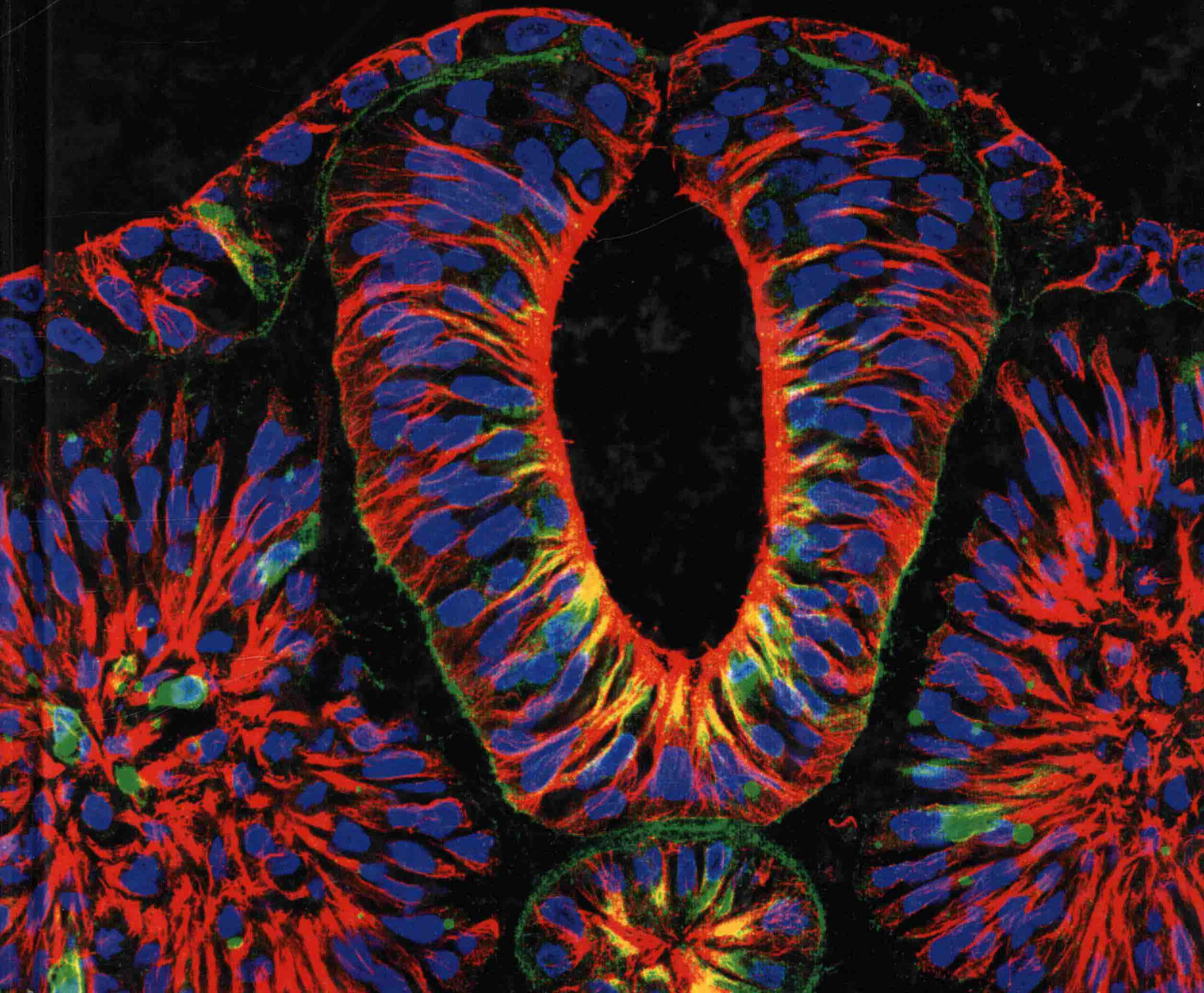


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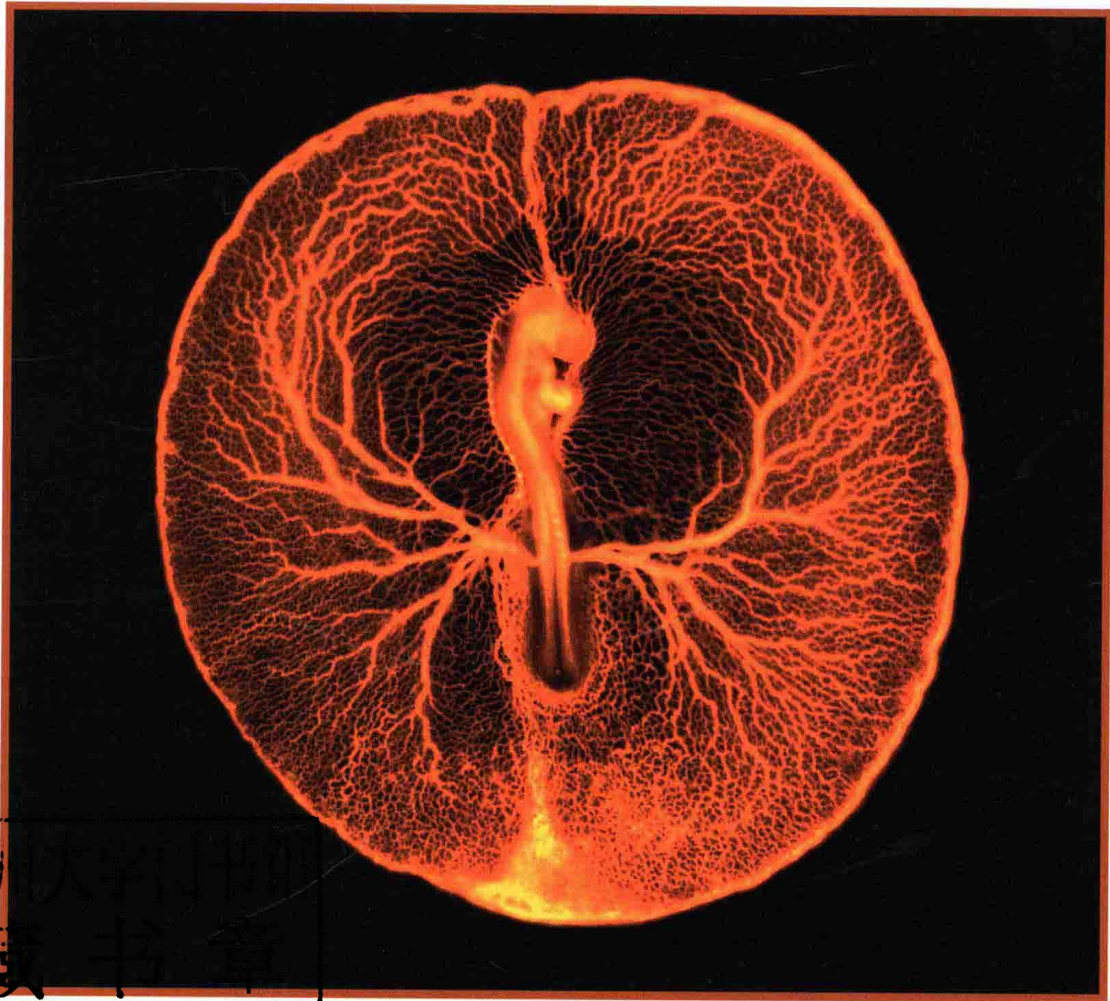
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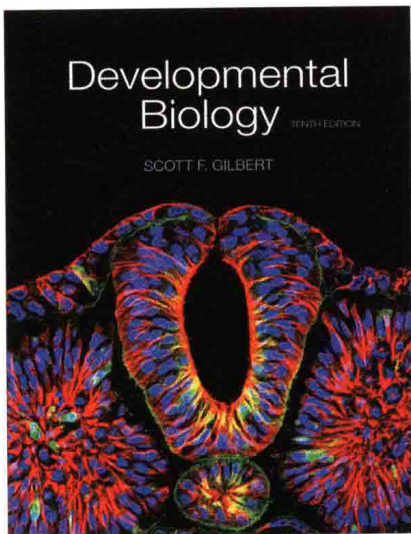


SCOTT F. GILBERT

Swarthmore College and the University of Helsinki



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The Cover

Cross-section of neural tube formation in a 2-day chick embryo. This confocal micrograph shows the neural tube (which will become the animal's central nervous system) closing at its most dorsal (top) region. The blocks of cells on either side are the somites, which will form muscles, vertebrae, and dermis. The upper cells become the epidermis (outer skin). Cell nuclei are stained blue, the microtubules of the cytoskeleton are red, and the vitronectin of the extracellular matrix appears green. Photograph by M. Angeles Rabadán and Elisa Martí Gorostiza, Instituto de Biología Molecular de Barcelona-CSIC.

The Title Page

Fluorescence micrograph of a late 2-day chick embryo (about 45 hours after the egg was laid, at which point the heart has begun to beat). The vascular system of this embryo was revealed by injecting fluorescent beads into the circulation. The three-dimensional effect was achieved by superimposing two separate images. Photograph by Vincent Pasque. Used with permission of The Wellcome Institute.

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Developmental Biology

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3.

To Daniel, Sarah, David, and Natalia

Preface

Change is the law of life. And those who look only to the past or present are certain to miss the future.

