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Perspective

Plastic pollution requires an integrative systems approach to understand and mitigate risk

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To date, much effort has been placed on quantifying plastic pollution and understanding its negative environmental effects, arguably to the detriment of research and evaluation of potential interventions. This has led to piecemeal progress in interventions to reduce plastic pollution, which do not correspond to the pace of emissions. For substances that are used on a global scale and identified as hazardous, there is a need to act before irreversible damage is done. For example, the history of dichlorodiphenyltrichloethane's (DDT) use has demonstrated that legacy chemicals with properties of persistence can still be found in the environment despite being first prohibited 50 years ago. Despite the growing evidence of harm, evidence to inform actions to abate plastic pollution lag behind. In part, this is because of the multifaceted nature of plastic pollution and understanding the connections between social, economic and environmental dimensions are complex. As such we highlight the utility of integrative systems approaches for addressing such complex issues, which unites a diversity of stakeholders (including policy, industry, academia and society), and provides a framework to identify to develop specific, measurable and time-bound international policies on plastic pollution and meet the ambitious yet necessary goals of the UN Plastic Treaty.

The continued and increasing quantities of plastic waste in managed systems and the environment has gained widespread attention and demand for change among the public, policymakers and industry [1,2]. Despite this awareness, use and generation of plastic waste continues to escalate [3]. Over the past 20 years there has been a considerable body of research dedicated to understanding how plastic pollution affects the natural world. Early studies focussed on determining the sources and distribution of plastics in natural systems along with their environmental transport and fate [4–8] and they have documented the ubiquitous presence from the deepest parts of our ocean to the highest mountain peaks [9–11].

Despite decades of research, our understanding of the impact of plastic pollution on the natural world remains incomplete. There is a general agreement among scientists that plastics have detrimental impacts on aquatic and terrestrial organisms and ecosystems [12–14], yet the specific mechanisms of action are not always clear at a cellular level. Given the diversity of chemical (polymer, additives) and physical (size, shape, topography) properties of plastics, concerns emerged about the ability of plastics to act as vectors for other hazardous chemicals [15] or pathogens [16] that could adversely affect organisms upon exposure. Questions exist surrounding how chronic plastic exposure at sub-lethal concentrations can lead to bioaccumulation, or even biomagnification, and how impacts may manifest when coupled with other global change stressors such as climate change or ocean acidification [17,18]. Despite these uncertainties there is a growing consensus that we have sufficient knowledge to justify action to reduce plastic leakage [19–21].

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For any substance that is used on a global scale and identified as hazardous, there is a need to act before irreversible damage is done to ecosystems, and lessons from other chemicals may apply to plastics. Consider two examples that are not directly linked to the issues with plastics, but which have analogies to the plastic pollution crisis. The application of dichlorodiphenyltrichloethane (DDT) is credited for preventing the spread of malaria and saving millions of people's lives. However, concerns of its overuse leading to negative ecological effects became apparent as early as 1945 [22] just two years after industrial scale production started. However, it was not until 1970 that DDT was first banned [23], following which evidence emerged indicating links between DDT exposure and adverse human health effects [24,25]. In recent years perfluoroalkyl and polyfluoroalkyl substances (PFAS), a broad group of >9000 chemical compounds [26], have been shown to adversely affect human health [27]. Due to the number of chemical substances, it is not pragmatic to perform environmental risk assessments on each chemical [28], leaving a paucity of data and hindering the implementation of regulations, despite concerns over their potential toxicity emerging as early as the 1960s [29]. A similar scenario is present with plastics, which encompass 10 000 monomers, additives and processing aids used in the life cycle of a product, many of which have not been widely studied [30], leading to a dearth of environmental risk data. It is clear that plastic products can bring societal benefit [31] and production continues at an insurmountable rate. The associated accumulation of end of life plastics has led to the breaching of the planetary boundary for novel entities (such as micro- and nanoplastics) [32]; consequently business simply cannot continue as usual. However, it is interesting to note that most of the benefits that are derived from the use of plastics could be achieved without the accumulation of end of life plastics in the natural environment — in short the problem is not about not using plastics it is about starting to use them more responsibly than we have to date.

In all three cases presented above, it is the mismanagement of the chemicals throughout their life cycle which can lead to environmental problems. For the case of DDT, its environmental persistence has meant that 30 years after its widespread use was banned, it is still detectable in the environment [33]. A similar scenario is occurring for PFAS. For plastics; to avoid their increasing pollution, which has the potential for global ramifications [32] appropriate action needs to occur now, but how best do we identify and prioritise these actions?

A shift in the research perspective regarding environmental safety from that of linear, sequential thinking (i.e. problem formulation/characterization and then solving it if required), to a more precautionary and integrated approach whereby solutions to potential problems are investigated earlier in hazard identification is required. Plastic pollution has commonly been defined as a waste, resource, economic and a societal problem [34,35]. Framing the plastic pollution crisis from predominantly these viewpoints promotes different solutions. For example, viewing plastic as a waste problem may encourage clean-up activities and lead to improvements in waste management infrastructure and practises. On the other hand, plastic framed as a societal problem prompts responses that raise awareness and reduce consumption of plastic (behavioural change, levies, bans) [34,35]. Defining the plastic crisis from just one viewpoint neglects the interconnections between economic, societal, and environmental dimensions of plastic pollution, and fails to make marked progress to developing effective solutions to plastic pollution [36].

