



## Article

*The Panda's Thumb: Design and Optimality from Plato to Endo*

# The Panda's Thumb: Design and Optimality from Plato to Endo



*Darwin and modern Darwinists such as Gould and Dawkins argue that the sub-optimality of biological structures is evidence against their having been consciously designed. Creationists and other design theorists often respond by arguing that biological structures are actually optimal. These arguments have a certain weight, as doubt has been cast upon the sub-optimality of the most popular Darwinist example, the panda's pseudo-thumb. However, conscious, and even divine, design is logically independent of optimality.*

*In fourth century BC Greece, the relationship between design and optimality was the opposite of the usual one today, as Plato believed in designed sub-optimality, and Aristotle in non-designed optimality. The tendency to confuse these issues can be traced back to Aristotle and Galen. Darwinist (and anti-Darwinist) arguments have a long history, which is generally disregarded, exemplifying the ignorant ahistoricity of much modern science.*

*One modern incarnation of [the] argument, that the sub-optimality of biological structures shows that they were not consciously designed, is a crucial component of Darwinism.*

The argument that the sub-optimality of the natural world provides evidence against it having been consciously designed has a long pedigree,<sup>1</sup> and is closely allied to the wider anti-theist argument based on the problem of evil. One modern incarnation of this argument, that the sub-optimality of biological structures shows that they were not consciously designed, is a crucial component of Darwinism. This argument was central to the thought of Charles Darwin,<sup>2</sup> and is perhaps even more so to that of many modern evolutionary biologists, particularly Stephen Gould.<sup>3</sup>

Anti-Darwinists often respond to the Darwinist argument from sub-optimality by disputing the sub-optimality of biological structures. For example, they may argue that many vestigial structures are functional,<sup>4</sup> that structures supposedly rendered sub-optimal by their ancestry, such as the vertebrate eye, are actually optimal,<sup>5</sup> and/or that there is no such thing as nonfunctional DNA.<sup>6</sup> These arguments may or may not be valid, but they are beyond the scope of

this article, the aim of which is to uncouple design and optimality, which are frequently linked in the debate between Darwinists and design theorists. William Dembski has shown that nondesign cannot be reliably deduced from non-optimality,<sup>7</sup> but I go further than he does, arguing that design and optimality are logically independent, quite apart from his suggestion of the possibility of non-apparent optimality in circumstances in which optimization is constrained. In addition, I examine the historical relationship between design and optimality, which has led to a great deal of confusion.

## Logical Independence of Optimality and Design The Possibility of Nondesign Optimality

One may reject design yet accept optimality. A striking example is provided by the giant panda's pseudo-thumb. The panda's hand has six digits, but its pseudo-thumb, the only opposable digit in a nonprimate, is considered to have evolved from the radial sesamoid bone in the wrist.<sup>8</sup> This organ was Gould's "favorite example" of imperfection due to history.<sup>9</sup> He writes:

An engineer's best solution is debarred by history. The panda's true thumb is committed to another role, too specialized for a different function to become

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an opposable, manipulating digit. So the panda must use parts on hand and settle for an enlarged wrist bone and a somewhat clumsy, but quite workable, solution. The sesamoid thumb wins no prize in an engineers' derby. It is ... a contraption, not a lovely contrivance.<sup>10</sup>

Richard Dawkins, praising Gould's essay, comments that "evolution can be more strongly supported by evidence of telling imperfections than by telling perfection."<sup>11</sup>

Hideki Endo, et al., however, now have shown this pseudo-thumb to be at least less sub-optimal than thought:

We suggest that the three functional units, and the double-pincer-like apparatus of which they are made, can be completely controlled only by the same muscular system that is found in other bear species. ... the hand of the giant panda has a much more refined grasping mechanism than has been suggested in previous morphological models.<sup>12</sup>

This presents no difficulty for Darwinism. To take a hypothetical extreme case, if every biological structure were proven to be optimal, it would be possible to explain this in Darwinian terms, as one would be able to argue that structural optimization by convergent evolutionary pathways has been followed through to completion. As Darwinism is equally compatible with optimality and sub-optimality, it is not valid to offer sub-optimality as evidence for Darwinism.

