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Reflections on bioengineering's disruptiveness

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The debate on whether science has become less disruptive is white-hot, prompting us to reflect on how such observation mirrors in an inherently multidisciplinary field such as bioengineering.

Assessing the degree of disruptiveness in science is fundamentally different than evaluating disruptive innovation in markets — from which the definition of disruptiveness originates[1] — as 'value' has a different meaning and means of quantification in business settings. A similar distinction holds when comparing basic and applied science; the latter — especially bioengineering — is inter-multidisciplinary and more difficult to evaluate with regard to disruptive advances. The 'usefulness' (or eventual disruptiveness) of bioengineering research may not be immediately evident, as the aim of technology-oriented science is mainly to 'solve' problems rather than discovering new knowledge[2]. Moreover, large teams — common in interdisciplinary research — are less likely to produce disruptive science[3], pushing bioengineering, an inherently multidisciplinary and applied field, further down the 'disruptiveness scale'. However, as it is unclear if the process of innovation and disruptiveness in customer-oriented industrialized products applies to the more regulated and incentivized health-care market (for example, for interventional medical devices and in particular, prosthetic heart valves, it does not[4]), the criteria of disruptiveness across different science disciplines might be worth reassessment.

Biomedical and health-care research have experienced fundamental changes in the past years, many of which have been driven by disruptive engineering advances. The fast-paced shift from centralized diagnostics and therapeutics to more personalized treatments has been galvanized by advances in patient-specific in vitro model systems (for example, organoids) and cell therapies (adoptive cell transfer and chimeric antigen receptor T cell technologies). Similarly, the emergence of smart wearables and the Internet-of-Things, combined with a huge leap in computational and data processing power, has further accelerated the switch to a more digital, remote and consumer-centred care.

Engineering also played a key role in the creation of entire new fields; for example, the drug delivery field, which emerged from a technical quest to sustainably and non-toxically release pharmaceuticals in the body[5], relies on the design of materials to control drug delivery and release in vivo. Such engineered delivery platforms, including polyethylene glycol (PEG) and lipid nanoparticles, have now become standard carrier components for vaccines and other pharmaceuticals. Following a similar materials-mediated approach, the idea of combining materials, cells and biomolecules to restore or replace biological tissues resulted in the new field of tissue engineering[6], which in turn, fuelled the development of new manufacturing techniques, such as 3D bioprinting.

From a more mechanistic perspective, the design of engineered extracellular matrices and synthetic microenvironments[7] for fundamental biology studies has led to a paradigm shift (either in a Kuhnean or more literal definition of the term) in how biomedical researchers view the role of biophysical cues in mediating cellular behaviour, a glimpse of which can be caught by the growing usage of (materials-based) 3D cell culture models compared to 2D cultures. Similarly, questioning of the relevance of the enhanced permeability and retention effect in cancer nanomedicine[8], the discovery of the accelerated blood clearance phenomenon after repeated administration of PEG-based molecules[9], or the finding that an immediate fibrotic body response after biomaterials implantation compromises medical devices' function[10], have all challenged long-lasting central paradigms in their own respective areas.

> **"Bioengineering has changed the way biomedical science is conducted, disruptively or not"**

Surely, these disruptive shifts cannot be claimed by any particular field, as these were joint efforts of multidisciplinary teams; however, the central role of bioengineers in driving these advances is equally undeniable. The ability of the bioengineering community to work at the cross-section of medicine, biology and engineering, has contributed to an open mindset, proven by the fact that, despite being a young field, it has already changed the way biomedical science is conducted, disruptively or not.

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