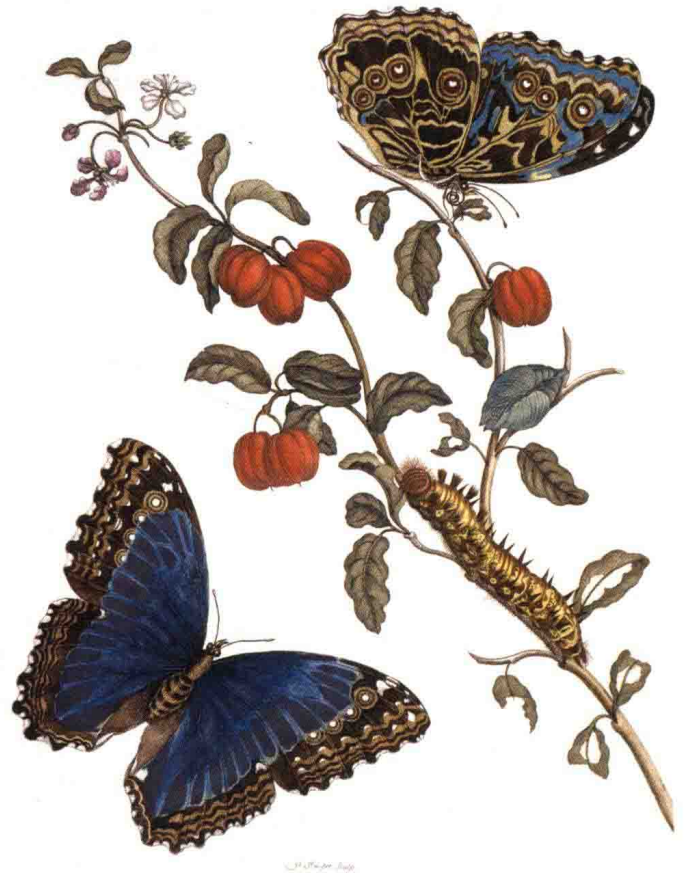
JOHN FITZGERALD KENNEDY (1963)

Metamorphosis is a time of redefinition and dramatic developmental transition. Caterpillars go from crawling and eating to flying and mating; tadpoles go from swimming to hopping, developing new muscles as their old ones decay. Today there's a feeling in the air that developmental biology is about to undergo another metamorphic molt. Don't panic!

I don't know what caterpillars experience as their new molt gives them wings. I don't know how a tadpole feels when it is about to become a frog. But I do know how developmental biology feels when it is about to undergo a major change, and this is how it feels today. It felt this way as I first wrote this textbook between 1980 and 1985. There were hints back then that developmental biology was about to change in a big way. Recombinant DNA was coming of age. It was becoming possible to identify and add new genes into an organism, and to take genes away. In 1985, the first edition of *Developmental Biology* had no mention of transcription factors or paracrine factors—but it mentioned the research that led to our discovery of them. Transcription factors entered the book's second edition three years later, and paracrine factors appeared in the next edition, three years after that. Between 1985 and 1991 the form of developmental biology changed from experimental embryology to developmental genetics. Our metamorphosis had occurred. Even journals changed their names.

My sense today is that the present metamorphosis will transform developmental genetics into an as yet unnamed developmental science that will integrate anatomy, physiology, genetics, cell biology, systems theory, genomics, and structural biology. Development has always been a science of syntheses and relationships, and these will be major themes for *all* science in the twenty-first century. Developmental biology will become a "biology without borders." The new developmental biology may be simultaneously molecular, ecological, evolutionary, and physiological. In fact, I would be surprised if it were not. As Mark Lewandoski told me at a recent meeting, "Developmental biology is dead. Long live developmental biology!"

Metamorphic change is in the nature of science. From within the larva, the rudiment of a new organism emerges. I



A plate from *Metamorphosis Insectorum Surinamensium* (1705) by the artist and scientist Maria Merian. She was one of the first scientists to document that caterpillars, pupae, and butterflies were different life cycle stages of a single organism.

hope this book helps to bridge those epistemes, the older and the newer way of approaching development. For me personally, the metamorphosis can hardly have occurred at a more appropriate time. Thirty years ago, as I started writing the first edition, I had a 2-year old child and a new job. Now that child has a 2-year old child and a new job. Revolution is nothing less than the turning of the cycle, and metamorphosis is the act of renewal. Long live developmental biology!

Acknowledgments

In book publishing, as in animal development, there are two types of relationships, the instructive and the permissive. Instructive relationships change the information in the product. They shape the phenotype. The reviewers listed on the following page have played this instructive role to great effect, letting me know what research is coming to the fore, reassuring me when my interpretations of data were sound, and correcting me when they were not. Such input both stabilizes and alters the content of the book, and to these reviewers I owe a huge debt of gratitude. If my book has some “OMG, how did he know that?” moments, the reviewers are the ones to credit. If there are any “WTF, why is this still being cited?” moments, I’m most likely the one to blame.