### The Possibility of Designed Sub-optimality

One can accept design yet reject optimality. The approach one takes depends on the type of designer in which one believes: nondivine designer(s) or God.

If one believes in an incompletely good, wise or powerful designer, sub-optimality presents little difficulty. This applies to John Stuart Mill's non-omnipotent "God,"<sup>13</sup> the gods of polytheistic religions, and the extraterrestrials of Erich von Däniken<sup>14</sup> and Francis Crick.<sup>15</sup> Such a belief was also a feature of the Manichaeic and classical Zoroastrian systems, with the former involving creation by an evil deity in rebellion against a good one, and the latter a conflict between good and evil deities.

Jews, Christians, and Muslims believe in the absolute goodness, wisdom, and power of God, and this doctrine, theism, also sometimes has appeared in non-Abrahamic intellectual milieus, such as Dvaita Vedanta. There are four ways in which theists may tackle the problem of biological sub-optimality, none of which are especially *ad hoc*:

First, theistic thinkers have formulated various theodicies with respect to evil. As Paul Nelson has pointed out,<sup>16</sup> some of these are equally applicable to sub-optimal biological design. For example, Augustine of Hippo<sup>17</sup> and Leibniz<sup>18</sup> argued that evil exists for a good purpose, and only appears evil to humans because we lack God's omniscience.

Second, notwithstanding the popularity of theodicy, I would argue that the main teaching to be drawn from the Bible is that questioning of God's motives is illegitimate.<sup>19</sup> This attitude is influential in most forms of Judaism and Christianity, and is dominant in Calvinism<sup>20</sup> and Islam. Clearly, if it is illegitimate to question why God permits evil, it may be equally illegitimate to question why his designs are sub-optimal.

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Third, it is possible that biological structures were designed to be optimal, but have since degenerated. For example, most creationists accept that some "vestigial" structures, such as the sightless eyes of cave fish<sup>21</sup> and the wings of ostriches, are or may be the results of intra-specific or intra-baraminic degeneration. The Christian doctrine of the Fall lends itself to this type of explanation, although the explanation could exist without this doctrine.

Fourth, one could postulate an almost unlimited range of reasons why God might have created sub-optimal structures. Three such reasons sometimes are, or have been, accepted. They are:

1. One interpretation of the Fall is that a wide range of features of the biological world are the results of human sin. The same people often believe in this as believe in the degenerate nature of sub-optimality, but it is actually a different belief, as it means that not only have structures deteriorated, but that new structures have been formed, and/or the structure and/or behavior of organisms has been drastically changed, post-creation, by either God or the Devil. One outcome of this change is sometimes seen as being the existence of carnivores,<sup>22</sup> and noxious or troublesome animals<sup>23</sup> and plants,<sup>24</sup> and another as being the leglessness of snakes.<sup>25</sup> Biblical interpretations of this type are currently accepted by many fundamentalist evangelicals and by groups such as the Jehovah's Witnesses, and they were historically taught by such Catholic theologians as Peter the Lombard, Bonaventure, and Alexander of Hales.<sup>26</sup> If one accepts this doctrine, sub-optimal design is not merely compatible with, but deducible from, Christianity.
2. Sub-optimal structures may have been designed in preparation for future use in a more advanced organism. This is accepted by some believers in guided evolution.
3. Sub-optimal structures may have been designed for future use in degenerate organisms, as taught by Plato. He wrote:



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For our creators well knew that women and other animals would some day be framed out of men, and they further knew that many animals would require the use of nails for many purposes; wherefore they fashioned in men at their first creation the rudiments of nails.<sup>27</sup>

#### Historical Relationship Between the Issues of Optimality and Design

Aristotle repeatedly asserted the functional optimality of biological structures, stating that nature (*physis*) makes nothing superfluous,<sup>28</sup> never fails,<sup>29</sup> omits nothing necessary,<sup>30</sup> and always produces the best possible workmanship.<sup>31</sup> This was a reaction against Plato's doctrine of sub-optimality.<sup>32</sup> However, Plato believed in the conscious design of biological structures,<sup>33</sup> whereas Aristotle did not. Therefore, in fourth century BC Greece, the orientation of the optimality versus non-optimality and design versus non-design debates was the opposite of today, with Plato arguing for designed sub-optimality, and Aristotle arguing for non-designed optimality.

