A child-centric microbiology education framework

The Microplastic Pollution Problem and the sea

"Mum, can we play in the sand?"

Photo by Heide Schulz-Vogt from IOW

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The Microplastic Pollution Problem

Storyline

We all have an innate feeling that the ever-increasing accumulation of plastic in our natural environments is problematic. Even worse, the concept of *microplastics*, microscopic plastic dust, as an ever-present contaminant all around us, is particularly alarming and might feel like a pollution crisis. Yet, how alarmed should we really be? Perhaps the greatest impact microplastics pose is to microscopic life – bacteria and other microorganisms. Understanding how microplastics interact with microorganisms is essential to understanding how problematic microplastics are as pollutants. To do this we must first understand what a microplastic is, how it differs from both other natural particles as well as larger plastic waste, and the ways in which microplastic might influence microorganisms to cause larger issues with implications for the wider environment and us. Only by understanding and addressing such concerns can we really answer whether we are experiencing a microplastic crisis or not.

The Microbiology and Societal Context

The microbiology: plastic as surfaces for growth of biofilms; microplastics as transportation vehicles: plastic biodegradation. *Sustainability issues:* health; environmental pollution.

1. ***Historical background – Plastics, society and the environment.*** Since the Paleolithic, a hallmark of the human experience has been the development of tools essential for survival, and the use of natural polymer materials such as wood, wool, flax, hemp, bones, gut, resin and latex has played a major role in the success of humanity. However, usage of such materials has often been limited due to their restricted formability, modifiability, consistency and vulnerability to biodegradation.

The first synthetic polymer, "Bakelite", was invented in the 1950s, and since then plastic innovation and production has steadily increased to an annual yield of over two hundred million tons worldwide. Yet a key property of plastics that makes them so useful also make them problematic; resistance to degradation. We need packaging that can keep bacteria away from products which could spoil or become contaminated but, at the same time, we don't want waste material which will never break down. We want products that are strong and light, such as the polymers used to construct finishing nets, but we don't want that strength once the net has reached the end of its useful life.

2. ***The plastic problem is one of waste disposal.*** But to be honest: the low biodegradability of plastic is not the real problem at all. It only became a problem because in the past, and still very often today, we as humans treat plastic waste very unwisely and carelessly. And therefore, a not inconsiderable amount of plastic ends up in the environment. This is still an unsolved problem, and what we currently see globally is a problem of waste plastic accumulation – especially in the Ocean.

3. ***What makes a plastic?*** Plastic is comprised, in the main, of chains (polymers) of simple repeating units of a chemical molecule (monomers). The monomers of these chains vary from plastic to plastic, and the differences in these dictate the type of polymer. For example, it is a single atom change in the monomer molecule that determines the difference between

polyethylene (PE) and polyvinyl chloride (PVC): a chlorine atom in PVC replaces a hydrogen atom in PE.

However, not all PEs or PVCs are the same; other ingredients play a role. A range of different chemicals are added to plastics during manufacturing to change the properties of a plastic. These additives can be categorised into 4 different groups; colourants, fillers, reinforcements, and functional additives. Three of these groups are fairly straightforward; colourants are added to change plastic colour, fillers (such as talc or mica) for bulking out, and reinforcements (glass/carbon fibres) for strength. But functional additives vary considerably in the properties they provide. This groups includes flame retardants, UV stabilisers and plasticisers (to increase plasticity/flexibility), as well as a host of other properties.

4. Toxicity of plastics. Many additives, while often only included at trace amounts compared to the bulk polymer, can be toxic. In addition to this, while polymers are generally safe, unreacted residual monomers trapped in the polymer matrix, like other unbound additives, may leach out into any water in contact with the plastic. Moreover, some monomers are also known to be toxic, especially bisphenol A (BPA), which is used to make polycarbonates and epoxy resins.