Permissive relationships don’t change the information content, but enable that information to come into being. These are the transcription, translation, scaffolding and patterning apparatuses. Since the early editions of this book, my words, sentences, and paragraphs have been queried, clarified, rearranged, reordered, and realigned by Carol Wigg of Sinauer Associates. Carol’s work on important biology textbooks deserves some kind of award for making biology accessible to the reader. It’s an honor to have her work on my book. I have also been incredibly fortunate to have Elizabeth Piereson as copyeditor. She has an eagle eye, a sense of humor, and an uncanny ability to point out discrepancies hundreds of pages apart and make you smile at your own mistakes.

This is a beautiful book, and I can say that because it is not my doing. It is due in large part to the many wonderful photographs my generous colleagues continue to supply. It is also due to Chris Small and his production staff at Sinauer, especially designer Joan Gemme. Also at Sinauer, Johannah Walkowicz coordinated the academic reviews and course input for this revision, while Marie Scavotto and Nancy Asai of marketing made sure everyone knew the new edition was coming along.

The original vision of what this book could be and its evolution from its instar in 1985 has been directed by Andy Sinauer in collaboration with myriad reviewers and editors (and of course the author). Andy’s many longstanding relationships with leading scientists (Andy doesn’t “lose”

authors) testify to his integrity and his standards for excellence, which have set a high bar few others can reach.

Like developmental biology, textbook publishing is undergoing a metamorphosis. I like to think this book helped usher in the age of electronic publishing when, back in the mid-1990s, we offered embedded websites in the text. The original website was a Gopher Wiki, and I had a map on my wall of all the biology websites then in existence. Today this book has its own large website, www.devbio.com, maintained by Jason Dirks, Nate Nolet, and the ever-growing number of Associates at Sinauer who work in multimedia and electronic formats. Among many other things, this expansive site allows the reader immediate access via links to PubMed to most of the original references cited in the book.

Also online is the wonderful Vade Mecum³, created as a laboratory resource by Mary Tyler and Ron Kozlowski. This is the low-cost “electronic laboratory manual” for developmental biology laboratories, and it should also be looked at for its remarkable movie footage of the development of model organisms.

The administration of Swarthmore College and the University of Helsinki went above and beyond the call of duty in providing me with the facilities to write this book. Both venues remain full of stimulating people and great opportunities to continue learning. I have also been blessed with remarkable students who have never been shy about asking questions. Many of the footnotes in this book began as answers to questions posed by savvy students. Other footnotes attempt to highlight connections between developmental biology and other fields of study, particularly the perspectives offered by the humanities, which demand that we think about the context of what we do.

This is the tenth edition of *Developmental Biology*, and “what a long strange trip it’s been.” Either there is much more material to integrate than there used to be, or I’m getting older and slower (I’m sure it must be the former). The book is done, and I am looking forward to seeing my friends and family again! My wife, Anne Raunio, has been incredibly patient, and there seem to be all sorts of things around the house that need fixing.

SCOTT GILBERT

Reviewers of the Tenth Edition

It is no longer possible (if it ever was) for one person to comprehend this entire field. As Bob Seger so aptly sings, “I’ve got so much more to think about ... what to leave in, what to leave out.” The people who help me leave in and take out the right things are the reviewers. Their expertise in particular areas has become increasingly valuable to me. Their comments were made on early versions of each chapter, and they should not be held accountable for any errors that may appear.

Ehab Abouheif, *McGill University*

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labs.devbio.com

MARY S. TYLER and RONALD N. KOZLOWSKI

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Brief Contents

PART ONE ■ QUESTIONS Introducing Developmental Biology 1

- CHAPTER 1 Comprehending Development: Generating New Cells and Organs 5
- CHAPTER 2 Differential Gene Expression in Development 31
- CHAPTER 3 Cell-Cell Communication in Development 69

PART TWO ■ SPECIFICATION Introducing Cell Commitment and Early Embryonic Development 107

- CHAPTER 4 Fertilization: Beginning a New Organism 117
- CHAPTER 5 Early Development: Rapid Specification in Snails and Nematodes 153
- CHAPTER 6 The Genetics of Axis Specification in *Drosophila* 179
- CHAPTER 7 Sea Urchins and Tunicates: Deuterostome Invertebrates 217
- CHAPTER 8 Early Development in Vertebrates: Amphibians and Fish 241
- CHAPTER 9 Early Development in Vertebrates: Birds and Mammals 285