Aristotle's belief in biological optimality was developed further by Galen:

Come now, let us investigate this very important part of man's body [the hand], examining it to determine not simply whether it is useful or whether it is suitable for an intelligent animal, but whether it is in every respect so constituted that it would not have been better had it been made differently.<sup>34</sup>

Galen repeated this argument numerous times, with the eye being perhaps his favorite example.<sup>35</sup> He was particularly dismissive of Plato, and saw himself as providing explanations where Aristotle's were unsatisfactory.<sup>36</sup> Furthermore, unlike Aristotle, he allowed no exceptions to the rule of optimality.

Aristotle and Galen were the canonical authorities in zoology and medicine, respectively, in Europe from about 1250 until about 1700. Therefore, the assumption of biological optimality was included uncritically as part of the argument that the complexity of biological structures provides evidence for theism (the argument from biological design),

when this was formulated by late-seventeenth-century English thinkers such as John Wilkins<sup>37</sup> and John Ray.<sup>38</sup> This was the first time since Roman times that any form of the argument from biological design had been formulated in the West, and it was probably the first time ever for the formulation of the fully theistic version. The assumption of biological optimality then remained an important component of the argument from biological design, and was defended in its most famous version, that formulated by William Paley.<sup>39</sup> Therefore, when Darwin and his followers rejected Paley's argument from biological design, they also rejected the logically unrelated doctrine of biological optimality. Anti-Darwinists have now followed suit in defending this irrelevant doctrine. Both sides in the creation versus evolution dispute appear to be formulating invalid arguments.

In this context, it is illuminating to look at the reaction to Endo's work in the three years since its publication. By Internet search, I found four articles in which creationists gleefully seized upon Endo's findings,<sup>40</sup> but none that offered a Darwinian perspective, suggesting that many Darwinists are genuinely embarrassed by these findings. However, the two sides are equally mistaken, and the arguable optimality of the panda's thumb offers no more evidence for conscious design than its sub-optimality did for Darwinism.

#### Three Possible Objections to the Above Argument about the Historical Relationship

1. *Aristotle did not invariably ascribe optimality to biological structures.*

Aristotle considered flatfish, molluscs, bats and seals to be sub-optimal.<sup>41</sup> This aspect of his thought is best seen as an inconsistency in, rather than a crucial component of, his thought, and was perhaps a hangover from his Platonist past. Significantly, none of his examples of sub-optimality were in humans.

Almost incomprehensibly, Aristotle explained apparent sub-optimality in terms of deviation from, rather than poor design by, nature. For example, he stated that flatfish have "twisted" heads because "they have

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their natural shape distorted."<sup>42</sup> Incidentally, this is Dawkins' favorite example, too.<sup>43</sup> Aristotle also described molluscs as "mutilated," and moving "in a manner contrary to nature."<sup>44</sup>

## 2. *Plato was not a theist.*

Plato believed in a personal creator (*demiourgos*) of the universe.<sup>45</sup> Yet in at least some phases of his thought, this creator was a non-ultimate being,<sup>46</sup> and, furthermore, he also considered biological design to have involved subordinate gods.<sup>47</sup> That he was not a true theist is irrelevant to his belief in biological design.