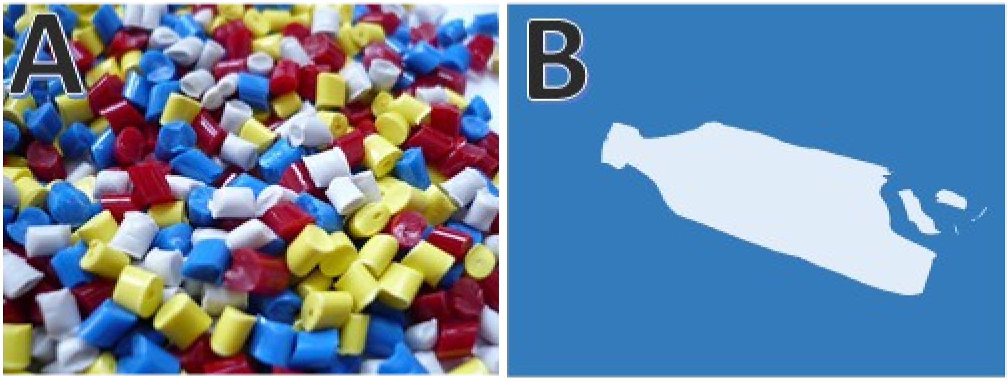
While investigations of the toxicity of certain chemicals used as monomers and additives have been carried out, much is still unknown, especially with regard to microbiological effects. It is known that additives and monomers can be degraded by microorganisms, so it is to be expected that compositions and leaching rates of such ingredients will influence the microbial communities on and around plastic waste.

5. ***Plastics in the ocean.*** The place where plastics accumulate the most is the ocean. This is because most plastic is lightweight and most commonly-used plastics float or stay suspended in water. Therefore, rivers wash a great deal of poorly managed plastic waste into the oceans. Much of this plastic waste remains floating or suspended near the surface in the ocean, although such plastic can become bio-fouled (covered in layers of bacteria and algae) and become dense enough to sink.

While it seems that a lot of waste plastic ends up on our beaches, where it is highly visible and can ruin the attractive appearance of one of our favourite places for leisure time, most waste plastic in the larger oceans gets transported by ocean current systems and eventually end up and become trapped in gyres, rotating ocean current systems. The most important of these is known as the great pacific garbage patch, and is hundreds of kilometres in size. Yet how a plastic is transported, and whether it sinks or suspends, is often dictated by particle size, and it is here where distinguishing microplastics from larger plastic debris becomes important.

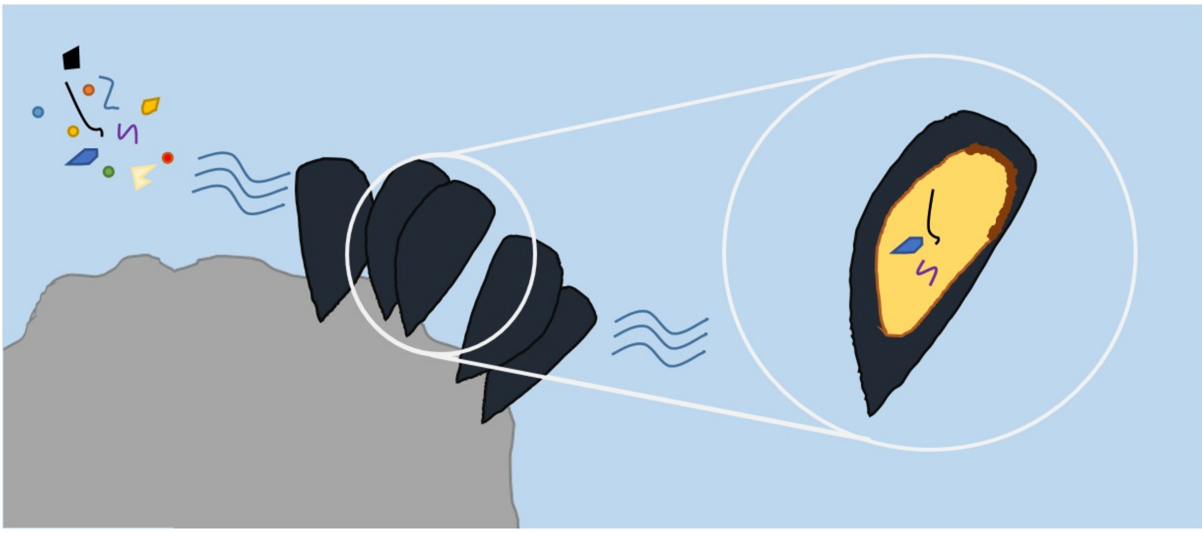
6. ***Macroplastics versus microplastics.*** There is no chemical or physical difference that distinguishes a microplastic from other plastic waste (sometimes referred to as macroplastic) aside from size. Microplastics are simply plastics below a given size (typically below 5mm, although a more modern perspective might set this to below 1 mm). Yet, despite size being the only distinction, such a distinction is very important because there are several aspects for which size has an important influence. The size of a given particle will influence how it can be transported, not only throughout environmental systems but also within an organism once ingested. Additionally, the smaller a given particle, the greater its surface area:volume ratio, which has important implications, particularly for microorganisms, and especially once a particle becomes small enough to the point where growth of microorganisms on the surface (known as biofilms) starts to influence particle characteristics, such as buoyancy.