To date, local and national policies have largely focussed on banning specific, often single-use, items such as plastic bags, straws and cotton swabs [37–39]. Legislation has been passed in a number of countries, including the UK and US, to ban microplastics in rinse-off cosmetics, e.g. microbeads in facial scrubs [37,40]. The campaign received widespread cross-sectoral support because the removal or substitution of microbeads was relatively inexpensive and straightforward [41–43]. It is projected that the majority of plastics in the environment are derived from mismanaged waste [44] and therefore banning these specific items may not be tackling the root cause of the systemic issue of plastic pollution. The microbead ban has also received criticism as it only tackles one application of the diverse and complex contaminant that is 'microplastics', which has been compared with banning one specific use of a pesticide (i.e. in the home), while leaving the market saturated with other diverse pesticides that require continued assessment for their environmental persistence and toxicity [45]. Overall, the progression of these fractional measures does not correspond with the pace of plastic emissions.

Understanding the multifaceted nature of plastic pollution and the connections between social, economic and environmental dimensions are complex. How the issue of plastic pollution is framed (i.e. as a waste, resource, societal or economic problem) is largely dependent upon the views and goals of the stakeholders involved. As such, it is vital to unite a diversity of stakeholders (i.e. industries, policymakers, academics, consumers) and disciplines such as natural sciences, material design, social sciences, economics and humanities (Figure 1). Holistically drawing together these separate areas brings a greater understanding of the

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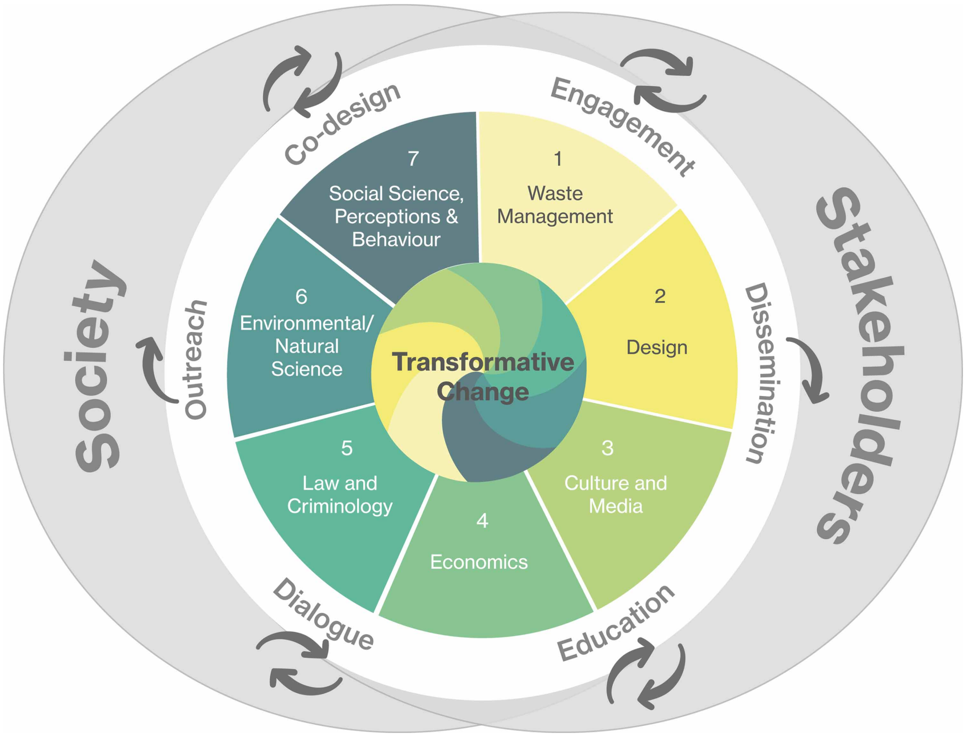

Figure 1. A conceptual summary illustrating how society and stakeholders (i.e. industry, policy, academia) interact at different levels, and the unity required between disciplines such as natural science, social science, economics and humanities to ensure positive transformative change in the plastic life-cycle.
Arrows depict the flow of information, which is largely a two-way process.

opportunities available and the barriers for change. On the other hand, it undoubtedly adds a complexity, and potentially competing interests, when evaluating solutions.

The adoption of an integrative systems approach provides a useful tool to cut through systemic complexity and understand the dynamics and connections between processes, and as such provides an inclusive and consolidative way to look at problem-solving [46]. Systems thinking has been used to better understand linkages between air pollution and non-communicable disease [47], shipping-related pollution [48] and where there may be leverage points for change [49]. More recently, this approach has been used to identify priority areas across different plastic life-cycle stages, e.g. within the product design, production, use and end-of-life [50] in order to achieve a circular economy, and facilitate the development of regulations [51]. System approaches provide a framework for the convergence and exploration of scenarios to reduce plastic pollution from waste, resource, economic and societal perspectives, to inform where tangible and effective actions lie across the life-cycle of plastic.

A life-cycle view is central to the recent resolution to establish an international legally binding treaty to end plastic pollution by 2024 [20,52]. With limited time and resources, and varying political willingness of those United Nations Member States, establishing which actions may yield the greatest reduction in plastic pollution are required. Utilising an integrative system approach will facilitate with the identification the leverage points where transformative changes can be implemented to cap virgin plastic production [19] and prevent leakage into the environment [20,53] in order to achieve the ambitious yet necessary goals of the UN Plastic Treaty [52].

In summary, a great deal of effort has been placed on understanding the negative effects of plastic pollution in ecosystems, to the detriment of the early development and evaluation of interventions. Thinking to date has predominantly been siloed, but the adoption of integrative systems approaches that consider the interrelations between problems and solutions from a diversity of disciplines (e.g. material design, social sciences, economics and humanities, industry and policy in addition to the natural sciences) are required to change the life cycle of plastic use from linear to a circular economy, and to develop specific, collaborative, measurable and time-bound global interventions on plastic pollution.

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Competing Interests

The authors declare that there are no competing interests associated with the manuscript.

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Abbreviations

DDT, dichlorodiphenyltrichloethane's; PFAS, polyfluoroalkyl substances.

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