## 3. *Aristotle held quasi-theistic and teleological beliefs.*

Aristotle seems to have held theistic or quasi-theistic beliefs.<sup>48</sup> However, he did not believe that God affects the sublunary realm. Therefore, his theism or quasi-theism did not imply biological design.<sup>49</sup>

One could accept that Aristotle did not believe in conscious design by God (or a *demiourgos*-like quasi-God), yet still argue that he considered biological structures to have purposes, and therefore must have believed that they were consciously designed, perhaps by a minor deity. Although he discussed biological structures' purposes almost continuously in most of his zoological writings,<sup>50</sup> and occasionally in his other works,<sup>51</sup> he, however, does not seem to have been referring to *conscious* purpose.<sup>52</sup> Indeed, at points, he seems to have contrasted nature's purpose with that of a conscious agent. He wrote:

Now surely as in intelligent action, so in nature ... It is absurd to suppose that purpose is not present because we do not observe the agent deliberating. ... If the ship-building art were in the wood, it would produce the same results *by nature*.<sup>53</sup>

For just as human creations are the products of art, so living objects are manifestly the products of an analogous cause or principle, not external but internal, derived like the hot and cold from the environing universe.<sup>54</sup>

In his cosmological and philosophical writings, the first cause or final end is probably God or a quasi-God. Yet in his biology, it seems simply to be heredity. He wrote:

For any living thing ... the most natural act is the production of another like itself ... That is the goal towards which all things strive, that for the sake of which they do whatsoever their nature renders possible.<sup>55</sup>

Whenever there is plainly some final end, to which a motion tends should nothing stand in the way, we always say such final end is the aim or purpose of the motion; and from this it is evident that there must be a something or other really existing, corresponding to what we call by the name of Nature. For a given germ does not give rise to any chance living being, nor spring from any chance one; but each germ springs from a definite parent and gives rise to a definite progeny.<sup>56</sup>

Aristotle's thought is rather confused, and the works of Gotthelf,<sup>57</sup> Balme,<sup>58</sup> and Cooper<sup>59</sup> must be referred to for detailed analysis. However, one is probably not going too far wrong in suggesting that by "Nature" Aristotle meant the principle of heredity. It must be remembered that many contemporary thinkers, such as Empedocles, played down the importance of heredity in favor of the intra-uterine environment,<sup>60</sup> and Aristotle was emphasizing his disagreement with these thinkers rather than with believers in conscious biological design.

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Finally, one could acknowledge that Aristotle confused the issues of heredity and conscious design, yet still insist that he believed in the conscious design of biological structures. Dawkins, for example, would probably assume that, as Aristotle did not know about evolution, he had no choice but to believe in conscious design.<sup>61</sup> However, this is mere parochial modernism, because two other explanations for biological origins were available to Aristotle. They were:

1. He accepted the spontaneous generation of plants, invertebrates, and fishes,<sup>62</sup> and did not rule out this possibility with respect to humans and large quadrupeds.<sup>63</sup>
2. He believed in the infinite age of the world.<sup>64</sup>

Aristotle was, therefore, perfectly free to reject both conscious design and the proto-Darwinist ideas, derived from Empedocles,<sup>65</sup> with which he, at times, did toy.<sup>66</sup>

## Conclusions and Observations

Sub-optimality, in itself, provides little evidence for Darwinism or against the conscious design of biological structures. Equally, optimality provides little evidence for conscious design.

It is often argued that the complexity of biological structures is evidence for divine design. This argument is weak, because, even if a biological structure could be indisputably shown to have been consciously designed, it would be possible to argue that its designer was an extra-terrestrial, for example. Even the argument that biological complexity is evidence for design by an unspecified conscious (not necessarily divine) designer<sup>67</sup> is not very strong.<sup>68</sup> However, regardless of its weakness, the argu-



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ment from complexity to either divine or merely conscious design is logically independent of the argument from optimality, as sub-optimal structures may be just as complex as optimal ones.

In addition to the above central conclusions, two observations that I find telling may be made. They are:

1. Scientists should pay more attention to the long shadows cast by history. Darwinists routinely explain the imperfections in biological structures in terms of their evolutionary histories, and argue that "evolution can be ... strongly supported by evidence of telling imperfections."<sup>69</sup> This is deeply ironic, as the imperfections in this argument are themselves best explained in terms of its history. Postmodernists would pounce on this as an example of the self-referential nature of science.