While size alone distinguishes a microplastic from larger plastic debris, we can sub-categorise a microplastic in a number of ways. The first is primary vs secondary microplastics. A primary microplastic is one which has been directly manufactured as a microplastic and includes "microbead" exfoliators found in personal care products, such as shower gels, glitters and nurdles (plastic pellets used as a starter for manufacturing larger plastic products). Secondary microplastics include any microplastic produced by fragmentation of larger debris, including fragments, flakes and fibres. The overwhelming majority of microplastics in our environment are secondary microplastics. Note that fragmentation and degradation are different processes with different implications, as explained below.



A: Primary microplastic granules called nurdles produced as starter stock for further plastic manufacturing; B: Secondary microplastics produced by the fragmentation of larger plastic waste

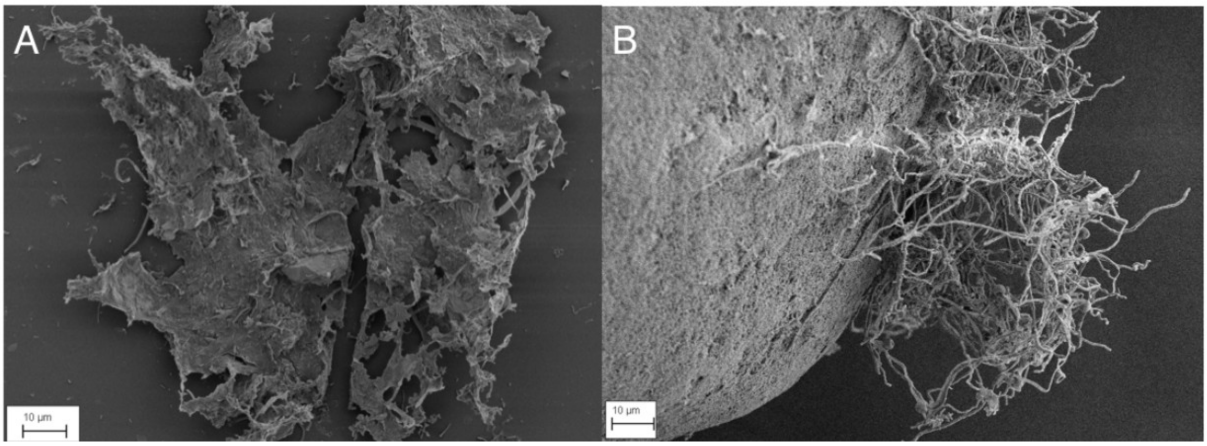
7. ***Plastics, microplastics and diet.*** Whilst we are aware that ingestion of plastic debris such as drinking straws and plastic bags is a problem for marine birds and mammals, microplastics pose a similar ingestion quandary for smaller marine life, such as filter feeders. This is not only a concern because of potential harm to these organisms, but also because some key species make it onto our dinner tables. This is an especially distasteful prospect as we often eat filter feeding species such as the blue mussel (*Mytilus edulis*) or the oyster whole, microplastics and all.



