sometimes refer to "T-shaped skills"—deep in one field but with a breadth that enables collaboration and application across many fields. The approach recommended in the editorial would cut off the broad arms of the T.

To improve the way physics programs prepare students for their careers, the J-TUPP report provides a well-researched road map of recommendations. To improve the US educational system, the data on career outcomes suggest that rather than moving away from broad-based education outside a student's major, the system would better serve students by more closely emulating liberal arts colleges.

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Promising polymers also pose problems

As a physical chemist familiar with polymers, I enjoyed the commentary "The promise of polymers" by Timothy Lodge (PHYSICS TODAY, December 2017, page 10). Those molecules, with their remarkable versatility and properties, have contributed much to human

society to date and promise even more wonders for the future. As an environmentally concerned citizen, however, I was disappointed with the short shrift given to the environmental problems caused by plastics—just two sentences in the three-page article.

Some 8 million metric tons of plastic waste currently enter the world's oceans from land-based sources each year. The accumulation of that nonbiodegradable substance threatens, at a minimum, marine populations, which are already under stress from overfishing, ocean warming and acidification, and chemical pollutants.

Despite decades of discussion about developing biodegradable plastics, particularly for the packaging of foodstuffs and consumer items, neither industry nor academia has come up with an affordable plastic that is sufficiently stable for its purpose yet will biodegrade in a reasonable amount of time after its use. Many plastics, such as polyethylene, are nearly 100% pure hydrocarbons, yet an environmentally safe technique has not been developed to use them as a fuel source on a large scale. In addition, no serious attempt has yet been made to remove plastic from the ocean gyres, where it has been accumulating in concentrations sufficient to make a cleanup feasible. Given today's available talent and technology, those three shortcomings are remarkable.

The rosy future of plastics, as presaged in the movie *The Graduate* and aptly described by Lodge in his commentary, could be a very mixed blessing if we end up soiling our nest. With more than two billion additional humans predicted to arrive on our planet before the population stabilizes, the accumulation of plastics on land and in the oceans is likely to accelerate, and the garbage patch twice the size of Texas in the Pacific Ocean will continue to grow unless the problem is addressed by government and industry and by the polymer chemists, physicists, and engineers themselves. Thus, in my opinion, the promise of polymers remains unfulfilled.

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▶ **Lodge replies:** Richard Neumann stresses a very important environmental concern, one that I noted in my Commentary but could not discuss at length in such a short piece. For more information, I encourage readers to consult the 2016 NSF workshop report *Frontiers in Polymer Science and Engineering*,[1] which places "societal needs" front and center.

Polymeric materials, like most advanced technologies, are accompanied by potential negative consequences associated with misuse. Environmental contamination is certainly topmost among them. In a real sense, we are victims of our success: Hydrocarbon polymers such as polyethylene and polypropylene deliver an amazing array of property combinations and at a remarkably low price; thus they are used in myriad applications, including the tens of millions of tons of packaging used annually. The essentially negligible cost in packaging does not reward proper disposal, while inherent physical and chemical robustness prevent degradation on reasonable time scales.

Neumann chides industry and academia for failing to "come up with an affordable plastic that is sufficiently stable for its purpose yet will biodegrade in a reasonable amount of time." Today there is no such material; even the most affordable is still significantly more expensive than polyolefins. Our market economy is quite ruthless at suppressing societally desirable innovations that cost even a small amount more, if the cost is borne by the individual consumer but the benefit is shared indirectly and over a longer time span.

In the short and medium terms, therefore, progress in addressing the serious problems associated with disposal of plastics is more likely to come from public-policy initiatives and regulatory action than from laboratory innovation. That said, an increasing number of skilled researchers are tackling the issues, and the subject merits an increasing share of our research investment.

Reference

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