An Analysis of the Treatment of

Homology

in

Biology Textbooks

currently being considered for adoption by the

Texas State Board of Education

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INTRODUCTION AND EXECUTIVE SUMMARY

The following analysis examines the treatment of homology in the chapters dealing with evolution in eleven biology textbooks currently being considered for adoption by the Texas State Board of Education. The analysis asks two questions: (1) Do the textbooks treat this topic in a manner that is "free from factual errors" (Texas Education Code, § 31.023)? (2) Do the textbooks enable students to "analyze, review, and critique scientific explanations, including hypotheses and theories, as to their strengths and weaknesses using scientific evidence and information" (TEKS §112.43c(3)A)?

The analysis concludes that all eleven textbooks fail, to varying degrees, to meet the Texas requirement for critical analysis on the topic of homology. The analysis also concludes that four of the textbooks fail to comply with the legal requirement that they treat this topic in a manner that is free from factual errors.

Study Methodology

The first two pages of the analysis contain background information about the concept of homology (including references to peer-reviewed scientific literature). Each textbook is then analyzed individually, beginning with the oldest, for its treatment of this topic. The evaluations of individual textbooks are followed by a summary table comparing the results, and an appendix containing suggested language for inclusion in biology textbooks.

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This analysis was prepared by staff and fellows of the Center for Science and Culture in Seattle, WA. The Center is a project of Discovery Institute, a not-for-profit public policy organization. The Center for Science and Culture is committed to the accurate presentation of evidence and arguments for and against Darwinian evolution and its alternatives. Center Fellows include biologists, biochemists, physicists, mathematicians, philosophers and historians of science, and other scholars with Ph.D.s in their respective fields. Many of the Center's fellows also have affiliations with colleges and universities. For more information, please consult the Center's web site at http://www.discovery.org.

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Homology

Biologists since Aristotle have noticed that very different organisms may share remarkable similarities. One kind of similarity is functional: butterflies have wings for flying, and so do bats, but the two animals are constructed very differently. Another kind of similarity is structural: the pattern of bones in a bat's wing is similar to that in a porpoise's flipper, though the wing is used for flying and the flipper is used for swimming. In the 1840s, British anatomist Richard Owen called the first kind of similarity "analogy," and the second kind "homology." The classic examples of homologous structures are the forelimbs of vertebrates (animals with backbones). Although a bat has wings for flying, a porpoise has flippers for swimming, a horse has legs for running, and a human has hands for grasping, the bone patterns in their forelimbs are similar. [1]

Like other pre-Darwinian biologists, Owen considered homologous features to be derived from a common "archetype," or plan. Darwin, however, attributed homologous features to descent from a common ancestor. In fact, Darwin considered homology important evidence for evolution, listing it among the facts which "proclaim so plainly, that the innumerable species, genera and families, with which this world is peopled, are all descended, each within its own class or group, from common parents." [2]

The link between homology and common descent was so central to Darwin's theory that his followers actually re-defined homology to mean similarity due to common ancestry. According to Ernst Mayr, one of the principal architects of modern neo-Darwinism: "After 1859 there has been only one definition of homologous that makes biological sense....: Attributes of two organisms are homologous when they are derived from an equivalent characteristic of the common ancestor." [3]

Once homology is re-defined to mean similarity due to common ancestry, however, it cannot logically be used as evidence for common ancestry. As some biologists and philosophers have pointed out, it is circular reasoning to argue that similarity due to common ancestry is due to common ancestry. [4]

The best way to avoid circular reasoning would be to demonstrate that similar features are derived from a common ancestor by a particular biological mechanism. Two mechanisms have been proposed in modern Darwinian theory. According to the first, homologous features arise from similar cells or developmental pathways in the embryo; according to the second, homologous features are produced by similar genes. Since an embryo's development pathways and genes are inherited from its ancestors, these mechanism would provide the necessary link between homologous features and common ancestry.