Graphic demonstrating the accumulation of microplastic in the tissues of filter feeders like mussels. Microplastics are drawn into the feeding systems of filter feeders but are not digested, and often due to entanglement of fibres and irregular shapes get caught in digestive tracks and accumulate in the animal.

Yet it is not just filter feeding organisms that ingest microplastics; fish do so as well, and while we don't eat the guts of most fish (although some types, such as whitebait, are consumed whole), microplastics may contain chemicals that can become absorbed into muscle tissue.

8. ***Microplastics as microbial vectors: the biofilm lifestyle.*** However, perhaps the most important way in which the size of microplastics has a particularly important influence is by providing microbial biofilms with dispersal ability. A biofilm is simply a collection of microorganisms (bacteria, fungi and, particularly in a marine context, microalgae) which grow on a surface, living within a sticky framework of proteins, polysaccharides and nucleic acids. These grow everywhere on all kinds of surfaces, to the point where some marine structures (such as boat hulls) require special coatings containing high amounts of antimicrobial ingredients (in the form of antifouling paints and coatings) to prevent biofilm growth. Thus biofilms grow on plastic waste, including microplastics.



Scanning electron microscopy image of biofilms growing on microplastics. A: bacterial biofilm growing on a plastic bottle fragment; B: fungal hyphae growing on a polypropylene "microbead" (primary microplastic spherule)

However, an important attribute of plastics has implications for such biofilms; plastics are generally low-density. Some of the most commonly used and environmentally abundant plastics, such as polyethylene and polypropylene have very low densities (~0.9 g/cm^3) in comparison to water (1 g/cm^3), and especially seawater (~1.03g/cm^3). This means that even particles with a substantial biofilm are still likely to remain buoyant and be transported long distances by currents, i.e. plastics, and especially microplastics, can act as microbial transport vectors.

The concern surrounding the subject of microplastics as vectors is primarily that these are long-lasting, highly mobile particles, more so than any normally-occurring particles, and this means there could be the potential for microplastics to transport microorganisms and/or adhered chemicals from an area where this wouldn't be a problem to an area it would. This issue is analogous to the long-distance transport of diverse species of marine microbes, plants and animals by ships in their ballast water.

At the moment, there is little information on the long-distance transport of microbes in microplastics biofilms, and hence poor predictive power, since microbial biofilms are highly dynamic and very much dependent on surrounding conditions. Moreover, such studies are challenging in multiple ways: in experimental approach, design, logistics and analytical technologies. Nevertheless, research on this issue is absolutely needed: until more is known, the potential implications of vector transport of microorganisms by microplastics is a concern that should not be forgotten when considering the microplastics problem as a whole.

9. ***The enormous quantity of plastics in the environment is the challenge.*** The main concern with plastics and microplastics, as opposed to other much more demonstrably detrimental marine pollutants, like pharmaceuticals or heavy metals, is the sheer quantity, especially since this is only expected to increase. So while microplastics may not be a particularly toxic pollutant, dose makes the poison, and this dose is set to increase substantially.

Most studies that have demonstrated some kind of reduced fitness effect in marine organisms have used concentrations well in excess of current environmental levels. So while there isn't yet so much that can currently be said about microplastic toxicity and microbial implications, plastic in the oceans is increasing so dramatically that at some point, if nothing changes, such toxicity levels might be reached, especially if it appears that microbial influences are found to be more problematic than what has so far been shown. However, the question of whether such levels would ever be reached is not only based on how much plastic continues to be added to the oceans, but also on how much is removed, and the way most natural polymers are "removed" is by biodegradation.

10. ***Fragmentation of plastics.*** As mentioned earlier, larger plastic items break down via a process known as fragmentation, into smaller plastics and eventually microplastics. This happens most often due to a combination of UV radiation combined with physical forces. The reason is that plastics exposed to sunlight become brittle as UV light starts to break chemical bonds in the hydrocarbon polymer and this, combined with wave action, causes the plastic to break apart where the polymer chains are weakest. However, the overall amount of plastic remains mostly unchanged: it just exists in more pieces.