PART THREE ■ THE STEM CELL CONCEPT Introducing Organogenesis 319

- CHAPTER 10 The Emergence of the Ectoderm: Central Nervous System and Epidermis 333
- CHAPTER 11 Neural Crest Cells and Axonal Specificity 375
- CHAPTER 12 Paraxial and Intermediate Mesoderm 415
- CHAPTER 13 Lateral Plate Mesoderm and the Endoderm 449
- CHAPTER 14 Development of the Tetrapod Limb 489
- CHAPTER 15 Sex Determination 519
- CHAPTER 16 Postembryonic Development: Metamorphosis, Regeneration, and Aging 549
- CHAPTER 17 The Saga of the Germ Line 591

PART FOUR ■ SYSTEMS BIOLOGY Expanding Developmental Biology to Medicine, Ecology, and Evolution 627

- CHAPTER 18 Birth Defects, Endocrine Disruptors, and Cancer 635
- CHAPTER 19 Ecological Developmental Biology: Biotic, Abiotic, and Symbiotic Regulation of Development 663
- CHAPTER 20 Developmental Mechanisms of Evolutionary Change 689

Contents

PART ONE QUESTIONS

Introducing Developmental Biology 1

CHAPTER 1

Comprehending Development

Generating New Cells and Organs 5

The Cycle of Life 6

A Frog's Life 6

- Gametogenesis and fertilization 6
- Cleavage and gastrulation 7
- Organogenesis 10
- Metamorphosis and gametogenesis 11

"How Are You?" 12

- Comparative embryology 12
- Epigenesis and preformation 12
- Naming the parts: The primary germ layers and early organs 14
- The four principles of Karl Ernst von Baer 15

Keeping Track of Moving Cells: Fate Maps and Cell Lineages 17

- Fate maps 19
- Direct observation of living embryos 19
- Dye marking 19
- Genetic labeling 19
- Transgenic DNA chimeras 23

Evolutionary Embryology 23

- Embryonic homologies 25

Medical Embryology and Teratology 27

- Genetic malformations and syndromes 27
- Disruptions and teratogens 27

CHAPTER 2

Differential Gene Expression in Development 31

- Evidence for Genomic Equivalence 32

■ SIDELIGHTS & SPECULATIONS The Basic Tools of Developmental Genetics 32

- Differential Gene Transcription 34
- Anatomy of the gene: Active and repressed chromatin 35
- Anatomy of the gene: Exons and introns 35
- Anatomy of the gene: Promoters and enhancers 37
- Enhancer functioning 39
- Transcription factor function 43
- Keeping the right genes on or off 45

■ SIDELIGHTS & SPECULATIONS Reprogramming Cells: Changing Cell Differentiation through Embryonic Transcription Factors 46

Mechanisms of Differential Gene Transcription 47

- Finding DNA regulatory sequences 48
- Differentiated proteins from high and low CpG-content promoters 48
- DNA methylation, another key on/off switch of transcription 49
- "Poised" chromatin 51

■ SIDELIGHTS & SPECULATIONS Genomic Imprinting and DNA Methylation 52

Differential RNA Processing 53

■ SIDELIGHTS & SPECULATIONS X Chromosome Inactivation: Noncoding RNAs in Transcriptional Gene Regulation 54

- Creating families of proteins through differential mRNA splicing 56
- Splicing enhancers and recognition factors 57

Control of Gene Expression at the Level of Translation 59

- Differential mRNA longevity 59
- Stored oocyte mRNAs: Selective inhibition of mRNA translation 59
- Ribosomal selectivity: Selective activation of mRNA translation 61

microRNAs: Specific regulation of mRNA translation and transcription 61

Control of RNA expression by cytoplasmic localization 64

Posttranslational Regulation of Gene Expression 65

Coda 65

CHAPTER 3

Cell-Cell Communication in Development 69

Cell Adhesion 70

Differential cell affinity 70

The thermodynamic model of cell interactions 71

Cadherins and cell adhesion 72

■ **SIDELIGHTS & SPECULATIONS** Shape Change and Epithelial Morphogenesis: “The Force Is Strong in You” 76

Cell Migration 78

Cell Signaling 79

Induction and competence 79

Reciprocal induction 81

Epithelial-mesenchymal interactions 82

Paracrine Factors: Inducer Molecules 84

Signal transduction cascades: The response to inducers 84

Fibroblast growth factors and the RTK pathway 84

The JAK-STAT pathway 86

The Hedgehog family 88

The Wnt family 90

The TGF- β superfamily 92

■ **SIDELIGHTS & SPECULATIONS** Cell Death Pathways 94

Other paracrine factors 96

Juxtacrine Signaling 96

The Notch pathway: Juxtaposed ligands and receptors 96

■ **SIDELIGHTS & SPECULATIONS** Juxtacrine Signaling and Cell Patterning 97

The Extracellular Matrix as a Source of Developmental Signals 99

Integrins: Receptors for extracellular matrix molecules 100

The Epithelial-Mesenchymal Transition 101

The Cell Biology of Paracrine Signaling 102

Coda 104

PART TWO SPECIFICATION

Introducing Cell Commitment and Early Embryonic Development 107

Levels of Commitment 107

Autonomous Specification 109

Conditional Specification 110

Morphogen Gradients and Conditional Specification 113

Syncytial Specification 114

Summary 115

The fast block to polyspermy 129

The slow block to polyspermy 130

Calcium as the initiator of the cortical granule reaction 132

Activation of Egg Metabolism in Sea Urchins 134

Release of intracellular calcium ions 134

■ **SIDELIGHTS & SPECULATIONS** Rules of Evidence: “Find It, Lose It, Move It” 136

