth, productivity and innovation, enterprise and employment creation).* The history of microbiology is in many respects a history of applied science. There is probably not a single finding in microbiology that has not been put to use for human benefit, whether that is medical (e.g., vaccination, antibiotics), nutritional (e.g., brewing, rising agents, fermented foods), or industrial (e.g., heat tolerant

enzymes, fermentation processes). If we think philosophically about all the many uses of microbes in our economic and manufacturing networks, we gain even more appreciation of our microbial world, and this in turn may lead to further innovations.

- **Goal 12. Ensure sustainable consumption and production patterns** *(achieve sustainable production and use/consumption practices, reduce waste production/pollutant release into the environment, attain zero waste lifecycles, inform people about sustainable development practices)*. A philosophical appreciation of microbes is very likely to underpin the technologies of the future for environmental remediation, pollution clean-up, and waste management. The incredible innovation powers of microbes are still only partly known, and future achievements can be guided by the view that if something can be done in an environmental situation, microbes will be doing it.
- **Goal 13. Take urgent action to combat climate change and its impacts** *(reduce greenhouse gas emissions, mitigate consequences of global warming, develop early warning systems for global warming consequences, improve education about greenhouse gas production and global warming)*. Realizing how microbial our world is, and how microbial we ourselves are, has the philosophical benefit of increasing our insight into what can be done at the macro-scale. A lesson can be learned from the tiny size of microbes, which collectively add up to some of the hugest planetary forces. And as greater insight grows into the roles of microbes in our rapidly changing world, we can be confident we will find at least some new resources and tricks to maintain a human-habitable world.
- **Goal 14. Conserve and sustainably use the oceans, seas and marine resources for sustainable development** *(reduce pollution of marine systems by toxic chemicals/agricultural nutrients/wastes like plastics, develop mitigation measures for acidification, enhance sustainable use of oceans and their resources)*. Understanding microbes and microbiology philosophically is basically a motivation to understand and treat our world better. Marine microbiology is a flourishing science, and the more that is learned, the more substantial that philosophy can become.

Potential Implications for Decisions

1. ***Individual***

   a. Recognizing our internal and external microbial worlds gives a better basis for decision-making of any kind (personal, environmental).

   b. A philosophical appreciation of microbiology also provides more options for changing situations, whether it is personal or planetary health.

2. ***Community policies***

   a. Recognizing microbial contributions starts at home and in the community, where greater awareness of microbes and microbiology can help with positive transformations (e.g., what is best microbiological practice for encouraging biodiversity in local nature reserves? How should waste be dealt with locally?)

3. ***National policies***

   a. Broad philosophical recognition of microbes is of importance for health policy and service provision.

   b. Broad philosophical recognition of microbes is also crucial for environmental policies of every sort.

Pupil Participation

1. ***Class discussion of what it means to think philosophically about microbes and microbiology***

2. ***Pupil stakeholder awareness***
   a. How does it feel to think about the microbes in your gut that are active right now and influencing your whole body?
   b. Can you imagine a world without microbes? Would it have humans in it? Would it be a good world?
   c. Should microbiology focus only on the microbes that we know cause disease? What are the pluses and minuses of doing that?
   d. Is synthetic biology a good thing or is it interfering too much with Nature?

3. ***Exercises***
   a. What is your instinctive view of microbes? What are the advantages of taking a broader philosophical view of microbes?
   b. Why do we live in a microbial world? Why haven't microbes disappeared as larger organisms (e.g., trees and animals) have evolved?
   c. Are microbes working for our benefit? Are they here to help us?

The Evidence Base, Further Reading and Teaching Aids

Small Wonders: How Microbes Rule Our World, by Idan Ben-Barak.
https://scribepublications.com.au/books-authors/books/small-wonders
A very carefully presented book that is philosophically inspired and expresses deep understanding and appreciation of the microbial world.
This book has an alternative title in some countries: *Invisible Kingdom: From the Tips of Our Fingers to the Tops of Our Trash, Inside the Curious World of Microbes.*

Small Friends Books: https://www.smallfriendsbooks.com/titles
Four exquisitely illustrated books for younger people on a variety of microbial relationships. Audio versions and teacher notes available too.

Life in Our Phage World: http://www.2015phage.org/art.php
A fantastic illustrated book about the role of bacterial viruses ('phage') and how they structure the microbial world.

The Invisible War: A Tale on Two Scales: https://theinvisiblewar.com.au/
An extraordinary graphic novel melding medical microbiology and microbiome science, against the historical backdrop of WW1.

https://www.microbes.info/
A highly informative site, with lots of links to both general information and specific details about microbes of every kind.

Glossary

Bacteria: one type of microbe, usually very small. Many millions of species, some well-known because of being discovered early in medical microbiology's history.
Archaea: Another type of microbe, less well-known than bacteria because discovered later, but with the same sort of fluid organization inside each cell. A few famous examples include 'extremophiles', which can cope with extremes of heat, cold, dryness etc.
Protists: A larger type of microbe, with highly structured cells. Many have very intricate shapes and often turn up in artwork.
Microbiome: The collection of all the microbes in a specific location, such as the gut microbiome. The microbiome can consist of bacteria, archaea, protists and viruses.