Fragmentation occurs comparatively quickly at the ocean surface, because this is where UV light is most intense and where physical forces are most pronounced. However, a large amount of plastic migrates to deeper waters or to the bottom of the ocean, because either lighter plastics like PE or PP have become bio-fouled to the point where they are no longer buoyant, or the plastic is already at a density which sinks in seawater, such as PET (polyethylene terephalate), the polymer from which plastic bottles are made. Since UV irradiation is absorbed by the water column, it does not penetrate deeper waters, which also are calmer than surface waters. Without the UV irradiation and physical abrasion, such plastics fragment extremely slowly, perhaps taking hundreds or thousands of years. So even if plastic pollution of the seas instantly ceased, fragmentation alone wouldn't reduce plastic in the oceans in any meaningful way.

11. ***Microbial degradation of plastics.*** Microorganisms, especially bacteria and fungi (often in association), are the final clean-up crew. While our eukaryotic cells are good at breaking down certain polymers, like starch, microorganisms are there at the very base of food webs, often obtaining their energy from some of the most basic carbon molecules; there are even some bacteria (called methanotrophs) that obtain their food from the most basic hydrocarbon of all: methane. Hydrocarbon metabolisers are an important link to the fate of plastics and microplastics because plastic is made of long chains of hydrocarbons. Biodegradation is the process by which large molecules are broken down in the environment and it is this process, mediated by microorganisms, which is responsible for eventual plastic decomposition.

Our cells need to transport the molecules we need for energy (namely polysaccharides) into our cells before we can break them down, using our enzymes, into glucose which is used in respiration. However, bacteria degrade large polymeric substrates outside of their cells by growing directly on them and releasing onto them enzymes that break them down into smaller products that can be assimilated. Bacteria have evolved to biodegrade compounds much larger than those eukaryotic cells can manage, and this means that initial molecule size isn't much of an issue for them. Indeed, we each have millions of gut bacteria to help us do this job, and some animals, such as ruminants like cows, sheep and giraffes that only eat vegetation, have highly specialised gut bacteria for breaking down particularly large bio-polymers like cellulose that make up the bulk of their food.

12. ***But plastics are hard to degrade.*** Part of the reason we find plastics so useful is also the reason they are environmentally problematic; they are very resistant to biodegradation. This is because most synthetic polymers have very closed chemistry, with no easy low-energy ways to break bonds and start hydrolysing plastic polymers. However, this doesn't mean that under certain conditions plastics will never biodegrade, and examples are available of specific situations where certain plastics have been shown to be hydrolysed by microbial activity.

Some plastics are more readily attacked than others; for example, PET is much more readily degradable than PE, although most examples of microbial degradation even of PET require temperatures >50 ºC, so such biodegradation of plastic waste in the oceans in such situations is not possible. As mentioned, microbial activity is highly influenced by environmental conditions, and circumstances where plastics biodegrade without parameter manipulation are very rare.

In order for microorganisms to evolve the necessary enzymatic toolkit to meaningfully metabolise carbon from plastics, there must be a strong and consistent environmental pressure for a very long time. Plastics have really only been around for 70 years, and serious accumulation of plastic in the ocean is a phenomenon seen only over the last few decades. Evolutionarily-speaking, this is not a very long time for bacteria to evolve capacities to degrade plastics. In addition, in most cases, and especially in the ocean, evolutionary selection pressure is not very pronounced, since there are other sources of more chemically-accessible carbon, i.e. more appetising food for bacteria.

13. ***Discovery of plastic-degrading microbes.*** Yet, despite these caveats, recent discoveries of microorganisms living on and metabolising plastic have been reported. The most notable is the 2016 discovery of the first PETase (PET-degrading enzymes) from the bacterium *Ideonella sakaiensis* strain 201-F6, which was found in sludge near a bottle recycling plant in Japan.