Effects of calcium release 137

Fusion of Genetic Material in Sea Urchins 139

Internal Fertilization in Mammals 140

Getting the gametes into the oviduct: Translocation and capacitation 141

In the vicinity of the oocyte: Hyperactivation, thermotaxis, and chemotaxis 143

CHAPTER 4

Fertilization

Beginning a New Organism 117

Structure of the Gametes 117

Sperm 117

Sperm anatomy 118

The egg 120

Recognition of egg and sperm 123

External Fertilization in Sea Urchins 124

Sperm attraction: Action at a distance 124

The acrosome reaction 125

Recognition of the egg's extracellular coat 126

Fusion of the egg and sperm cell membranes 128

One egg, one sperm 128

- The acrosome reaction and recognition at the zona pellucida 143
- Gamete fusion and the prevention of polyspermy 145
- Fusion of genetic material 146
- Activation of the mammalian egg 146

- **SIDELIGHTS & SPECULATIONS** The Nonequivalence of Mammalian Pronuclei 148

Coda 149

CHAPTER 5

Early Development Rapid Specification in Snails and Nematodes 153

Developmental Patterns among the Metazoa 153

- Sponges and the diploblastic animals 154
- The triploblastic animals: Protostomes and deuterostomes 155

EARLY DEVELOPMENTAL PROCESSES: AN OVERVIEW 155

Cleavage 155

- From fertilization to cleavage 156
- The cytoskeletal mechanisms of mitosis 157
- Patterns of embryonic cleavage 158

Gastrulation and Axis Formation 158

EARLY DEVELOPMENT IN SNAILS 161

Cleavage in Snail Embryos 161

- The snail fate map 164
- Autonomous cell specification and the polar lobe 164

- **SIDELIGHTS & SPECULATIONS** Adaptation by Modifying Embryonic Cleavage 167

Gastrulation in Snails 169

THE NEMATODE *C. ELEGANS* 170

Cleavage and Axis Formation in *C. elegans* 171

- Rotational cleavage of the egg 171
- Anterior-posterior axis formation 171
- Dorsal-ventral and right-left axis formation 172
- Control of blastomere identity 173

Gastrulation in *C. elegans* 176

CHAPTER 6

The Genetics of Axis Specification in *Drosophila* 179

EARLY *DROSOPHILA* DEVELOPMENT 179

Fertilization 180

Cleavage 180

- The mid-blastula transition 182

GENES THAT PATTERN THE *DROSOPHILA* BODY PLAN 185

Primary Axis Formation during Oogenesis 186

- Anterior-posterior polarity in the oocyte 186
- Dorsal-ventral patterning in the oocyte 186

Generating the Dorsal-Ventral Pattern in the Embryo 190

- Dorsal, the ventral morphogen 190
- Establishing a nuclear Dorsal gradient 190
- Effects of the Dorsal protein gradient 191

- **SIDELIGHTS & SPECULATIONS** The Left-Right and Inside-Out Axes 193

Segmentation and the Anterior-Posterior Body Plan 194

- Maternal gradients: Polarity regulation by oocyte cytoplasm 194
- The molecular model: Protein gradients in the early embryo 194
- The anterior organizing center: The Bicoid and Hunchback gradients 199
- The terminal gene group 201
- Summarizing early anterior-posterior axis specification in *Drosophila* 201

Segmentation Genes 202

- Segments and parasegments 202
- The gap genes 203
- The pair-rule genes 204
- The segment polarity genes 206

The Homeotic Selector Genes 209

- Initiating and maintaining the patterns of homeotic gene expression 211
- Realisator genes 211

Axes and Organ Primordia: The Cartesian Coordinate Model 212

Coda 213

CHAPTER 7

Sea Urchins and Tunicates

Deuterostome Invertebrates 217

EARLY DEVELOPMENT IN SEA URCHINS 217

Sea Urchin Cleavage 217

- Blastula formation 219
- Fate maps and the determination of sea urchin blastomeres 219
- Gene regulatory networks and skeletogenic mesenchyme specification 221
- Specification of the vegetal cells 224
- Axis specification 225