Unfortunately, neither mechanism fits the biological evidence. Although some features regarded as homologous arise from similar developmental pathways or similar genes, as a general rule homologous features may arise from different pathways or genes, and non-homologous features may arise from similar pathways or genes. As British embryologist (and evolutionist) Gavin de Beer wrote years ago: "The fact is that correspondence between homologous structures cannot be pressed back to similarity of position of the cells in the embryo, or of the parts of the egg out of which the structures are ultimately composed, or of developmental mechanisms by which they are formed." De Beer

also wrote: "Because homology implies community of descent from... a common ancestor it might be thought that genetics would provide the key to the problem of homology. This is where the worst shock of all is encountered... [because] characters controlled by identical genes are not necessarily homologous... [and] homologous structures need not be controlled by identical genes." De Beer concluded that "the inheritance of homologous structures from a common ancestor... cannot be ascribed to identity of genes." [5]

De Beer's assessment is still accurate. Furthermore, the lack of correspondence between homologous features and similar developmental pathways or genes in general extends to limbs in particular. Although biologists generally consider the limbs of salamanders and frogs to be evolutionarily homologous, they develop according to different patterns: In frogs, the digits (fingers) develop in a tail-to-head direction, while in salamanders they develop in the opposite order. In addition, the cartilage patterns that lay the groundwork for bone are different from the beginning in the embryos of frogs, chicks and mice. As for genes: One well-studied gene that is essential for limb formation is found in animals as different as mammals, insects and sea urchins, yet no biologist considers their limbs evolutionarily homologous. [6]

Yet many biology textbooks obscure the problem by ignoring it, by indulging in circular reasoning, or by misinforming students that homology can be explained by similar developmental pathways or similar genes. The first two approaches (ignoring the problem or indulging in circular reasoning) make it difficult for students to "analyze, review, and critique scientific explanations, including hypotheses and theories, as to their strengths and weaknesses using scientific evidence and information," and thus fail to comply with TEKS §112.43c(3)A. The third approach (misinforming students that homology can be explained by similar developmental pathways or similar genes) perpetuates factual error, and thus violates the Texas Education Code, § 31.023.

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NOTES

[1] For a history of the homology concept, see Alec L. Panchen, "Richard Owen and the Concept of Homology," pp. 21-62 in Brian K. Hall (editor), *Homology: The Hierarchical Basis of Comparative Biology* (San Diego, CA: Academic Press, 1994). See also Peter J. Bowler, *Evolution: The History of an Idea,* Revised Edition (Berkeley: University of California Press, 1989).

[2]Charles Darwin, *The Origin of Species*, Chapter XIV.

[3] Ernst Mayr, *The Growth of Biological Thought* (Cambridge, MA: Harvard University Press, 1982), pp. 232, 465.

[4] See, for example, Robert R. Sokal and Peter H. A. Sneath, *Principles of Numerical Taxonomy* (San Francisco: Freeman, 1963), p. 21. See also Ronald H. Brady, "On the Independence of Systematics," *Cladistics* 1 (1985): 113-126, p. 117.

[5] Gavin de Beer, *Embryos and Ancestors,* Third Edition (Oxford: Clarendon Press, 1958), p. 152; Gavin de Beer, *Homology: An Unsolved Problem* (London: Oxford University Press, 1971), pp. 15-16.

[6] For details and references to the scientific literature, see Jonathan Wells, *Icons of Evolution* (Washington, DC: Regnery Publishing, 2000), Chapter Four, especially pp. 71-77, and Research Notes, pp. 282-284. Much of the material in this summary is taken from that book.

LIST OF TEXTBOOKS

1
William K. Purves, David Sadava, Gordon H. Orians & H. Craig Heller
Life: The Science of Biology
6th edition
Sunderland, MA: Sinauer Associates
2001
ISBN 0-7167-3873-2

2
Peter H. Raven & George B. Johnson
Biology
6th edition
Boston, MA: McGraw-Hill
2002
ISBN 0-07-303120-8

3
Neil A. Campbell & Jane B. Reece
Biology
6th edition
San Francisco, CA: Benjamin Cummings
2002
ISBN 0-8053-6624-5

4
Biological Sciences Curriculum Study
BSCS Biology: An Ecological Approach
9th edition (BSCS Green Version)
Dubuque, IA: Kendall/Hunt
2002
ISBN 0-7872-7525-5

5
Biological Sciences Curriculum Study
BSCS Biology: A Human Approach
2nd edition
Dubuque, IA: Kendall/Hunt
2003
ISBN 0-7872-8685-0