Two aspects are notable concerning this discovery. Firstly, this was a chance discovery in a sample rather than an experiment with defined parameters, meaning that this enzyme had evolved in natural conditions to directly degrade PET. Secondly, since PET has only been in production since the 1970s, this shows that, under the right selection pressure, such evolution of plastic-degrading enzymes is happening currently, and suggests that in other places where the evolutionary pressure and plastic accumulation are high, other such enzymes may also be evolving.

Since this discovery, scientists have already been able to mutate these PETases into more efficient versions. So the idea that plastics may in the future biodegrade has credence. Yet it must be recognised that where plastic accumulates most prolifically (in the oceans), evolutionary pressure may be substantially less potent and expectations should be accordingly adjusted.

Additionally, as mentioned, PET, while considered extremely resistant to biodegradation, is much more chemically-accessible than something like PE or PP, and given how prominent these plastics are in plastic waste and particularly microplastics, the expectation that nature may eventually solve plastic pollution for us through microbial enzymatic evolution is optimistic, verging on fanciful.

14. ***Tackling the microplastic problem***. While it remains an open question about whether microplastics currently pose a crisis, it is undeniable that plastic pollution generally, and microplastic pollution specifically, is a problem that will need to be solved. Microplastics are prevalent across our planet and especially in our seas and oceans, even making it into the guts and tissues of animals, including some of the species we like to put on our dinner tables. While the dangers of such particles are, as far as has so far been shown, fairly low, the sheer environmental load and the expected systematic increase, combined with very slow rate of decomposition and low expectation of evolutionary help in the form of microbial enzymes means that the problem is only going to get worse.

We don't yet have a good understanding of whether (and if so what types of) plastics select for enrichment of pathogenic or antimicrobial resistant microorganisms, and whether microplastics can act as a vector for such organisms. Current scientific concerns for these are low. However, the topic is virtually unstudied and, given how prevalent microplastics are and will increase to be, if such problems are found to exist, the ramifications could be huge. As such, whether we are already in crisis or not, there are a number of actions that can be taken now to help mitigate the plastics-microplastics problem.

a. **Reduce plastic use**. This is something obvious and already widely publicised. Yet it is by far the most impactful everyday action that one can take. But it should be noted that it is not just the reduction of large and obvious plastic (like plastic bags or bottles) which should be reduced where possible. Products which already contain (or are) microplastics should be particularly avoided where possible. Facewashes and shower gels which contain microplastics should be avoided (although bans on these in the EU are culminating), plastic clothing should be avoided or washed more sparingly. When glitter is needed, natural options should be preferred, and when not possible should not be rinsed down sinks during clean-up, but properly disposed in normal refuse. Realistically, we can reduce our plastic use, but often this is difficult, inconvenient and at times simply not possible. Therefore, for the plastic that we do use, how it is handled at end-of-life is vitally important.

b. **Reduction of plastic waste reaching the ocean**. As mentioned, microplastic-containing products should not be washed down drains but disposed of in a properly managed way. Landfills near waterways should be discouraged, as should be the use of wastewater treatment plant sludge in agriculture, since this is highly contaminated with microplastics. In general, the adoption of extra filtration steps designed to reduce microplastics during wastewater treatment should be encouraged, possibly also built into washing machines to reduce release of synthetic clothing fibres. More legislation, but especially enforcement, is also needed to police the dumping of plastic waste by ships in the ocean, especially fishing gear. In fisheries where this is an established issue, avoid buying seafood from that region: *incentivise responsible behaviour*!

c. **Improve recycling**. While plastic recycling has been established for decades, its implementation is still far from ideal. Most single-use plastic items still have little thought put into how effective they can be recycled, and include materials which can be recycled combined with materials that cannot. This can make recycling them, a process already with little financial rewards, even less economically viable or overtly challenging.

In fact, for many years most of the western worlds' plastic waste was shipped to China for recycling because recycling it in many developed nations was and still is a negative investment, i.e. the process of recycling costs more than the end product is worth (e.g. see:

http://sdg.iisd.org/news/sdg-index-report-calls-for-eu-wide-vnr-by-2023/). In 2017, China ended this policy, and it is unclear now what happens with most of the worlds' plastic recycling. It has been shown already that some is sold to poorer nations to be dumped out of the public eye or burnt, a process which has enormous pollution and climate change implications.