Sea Urchin Gastrulation 225

Ingression of the skeletogenic mesenchyme 226

Invagination of the archenteron 229

EARLY DEVELOPMENT IN TUNICATES 232

Tunicate Cleavage 232

The tunicate fate map 233

Autonomous and conditional specification of tunicate blastomeres 234

Specification of the embryonic axes 236

Gastrulation in Tunicates 237

Coda 238

CHAPTER 8

Early Development in Vertebrates

Amphibians and Fish 241

EARLY AMPHIBIAN DEVELOPMENT 241

Fertilization, Cortical Rotation, and Cleavage 242

Unequal radial holoblastic cleavage 242

The mid-blastula transition: Preparing for gastrulation 245

Amphibian Gastrulation 245

Vegetal rotation and the invagination of the bottle cells 245

Epiboly of the prospective ectoderm 250

Progressive Determination of the Amphibian Axes 251

Specification of the germ layers 251

The dorsal-ventral and anterior-posterior axes 251

The Work of Hans Spemann and Hilde Mangold 252

Autonomous specification versus inductive interactions 252

Primary embryonic induction 254

Molecular Mechanisms of Amphibian Axis Formation 256

How does the organizer form? 256

Functions of the organizer 261

Induction of neural ectoderm and dorsal mesoderm: BMP inhibitors 262

Epidermal inducers: The BMPs 264

■ **SIDELIGHTS & SPECULATIONS** BMP4 and Geoffroy's Lobster 266

The Regional Specificity of Neural Induction 266

The head inducer: Wnt antagonists 266

Trunk patterning: Wnt signals and retinoic acid 269

Specifying the Left-Right Axis 270

EARLY ZEBRAFISH DEVELOPMENT 271

Cleavage 273

Gastrulation and Formation of the Germ Layers 275

Axis Formation 277

Dorsal-ventral axis formation 278

The fish Nieuwkoop center 279

Anterior-posterior axis formation 280

Left-right axis formation 280

Coda 282

CHAPTER 9

Early Development in Vertebrates

Birds and Mammals 285

EARLY DEVELOPMENT IN BIRDS 286

Cleavage 286

Gastrulation of the Avian Embryo 287

The hypoblast 287

The primitive streak 287

Molecular mechanisms of migration through the primitive streak 291

Regression of the primitive streak and epiboly of the ectoderm 292

Axis Specification and the Avian "Organizer" 293

The role of gravity and the PMZ 293

The chick "organizer" and the role of fibroblast growth factors 294

Anterior-posterior patterning 296

Left-right axis formation 297

EARLY MAMMALIAN DEVELOPMENT 298

Cleavage 298

The unique nature of mammalian cleavage 299

■ **SIDELIGHTS & SPECULATIONS** The Decisions That Really Shape Your Life 300

Compaction 301

Escape from the zona pellucida 303

Mammalian Gastrulation 303

Modifications for development inside another organism 303

■ **SIDELIGHTS & SPECULATIONS** Twins and Chimeras 304

Formation of the chorion 308

Mammalian Axis Formation 309

The anterior-posterior axis: Two signaling centers 309

Anterior-posterior patterning by FGF and retinoic acid gradients 310

Anterior-posterior patterning: The Hox code hypothesis 311

The dorsal-ventral and left-right axes 314

Coda 314

PART THREE THE STEM CELL CONCEPT

Introducing Organogenesis 319

The Stem Cell Concept 319

Stem Cell Vocabulary 321

Adult Stem Cells 322

Stem Cell Niches 322

Mesenchymal Stem Cells: Multipotent Adult Stem Cells 326

Pluripotent Embryonic Stem Cells 327

Stem Cell Therapy 328

A New Perspective on Organogenesis 331

CHAPTER 10

Emergence of the Ectoderm

Central Nervous System and Epidermis 333

NEURAL PLATE AND CENTRAL NERVOUS SYSTEM 333

Formation of the Neural Tube 334

Primary neurulation 334

Secondary neurulation 339

Building the Brain 340

The anterior-posterior axis 341

The dorsal-ventral axis 343

Differentiation of Neurons in the Brain 345

Tissue Architecture of the Central Nervous System 347

Neural stem cell differentiation 347

Spinal cord and medulla organization 349

Cerebellar organization 350

Cerebral organization 351

Adult Neural Stem Cells 354

■ **SIDELIGHTS & SPECULATIONS** The Unique Development of the Human Brain 356

THE DYNAMICS OF OPTIC DEVELOPMENT: THE VERTEBRATE EYE 359

Formation of the Eye Field: The Beginnings of the Retina 360

The Lens-Retina Induction Cascade 362

Lens and cornea differentiation 364

Neural retina differentiation 364

THE EPIDERMIS AND ITS CUTANEOUS APPENDAGES 367

Origin of the Epidermis 367

The Cutaneous Appendages: Mammalian Hair 368

Hair follicles and hair generation in mammals 368