6
Joseph Raver
Biology: Patterns and Processes of Life
1st edition
Dallas, TX: J.M. LeBel
2004
ISBN 0-920008-05-4

7
Sylvia S. Mader
Biology
8th edition
Boston, MA: McGraw-Hill
2004
ISBN 0-07-121487-9

8
Alton Biggs, Whitney Crispen Hagins, Chris Kapicka, Linda Lundgren, Peter Rillero, Kathleen G. Tallman, Dinah Zike & National Geographic Society
Biology: The Dynamics of Life
Texas Edition
New York, NY: McGraw-Hill
2004
ISBN 0-07-829904-7

9
George Johnson & Peter Raven
Holt Biology
Orlando, FL: Holt, Rinehart & Winston
2004
ISBN 0-03-068264-9

10
Kenneth R. Miller & Joseph Levine
Prentice Hall Biology
Texas edition
Upper Saddle River, NJ: Pearson Prentice Hall
2004
ISBN 0-13-115291-2

11
Cecie Starr & Ralph Taggart
Biology: The Unity and Diversity of Life
10th edition
Belmont, CA: Thomson
2004
ISBN 0-534-38801-9

Textbook 1

William K. Purves, David Sadava, Gordon H. Orians & H. Craig Heller
Life: The Science of Biology, 6th edition (2001)

This book discusses homology on pages 427-428. It defines homology as similarity due to common ancestry: "Any two features descended from a common ancestral feature are said to be homologous." It also points out that some features ("homoplastic traits") may be "similar for some reason other than inheritance from a common ancestor." (p. 427) The book does not claim that homologies provide evidence for evolution; instead it acknowledges that in reconstructing possible evolutionary trees homology must be assumed (unless evidence suggests otherwise). (p. 428)

The book does not discuss hypotheses about mechanisms that might produce homologies (such as similar developmental pathways or similar genes).

SUMMARY: This book's treatment of homology contains neither factual error nor circular reasoning, though it ignores scientific problems with the concept and thereby misses an opportunity to provide students with resources to "analyze, review, and critique scientific explanations, including hypotheses and theories, as to their strengths and weaknesses using scientific evidence and information."

Textbook 2

Peter H. Raven & George B. Johnson
Biology, 6th edition (2002)

This book discusses homology on pages 15, 450, and 453. It defines homology in terms of common ancestry: "The [limb] bones are said to be homologous in the different vertebrates; that is, they have the same evolutionary origin, but they now differ in structure and function." (p. 15) Also: ""The forelimbs of vertebrates are all homologous structures, that is, structures with different appearances and functions that all derived from the same body part in a common ancestor." (p. 450)

Yet both of these passages are in sections that purport to provide students with evidence for evolution. The first is in a section entitled "Evolution After Darwin: More Evidence" (p. 15), while the second is in a section entitled ""Evidence for evolution can be found in other fields of biology." (p. 450) Though not stated explicitly, these are both subtle forms of circular argument.

The book does not discuss hypotheses about mechanisms that might produce homologies (such as similar developmental pathways or similar genes).

SUMMARY: By giving students the impression that similarity due to common ancestry is evidence for common ancestry, this book implicitly engages in circular reasoning and thereby fails to provide students with resources to "analyze, review, and critique scientific explanations, including hypotheses and theories, as to their strengths and weaknesses using scientific evidence and information."

Textbook 3

Neil A. Campbell & Jane B. Reece
Biology, 6th edition (2002)

This book discusses homology on pages 438-440, and it applies homology to the construction of evolutionary trees on 495-496.

The book defines homology in terms of common ancestry: "Similarity in characteristics resulting from common ancestry is known as homology." (p. 438) This definition occurs in a section entitled "Other evidence for evolution pervades biology" that also includes the following argument: "Surely, the best way to construct the infrastructure of a bat's wing is not also the best way to build a whale's flipper. Such anatomical peculiarities make no sense if the structures are uniquely engineered and unrelated. A more likely explanation is that the basic similarity of these forelimbs is the consequence of the descent of all mammals from a common ancestor. The forelegs, wings, flippers and arms of different mammals are variations on a common structural theme. In taking on different functions in each species, the basic structures were modified. Such anatomical signs of evolution are called homologous structures." (pp. 438-439)

This passage is not circular reasoning, because "anatomical similarities" are held up as evidence for common ancestry and defined as homologies only after common ancestry is inferred. Yet the argument is weak: It merely re-states Darwin's theory that what his scientific contemporaries considered "variations on a common structural theme" are, in fact, due to inheritance from a common ancestor. It is not at all clear how a re-statement of Darwin's theory provides evidence for evolution.