Recycling costs can be brought down by better technologies, but by far the best way is to support policies which put the recycling requirement on the companies producing the product, greatly incentivising pro-recycling design choices. Even if no such policies are in existence to support, the best everyday action to imitate such a change would be to "vote with your wallet", and purchase products with good prospects for recycling over other which don't.

Visual depiction of the goals needed to tackle the plastic, and by extension microplastic, problem: a. reduction of plastic use, especially by switching from plastic to non-plastic products; b. reduction and increased effective management of plastic waste, especially discarded fishing gear, from accumulating in the environment; c. increasing support for products that can be easily and economically recycled; d. increasing research on microbial biofilms (on microplastics), with a focus on degradation of plastic or plastic-like biopolymers. Based on the findings obtained, new plastics may be developed that degrade in the environment, since corresponding enzymes already exist there; e. increasing research on biodegradable plastics, in particular adapted to the already existing biodegradation potentials in the environment; f. increasing research into plastic-degrading enzymes. While some goals are standalone (blue arrows), others rely heavily on each other (see the green arrow pathway) and provide an example of how basic (exploratory) science paves the way for applied (problem-tackling) science.

d. **Support research on microbial biofilms on (micro)plastics**. Despite the fact that plastic biodegradation has not been demonstrated for the ocean yet, basic exploratory research is always to be encouraged, because it is not possible to know beforehand how important a potential discovery might be. History is littered with examples of accidental or unintended findings kick-starting huge scientific developments. It may well be that in some plastic biofilm lives a new, plastic-degrading bacterium awaiting discovery. Therefore, supporting funding for further plastic biofilm research, however basic, is a worthy goal.

In addition, and maybe even the most promising approach, microbial potentials for degrading polymers in the ocean as a whole should be further investigated in detail. Based on these findings, corresponding new and right from the beginning designed plastics may be developed that are actually degraded later in the environment. This directly leads to biodegradable plastics:

e. **Develop and promote the use of biodegradable plastics**. Biodegradable plastics generally fall into 2 categories. Firstly, plastics which have synthetic-like properties but are made from natural polymers (i.e. protein- or polysaccharide-based) are very biodegradable but sometimes lacking the rigidity, stability or strength of traditional polymers. Secondly, plastics made either using extracts made by microorganisms or from fossil resources can have good properties but can still sometimes be lacking in required properties which traditional petrochemical polymers have, making their use still somewhat limited. For use in food and medicine, this can be a deal-breaker.

Compounding this, most biodegradable plastics are also significantly more expensive to produce than their traditional counterparts, and in packaging there is little incentive for companies to use less stable, more expensive plastics. Buying sometimes more expensive biodegradable plastic packaged products over others encourages companies to switch to biodegradable plastics when viable, is an incentivising policy each one of us can adopt immediately.

Looking to the future, the support of research to develop plastics (see point e) alongside degrading enzymes already identified in the environment (see point d) and optimised for greater performance in natural conditions (see point f) is perhaps the most effective approach for eventually producing an uncompromising plastic which would nevertheless not burden the environment.

f. **Promote research on plastic-degrading enzymes.** In addition to the discovery of new and promising enzymes, research is needed to improve efficiency and conditions by which such enzymes can operate, to reach a point where enzymes are a viable tool for dealing with plastic waste on a mass scale.

Not all plastics can be recycled, even if the economic case for recycling is improved. What to do with plastic waste which cannot be meaningfully recycled is still an open question, and at the rate it is produced, filling landfills with such plastic is a poor option. If enzymes can be developed which can effectively convert such non-recyclable plastics into other useful or bioavailable compounds, this would provide a solution for a problem which, as of yet, has none. Funding for such research should be encouraged.