Adult stem cells and hair regeneration 369

Coda 372

CHAPTER 11

Neural Crest Cells and Axonal Specificity 375

THE NEURAL CREST 375

Specification of Neural Crest Cells 376

Regionalization of the Neural Crest 379

Trunk Neural Crest 380

Migration pathways of trunk neural crest cells 380

Mechanisms of trunk neural crest migration 380

The ventral pathway 382

The dorsolateral migration pathway 384

Cranial Neural Crest 386

Intramembranous ossification: Neural crest-derived head skeleton 388

Coordination of face and brain growth 390

Tooth formation 391

Cardiac Neural Crest 391

Cranial Placodes 392

NEURON SPECIFICATION AND AXON SPECIFICITY 394

■ **SIDELIGHTS & SPECULATIONS** The Growth Cone 394

The Generation of Neuronal Diversity 396

Pattern Generation in the Nervous System 398

Cell adhesion and contact guidance by attraction and repulsion 399

Membrane proteins: The ephrins and semaphorins 399

Guidance by diffusible molecules 400

Target selection 404

Synapse formation: Activity-dependent development 405

Differential survival after innervation: The role of neurotrophins 405

Paths to Glory: The Travels of the Retinal Ganglion Axons 407

■ **SIDELIGHTS & SPECULATIONS** The Brainbow 409

CHAPTER 12

Paraxial and Intermediate Mesoderm 415

PARAXIAL MESODERM: THE SOMITES AND THEIR DERIVATIVES 416

Formation of the Somites 417

- Where somites form: The Notch pathway 418
- Separation of somites from the presomitic mesoderm 420
- Periodicity of somite formation 420
- **SIDELIGHTS & SPECULATIONS** Coordinating Waves and Clocks in Somite Formation 421
- Epithelialization of the somites 423
- Specification of the somites along the anterior-posterior axis 423
- Differentiation of the somites 423
- Determination of the sclerotome 426
- Determination of the central dermamyotome 427
- Determination of the myotome 428
- Myoblasts and myofibers 429
- Satellite cells: Unfused muscle progenitor cells 431

Osteogenesis: The Development of Bones 432

- Endochondral ossification 432
- Vertebrae formation 434

- **SIDELIGHTS & SPECULATIONS** Mechanotransduction in the Musculoskeletal System 435

Tendon Formation: The Syndetome 436

Formation of the Dorsal Aorta 436

INTERMEDIATE MESODERM: THE UROGENITAL SYSTEM 436

The Progression of Kidney Types 438

Specification of the Intermediate Mesoderm: Pax2/8 and Lim1 439

Reciprocal Interactions of Developing Kidney Tissues 440

- Mechanisms of reciprocal induction 441

Coda 447

CHAPTER 13

Lateral Plate Mesoderm and the Endoderm 449

FORMATION AND DEVELOPMENT OF THE CIRCULATORY SYSTEM 450

Heart Development 450

- Formation of the heart fields 450
- Specification of the cardiogenic mesoderm 451
- Migration of the cardiac precursor cells 453

Heart cell differentiation 455

Fusion of the heart rudiments and initial heartbeats 456

- **SIDELIGHTS & SPECULATIONS** A Minimalist Heart 457

Looping and formation of heart chambers 457

Blood Vessel Formation 460

Constraints on the construction of blood vessels 460

- **SIDELIGHTS & SPECULATIONS** Redirecting Blood Flow in the Newborn Mammal 461

Vasculogenesis: The initial formation of blood vessels 463

Angiogenesis: Sprouting of blood vessels and remodeling of vascular beds 467

Arterial and venous differentiation 467

Organ-specific capillary formation 468

Anti-angiogenesis in normal and abnormal development 470

The lymphatic vessels 471

Hematopoiesis: The Stem Cell Concept 472

Sites of hematopoiesis 472

The bone marrow HSC niche 474

Hematopoietic inductive microenvironments 475

In conclusion 475

ENDODERM 476

The Pharynx 478

The Digestive Tube and Its Derivatives 478

Specification of the gut tissue 479

Liver, pancreas, and gallbladder 481

- **SIDELIGHTS & SPECULATIONS** Specification of Liver and Pancreas 481

The Respiratory Tube 484

Coda 486

CHAPTER 14

Development of the Tetrapod Limb 489

Formation of the Limb Bud 490

Specification of the limb fields 490

Induction of the early limb buds: Wnt proteins and fibroblast growth factors 492

Specification of forelimb or hindlimb 492

Generating the Proximal-Distal Axis of the Limb 495

The apical ectodermal ridge 495

FGFs in the induction of the AER 496

Specifying the limb mesoderm: Determining the proximal-distal polarity of the limb skeleton 497

The dual-gradient model of limb patterning 497