The book does not discuss hypotheses about mechanisms that might produce homologies (such as similar developmental pathways or similar genes).

SUMMARY: On the topic of homology this book does not contain factual error or circular reasoning, but by presenting theory as though it were evidence it fails to provide students with resources to "analyze, review, and critique scientific explanations, including hypotheses and theories, as to their strengths and weaknesses using scientific evidence and information."

Textbook 4

Biological Sciences Curriculum Study
BSCS Biology: An Ecological Approach, 9th edition (Green Version, 2002)

This book includes a color drawing of vertebrate limbs on p. 222, accompanied by a caption instructing students : "Use the color key to find comparable structures among the forelimb bones of these seven vertebrates." The book does not call these structures homologous, however, nor does it define homology or claim that homology is evidence for evolution. Instead, it states that such structures exhibit a "unity of pattern." On page 239, the book informs students: "Although biologists do not completely agree about the mechanisms of evolution, the overwhelming majority agree that diversity of type and unity of pattern are best explained by evolution."

The book does not discuss hypotheses about mechanisms that might produce homologies (such as similar developmental pathways or similar genes).

SUMMARY: On the topic of homology this book does not contain factual error or circular reasoning. By not even using the word "homology," however, and by essentially omitting all discussion of the topic, the book misses an opportunity to provide students with resources to "analyze, review, and critique scientific explanations, including hypotheses and theories, as to their strengths and weaknesses using scientific evidence and information."

Textbook 5

Biological Sciences Curriculum Study
BSCS Biology: A Human Approach, 2nd edition (2003)

On page 45, this book instructs students to read about homology in another text (*Modern Life: Evidence for Evolutionary Change*). On page 107, the book features a drawing of vertebrate limbs and states: "Additional evidence for biological change and the relatedness of different organisms comes from the study of comparative anatomy." The caption accompanying the drawing states: "Homologies are characteristics that suggest common ancestry." On the following page (108), the book states: "Because of their consistent similarities, biologists infer that the forelimb structure is a homology, a characteristic that is similar among different organisms because they evolved from a common ancestor."

The book does not discuss hypotheses about mechanisms that might produce homologies (such as similar developmental pathways or similar genes).

SUMMARY: On the topic of homology this book does not contain factual error or circular reasoning. The book's discussion of homology is correct and logical as far as it goes, though in its superficiality the book misses an opportunity to provide students with resources to "analyze, review, and critique scientific explanations, including hypotheses and theories, as to their strengths and weaknesses using scientific evidence and information."

NOTE: This book contains so little about evolution (it reads like a study guide keyed to other texts, rather than a textbook in its own right) that it is difficult to evaluate. Because of this, the book does not seem to fulfill the TEKS standards for teaching biology in general or biological evolution in particular.

Textbook 6

Joseph Raver
Biology: Patterns and Processes of Life, 1st edition (2004)

This book discusses homology on pages 100-101. Next to a drawing of "similar structures of limb bones of vertebrates," the book states: "Biologists compared anatomical features of vertebrate embryos…Scientists discovered that limbs, regardless of whether they are arms, legs, or wings, begin development in exactly the same way." The text goes on to claim: "Anatomical structures that have the same developmental pattern are called homologous structures. So a bat's wings, a dog's front legs, a whale's flippers and your arms are all homologous structures. It doesn't matter that their functions are all different. Knowing all vertebrate limbs develop by the same pattern helped us to understand how they all came to have the same number of bones in the same positions."

The basic message of this passage is false. In general, homologous features cannot be said to develop in the same ways. Even among amphibians, the limbs of salamanders and frogs develop by different patterns.

SUMMARY: This book's discussion of homology contains a basic factual error, so it fails to comply with Texas Education Code, § 31.023.

Textbook 7

Sylvia S. Mader
Biology, 8th edition (2004)

This book discusses homology on page 296, where it defines homology in terms of common ancestry: "Structures that are anatomically similar because they are inherited from a common ancestor are called homologous structures." In the same paragraph, the book goes on to claim that homology is evidence for common ancestry: "The presence of homology, not analogy, is evidence that organisms are related." This is circular reasoning.

