Achieving synergistic biopolymer functions using systems chemistry

Biology succeeds by maintaining intricate networks of chemical and structural information far from equilibrium. The guiding premise of the highlighted manuscript[1] asks whether synthetic and materials chemistry will be able to achieve a bottom-up construction of alternative networks that capture the versatile functionality and adaptability of biological systems. Such systems would not only allow for new methods for manufacturing and selecting versatile materials, but also reshape our understanding of Darwinian evolution. A new field of systems chemistry has emerged over the last decade that may address these challenges. Already, remarkable biology-emulating behaviors, such as molecular oscillation, dynamic information storage, fuel-driven molecular motors, and physical phase driven molecular selection have been achieved.

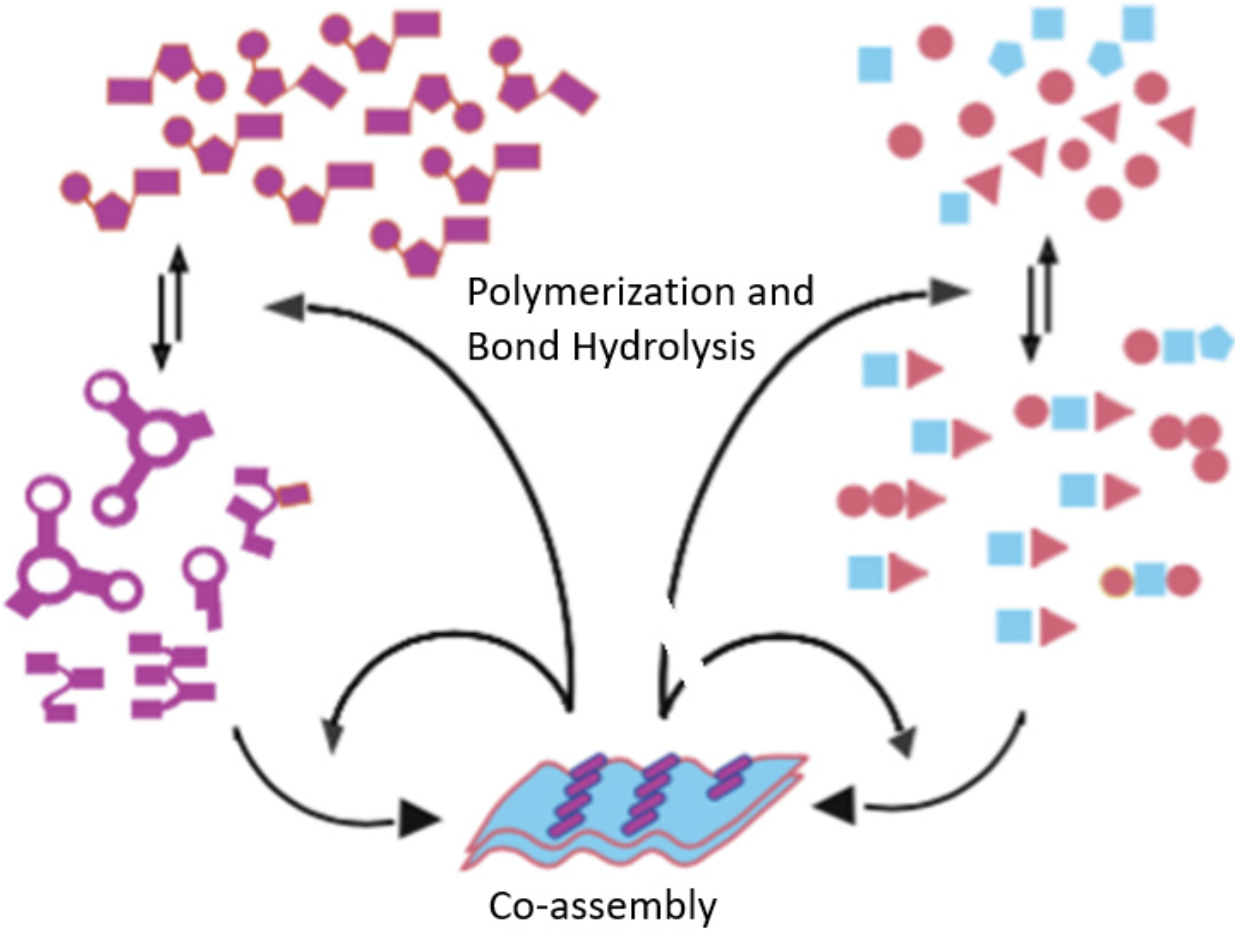

Fig. 1. Peptide (right) and nucleic acid (left) synergy diversifies biopolymer synergy.

As remarkable as these achievements are, mutualistic interdependencies are ever-present across all biological scales, from diverse associations in eukaryotic microbiomes to expansive aquatic communities and human societies. These molecular mutualisms are seen as foundational to Biology's Central Dogma. Re-engineering these macromolecular synergies remains a major challenge for synthetic biology, but creating them with simple chemical components and scaffolds presents the challenge for systems chemistry. By combining dynamic chemical networks (DCN) of information flow with dynamic phase networks (DPN) of biopolymer assembly, the essential elements of a viable cell, this article outlines a scheme to achieve alternative synergistic biopolymer functions complementary to those found in biology.

Synthetic DCNs have been inspired by the beautiful systems of gene regulation and autocatalytic feedback of biology, and new alternative networks for the storage and processing of information have emerged. Much as polymerases retain editing functions that improve fidelity, simpler synthetic networks have been achieved with reversible bonds, including disulfides, thioesters, and imines, that can be accurately kinetically trapped. These synthetic information templates remain responsive to environmental inputs and have given rise to autocatalytic, cross-catalytic, and even conformational mutation reaction pathways for storing and processing molecular information. While these DCNs have achieved novel means for the amplification of chemical information, the transition to mutualistic systems that might capture the diversity achieved with supramolecular composite scaffolds necessary for biological-like functionality remains.

DPNs underpin the architecture of the multi-component supramolecular co-assemblies contained in living cells, e.g. diverse membrane bilayers, replication complexes, and the ribosome. Figure 1 outlines the co-assembly of proteins and nucleic acids into such co-assemblies, and the highlighted manuscript develops the 2-step nucleation process as one that underpins biopolymer assembly and sets the stage for a process leading to more complex co-assemblies. The manuscript discusses the combination of chemical and phase networks central to the functioning of a minimal cell, and sets the stage for asking if these combined networks are capable of mimicking the essential elements of progressive amplification, mutation, and selection of chemical information for a sustained chemical evolution.

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Publication

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