Relevance for Sustainable Development Goals and Grand Challenges

- **Goal 3. Ensure healthy lives and promote well-being for all at all ages**. While we are currently lacking definitive evidence for health impacts of plastics and microplastics (though 'plasticisers', such as phthalates, have been implicated in a range of health issues (https://www.theguardian.com/lifeandstyle/2015/feb/10/phthalates-plastics-chemicals-research-analysis), the sheer quantity of plastics in the environment has the potential to negatively impact health, especially if microplastics are eventually shown to exhibit properties detrimental to health.
- **Goal 12. Ensure sustainable consumption and production patterns**. Despite recycling schemes, plastic production is currently the antithesis of the circular economy: it is largely classic linear production: production–use–discard. Sustainability absolutely requires solutions that do not include release into the environment.
- **Goal 14. Conserve and sustainably use the oceans, seas and marine resources for sustainable development.** The greatest **form of** plastic pollution is that of the oceans, with marine animal life and diversity severely impacted. Effective policy, legal, technical and logistical barriers that prevent plastic waste accessing waterways and hence marine systems must be urgently devised and implemented.

Potential Implications for Decisions

1. ***Individual***
   a. should I buy food and other items packaged in plastic?
   b. if this is necessary, should I check the packaging information to see if the packaging is biodegradable?
   c. should I use bags and other containers that are not biodegradable?
   d. should I use personal care and household products that contain microplastics?

2. ***Community policies***
   a. education campaigns on the environmental issues of plastics
   b. provision of state-of-the-art recycling facilities
   c. discouragement of local shops and businesses from using non-recyclable plastics

3. ***National policies***
   a. transition from non-degradable to degradable plastics and its incentivization
   b. consequential transition to a circular economy
   c. support of research on the development of better and less expensive plastic substitutes
   d. prohibition of the export of wastes, especially plastic wastes

Pupil Participation

1. ***Class discussion of the issues associated with plastic pollution***

2. ***Pupil stakeholder awareness***

a. Plastic pollution has negative consequences for several SDGs. Which of these are most important to you personally/as a class?

b. Can you think of anything that might be done to reduce these consequences?

c. Can you think of anything you might personally do to reduce the environmental footprint of plastics you feel are essential?

The Evidence Base, Further Reading and Teaching Aids

J. Eales, et al. 2022. Human health impacts of exposure to phthalate plasticisers: an overview of reviews. Environ Int 158: 106903 (https://doi.org/10.1016/j.envint.2021.106903

Harrison, J.P. et al. 2018. Microplastic-associated biofilms: A comparison of freshwater and marine environments. In Freshwater Microplastics, part of The Handbook of Environmental Chemistry series. Springer. Vol 58, pp 181 – 201 (https://doi.org/10.1007/978-3-319-61615-5_9)

Glossary

Biodegradation	The process by which substances are broken down into simpler and smaller sub-units by the actions of biological life, often microorganisms
Eukaryote	Organisms whose cells, unlike bacteria, contain membrane-bound organelles and an enclosed nucleus.
Fragmentation	The process by which substances are broken down into simpler and smaller sub-units by the actions of physical forces, such as wind or water erosion or UV radiation
Hydrocarbon	Any molecule made up of a carbon backbone saturated by hydrogen atoms
Macroplastic	A plastic larger than 5 mm
Methanotrophes	Microorganisms which get their energy (carbon source) from methane
Microplastic	A plastic smaller than 5 mm
Monomer	Small and simple molecules which make up repeating units of larger molecules called polymers. Monomer can be thought of as links in a polymer chain.
PE	Polyethylene, the most commonly-produced and used plastic
PET	Poly(ethylene terephthalate), a plastic typically hard and clear and used commonly for plastic bottles
Phalates	A group of chemicals typically added to plastics to increase durability.
Plasticisers	A group of chemicals added to plastics to change physical properties increasing functionality, often making a brittle plastic more pliable or flexible
Polymer	Large, chain-like, substances made up of simplistic repeating molecules called polymers. Polymers can be thought of as a chains made out of monomer-links
polysaccharides	A group of polymers made up of sugar monomers like glucose, commonly

	referred to as carbohydrates
PP	Polypropylene, the second-most commonly used plastic
Ruminants	Organisms with 4-chanmber stomachs known for utilising bacteria to ferment food during digestion.