The book does not discuss hypotheses about mechanisms that might produce homologies (such as similar developmental pathways or similar genes).

SUMMARY: In its discussion of homology, this book resorts explicitly to circular reasoning. Unless students are perceptive enough to catch the circularity, they will be unable to "analyze, review, and critique scientific explanations, including hypotheses and theories, as to their strengths and weaknesses using scientific evidence and information."

Textbook 8

Alton Biggs et al.
Biology: The Dynamics of Life, Texas Edition (2004)

This book discusses homology on pages 400-403 and 468. In introducing the topic, the book states: "Look at the forelimb bones of the animals shown in Figure 15.6 [which includes drawings of the forelimbs of a whale, a crocodile, and a bird, on page 401]. Although the bones of each forelimb are modified for their function, the basic arrangement of the bones in each limb is similar. Evolutionary biologists view such structural similarities as evidence that organisms evolved from a common ancestor. It would be unlikely for so many animals to have similar structures if each species arose separately. Structural features with a common evolutionary origin are called homologous structures."

This passage is not circular reasoning, because "structural similarities" are held up as evidence for common ancestry and defined as homologies only after common ancestry is inferred. The passage would be more informative if it presented as the counterpart to an evolutionary explanation the classic idea that homologies are based on a common plan, but there is nothing explicitly wrong with it.

Yet the book falls into circular reasoning, at least implicitly, when it reviews the topic of homology at the end of the chapter and the end of the unit on evolution. For example, on page 403 the "section assessment" asks: "How do homologous structures provide evidence for evolution?" Since homology has already been defined in terms of common ancestry, this question contains a circularity. Then, in the "unit review" on page 468, the book states: "Similar anatomical structures, called homologous structures, in different organisms, might indicate possible shared ancestry."

The book does not discuss hypotheses about mechanisms that might produce homologies (such as similar developmental pathways or similar genes).

SUMMARY: By relying on a study question and a review summary that give students the impression that similarity due to common ancestry is evidence for common ancestry, this book implicitly engages in circular reasoning and thereby fails to provide students with resources to "analyze, review, and critique scientific explanations, including hypotheses and theories, as to their strengths and weaknesses using scientific evidence and information."

Textbook 9

George Johnson & Peter Raven
Holt Biology (2004)

This book discusses homology on page 286. There the book states: "As different groups of vertebrates evolved, their bodies evolved differently. But similarities in bone structure can still be seen, suggesting that all vertebrates share a relatively recent common ancestor. As you can see in Figure 9, the forelimbs of the vertebrates shown are composed of the same basic groups of bones. Such structures are referred to as homologous. Homologous structures are structures that share a common ancestry. That is, a similar structure in two organisms can be found in the common ancestor of the organisms."

At the end of the chapter, in a section entitled "Study Zone: Chapter Highlights" on p. 293, the book includes under the heading "Evidence of Evolution" the following statement: "The presence of homologous structures and vestigial structures in vertebrates suggests that all vertebrates share a common ancestor." Since the book had already defined homologous structures on page 286 as "structures that share a common ancestry," this is explicitly circular reasoning.

Even worse, the caption for the drawing of vertebrate limbs (Figure 9) that accompanies the discussion of homology on page 286 states: "The forelimbs of vertebrates contain the same kinds of bones, which form in the same way during embryological development." The book thus combines circular reasoning with factual error.

SUMMARY: This book's discussion of homology contains a basic factual error, so it fails to comply with Texas Education Code, § 31.023. The book also resorts explicitly to circular reasoning. Unless students are perceptive enough to catch the circularity, they will be unable to "analyze, review, and critique scientific explanations, including hypotheses and theories, as to their strengths and weaknesses using scientific evidence and information."

