Essays in Biochemistry (2022) **66** 703–705
https://doi.org/10.1042/EBC20220200

PORTLAND PRESS

Editorial

A special issue of *Essays in Biochemistry* on evolutionary developmental biology

Alistair P. McGregor[1], Alexandra D. Buffry[2] and Renske M.A. Vroomans[3]

[1]Department of Biosciences, Durham University, South Road, Durham DH1 3LE, U.K.; [2]Department of Biological and Medical Sciences, Oxford Brookes University, Oxford OX3 0BP, U.K.; [3]Sainsbury Laboratory, University of Cambridge, 47 Bateman Street, Cambridge CB2 1LR, U.K.

Correspondence: Alistair P. McGregor (alistair.mcgregor@durham.ac.uk)

Evolutionary developmental biology (or evo devo) is a broad field that aims to understand how developmental processes evolve and how this underpins phenotypic change and organismal diversification. This encompasses a need to understand theoretical concepts in evolutionary biology and how tissues, cells, genes, proteins and regulatory elements function and evolve. The articles in this special issue review key topics in the field of evo devo including advances in theory and methodology as well as our latest knowledge about molecular, cellular and organismal functionality and diversification.

The contemporary field of evolutionary developmental biology (or evo devo) built on the pioneering evolutionary embryology of the 19th and early 20th centuries and became formalised in the 1980s, in part catalysed by the discovery and comparative analysis of Hox genes and other ‘toolkit’ genes, and the application of molecular tools to study and compare genes and development among organisms [1,2]. In the decades since, evo devo has made great contributions to understanding the theoretical and mechanistic bases for the regulation of the development of organisms and how this has evolved from common ancestors and underlies phenotypic diversification [3–5].

Evo devo has been further empowered by the development of new sequencing technologies and the ability to precisely manipulate and functionally analyse genes using RNA interference (RNAi) and more recently genome editing approaches such as CRISPR/Cas9. Consequently, the genomes of many organisms have not only been sequenced already, but individual labs can sequence and resequence the genomes of their focal organisms for evo devo studies [2]. Similarly, transcriptomics, including single-cell approaches, are now routine and the list of organisms that can be manipulated using transgenesis, RNAi and CRISPR/Cas9 is growing fast (e.g. [6]). This means that gene expression and function can now be studied basically in any organism, generating unprecedented opportunities to compare and understand development and evolution. Evo devo also continues to make an important contribution to the theory underlying concepts including the evolution of novelties, homology, heterochrony, convergent evolution, co-option and pleiotropy.

The idea for this collection was born from the timeliness of celebrating what evo devo has achieved and its great future potential to harness the advantages of new technologies and approaches to more fully understand the drivers and consequences of developmental evolution both theoretically and mechanistically. However, there is great potential in multidisciplinarity in biology and while evo devo has embraced and utilised data and knowledge from a wide range of fields, it can profit further from knowledge about the molecules and their interactions in cells; hence, a special issue in *Essays in Biochemistry*.

This special issue reflects the great diversity in the evo devo field in both theory and empirical work as well as the range of organisms and foci on both classic and emerging questions and concepts.

A key goal of evo devo is to identify the genetic and developmental mechanisms underlying the evolution of phenotypic differences between species, including organ size and shape. Masly and Azom review

Received: 12 October 2022
Revised: 12 October 2022
Accepted: 18 October 2022

Version of Record published:
08 December 2022

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https://doi.org/10.1042/EBC20220200

advances in identifying the genes and cellular mechanisms responsible for differences in the beak morphology among Darwin's finches, a classic example of adaptive morphological evolution, and the rapid evolution of insect reproductive structures [7].

Mallo's review revisits the Hox genes to explore how the activity of these genes contributes to phenotypic diversity in vertebrates [8]. This highlights recent new insights into the role of these genes in fin and tetrapod limb evolution, and axial extension in zebrafish and mice [8].

Colizzi et al. focus on the evolution of novelty, a classic but enigmatic question in evo devo [9]. They review computational models that explore different aspects of novelty and argue that continuing advances in computational evo devo mean there is great potential to help decipher the mechanisms for the evolution of novelty and contribute to building a broader theory for this important evolutionary question [9].

The article by Woollard and Baker discusses the key role gene duplication plays in developmental evolution [10]. In their review, they explore the evolution and fate of duplicated genes and insights into the contribution of paralogues to organismal development and evolution [10].

The article by Frankel and Preger-Ben Noon pursues the idea that chromosomal rearrangements, that lead to disruption of topologically-associating domains (TADs), can create novel expression patterns through the generation of new regulatory interactions [11]. They further discuss this important idea from an evolutionary standpoint, whereby TAD rearrangements may be selected for during the course of evolution due to the creation of advantageous phenotypes [11].

The article by Fairnie et al. showcases the multifaceted nature of flower phenotype [12]. The molecular processes that pattern the distribution of pigments and the mechanics that govern cell and cuticle shape, ultimately affect the interactions of the plant with the abiotic environment, with pollinators, predators, and the prey of carnivorous plants. The review discusses these aspects and the mechanisms by which the molecular processes may have evolved [12].

When plants conquered land, they evolved the ability to grow in three dimensions, which enabled the diversification of plant form. The review by Moody discusses what the moss *Physcomitrium patens* can tell us about the genetic toolkit that enabled this transition [13].

Colgren and Burkhardt examine the highly debated topic of the evolutionary origin of neurons by integrating recent studies from non-bilaterian animals to form predictions about when and how the first neurons arose [14]. They discuss new and advancing technologies, such as single-cell omics, which will be integral to understanding the history of this cell type [14].

Finally, Nedelcu discusses key concepts such as the evolution of multicellularity through a cancer perspective, for example, mechanisms that have evolved to suppress cancer and how the existence of cancer may have influenced cellular evolution [15]. This article highlights the importance of an evo devo framework in cancer research and how bridging the gap between these fields could provide insights into cancer treatments and prevention [15].

We hope you enjoy this special issue in *Essays in Biochemistry* and that it highlights the success to date and great potential of evo devo in the next decades.

Competing Interests

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

Abbreviations

evo devo, evolutionary developmental biology; RNAi, RNA interference; TAD, topologically associating domain.

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