Textbook 10

Kenneth R. Miller & Joseph Levine
Prentice Hall Biology, Texas edition (2004)

This book discusses homology on pages 384-385. On page 384 the book states: "Further evidence of evolution can be found in living animals. By Darwin's time, researchers had noticed striking anatomical similarities among the body parts of animals with backbones. For example, the limbs of reptiles, birds, and mammals -- arms, wings, legs, and flippers -- vary greatly in form and function. Yet, they are all constructed from the same basic bones, as shown in Figure 15-15 [which features drawings of the limbs of a turtle, an alligator, a bird, and a mammal, on the same page]. Each of these limbs has adapted in ways that enable organisms to survive in different environments. Despite these different functions, however, these limb bones all develop from the same clumps of cells in embryos. Structures that have different mature forms but develop from the same embryonic structures are called homologous structures. Homologous structures provide strong evidence that all four-limbed vertebrates have descended, with modifications, from common ancestors."

Actually, homologous structures have <u>similar</u> adult forms, but they do not necessarily develop from the same embryonic structures, so this statement has the truth exactly backwards!

<u>SUMMARY</u>: This book's discussion of homology contains a basic factual error, so it fails to comply with Texas Education Code, § 31.023.

Textbook 11

Cecie Starr & Ralph Taggart
Biology: The Unity and Diversity of Life, 10th edition (2004)

This book discusses homology on page 312. Next to a drawing of bones in vertebrate limbs, the book states: "Comparative morphology provides good evidence of descent with modification. This field of inquiry focuses on the body form and structures of groups of organisms, such as vertebrates and flowering plants. Often it reveals a similarity in one or more body parts that has a genetic basis, that reflect inheritance from a common ancestor. Such body parts are known as homologous structures."

By implying that homologous features are based on similar genes, this passage makes a basic factual error.

SUMMARY: This book's discussion of homology contains a basic factual error, so it fails to comply with Texas Education Code, § 31.023.

SUMMARY

On the topic of homology, all eleven books reviewed here fall short of providing students with adequate resources to "analyze, review, and critique scientific explanations, including hypotheses and theories, as to their strengths and weaknesses using scientific evidence and information."

In addition, the following books suffer from more serious problems:

TEXTBOOK	PROBLEM
2. Raven & Johnson	**CIRCULAR REASONING**
6. Raver	**FACTUAL ERROR**
7. Mader	**CIRCULAR REASONING**
8. Biggs et al.	**CIRCULAR REASONING**
9. Johnson & Raven	**FACTUAL ERROR and CIRCULAR REASONING**
10. Miller & Levine	**FACTUAL ERROR**
11. Starr & Taggart	**FACTUAL ERROR**

NOTE:
The BSCS Human Approach book contains so little about evolution (it reads like a study guide keyed to other texts) that it is difficult to evaluate.

APPENDIX

Suggested Language About Homology

Before Darwin published his theory of evolution in *The Origin of Species* (1859), biologists were aware that the limbs of very different vertebrates contained strikingly similar bone structures. Pre-Darwinian biologists called those similarities "homologies," and they attributed them to a common archetype or plan. Darwin, however, argued that homologies were better explained as features inherited from a common ancestor. In fact, Darwin thought that similar bone structures in vertebrate limbs provided evidence for common ancestry.

Since the time of Darwin, biologists have tended to limit the word "homology" only to similar features they think were acquired from a common ancestor. Similarities not due to common ancestry are now called "homoplasies." It is often difficult to tell whether a particular similarity is a case of homology or homoplasy, and this difficulty is a source of continuing controversy among evolutionary biologists. In any case, it is clear that once "homology" is defined as "similarity due to common ancestry," it cannot be used as evidence for common ancestry, since this would amount to saying that similarity due to common ancestry is due to common ancestry -- a form of circular reasoning.

Difficulties with the concept of homology might be overcome if we knew what mechanism produces homologous features in the descendants of a common ancestor. Two mechanisms have been proposed: similar developmental pathways, and similar genes. If similar features develop by similar pathways from similar cells in the embryos of two different organisms, then it could be argued that the features were inherited from a common ancestor and thus homologous. Alternatively, if similar features arise from similar genes in two different organisms, it could be argued that those genes were inherited from a common ancestor and the features are thus homologous.

Unfortunately, there is no neat correspondence between homology, development, and genes. Features thought to be acquired from a common ancestor (and thus evolutionarily homologous) sometimes develop by different developmental pathways or different genes, while features not thought to be evolutionarily homologous often develop from similar pathways or similar genes. In the absence of a clear mechanism to explain it, homology continues to be a controversial topic in evolutionary biology.