2. The six Japanese scientists who studied pandas at Ueno Zoo, and thus contributed facts rather than speculation to the debate, are from a culture that has been little influenced by theism, and hardly at all by Aristotle or the argument from biological design. One wonders whether, as evolutionists, they would have been more constrained in their work had they been from a culture in a state of angry reaction against Christianity.

#### Notes

<sup>1</sup>"GBWW" refers to: R. M. Hutchins, ed., *Great Books of the Western World* (Chicago: William Benton, 1952).

<sup>2</sup>"PIAB" refers to: A. Gotthelf and J. G. Lennox, eds., *Philosophical Issues in Aristotle's Biology* (Cambridge: Cambridge University Press, 1987).

<sup>3</sup>T. Lucretius Carus, 54 BC, *De Rerum Natura*, trans. W. H. D. Rouse (London: William Heinemann, 1966), II:180-1, V:196-234.

<sup>4</sup>Charles R. Darwin, 1859, *On the Origin of Species by Means of Natural Selection, or the Preservation of Favoured Races in the Struggle for Life* (Brussels: Culture et Civilisation, 1969), 437-58; and Charles R. Darwin, 1877, *The Various Contrivances by which Orchids are Fertilized by Insects*, in *The Works of Charles Darwin* 17, ed. P. H. Barrett and R. B. Freeman (London: Pickering and Chatto, 1988), 245-6/173.

<sup>5</sup>Stephen J. Gould, "Evolution and the Triumph of Homology, Or Why History Matters," *American Scientist* 74 (1986): 60-9; —, *The Panda's Thumb: More Reflections in Natural History* (London: Penguin, 1990): 19-39; and —, *Ever Since Darwin* (London: Penguin, 1991), 91.

<sup>6</sup>J. Bergman and G. Howe, *'Vestigial Organs' Are Fully Functional* (St. Joseph, MO: Creation Research Society, 1990).

<sup>7</sup>George Ayoub, "On the Design of the Vertebrate Retina," *Origins and Design* 17, no. 1(1996): 6-7.

<sup>8</sup>Richard Deem, "When 'Junk' DNA isn't Junk," in *Evidence for God from Science*, [www.jps.net/bygrace/evolution/junkdna.html](http://www.jps.net/bygrace/evolution/junkdna.html) (Pasadena, CA: R. Deem, 2000).

<sup>9</sup>William Dembski, *Intelligent Design* (Downer's Grove, IL: InterVarsity Press, 1999).

<sup>10</sup>Stephen J. Gould, *The Panda's Thumb*, 19-25.

<sup>11</sup>—, "Evolution and the Triumph of Homology, Or Why History Matters."

<sup>12</sup>—, *The Panda's Thumb*, 19-25.

<sup>13</sup>Richard Dawkins, *The Blind Watchmaker*, 2d ed. (London: Penguin, 1991), 91.

<sup>14</sup>Hideki Endo, D. Yamagiwa, Y. Hayashi, H. Koie, Y. Yamaya and J. Kimura, "Role of the Giant Panda's 'Pseudo-thumb,'" *Nature* 397 (1999): 309-10.

<sup>15</sup>John S. Mill, 1870, *Theism*, in F.E.L. Priestley, ed., *Collected Works of John Stuart Mill* 10, (Toronto: University of Toronto Press, 1969), pt. 2.

<sup>16</sup>Erich von Däniken, *Chariots of the Gods?* (London: Corgi, 1971); and —, *Return to the Stars*, (London: Corgi, 1972)

<sup>17</sup>Francis Crick, *Life Itself: Its Origins and Nature* (New York: Simon and Schuster, 1981).

<sup>18</sup>Paul A. Nelson, "The Role of Theology in Current Evolutionary Reasoning," *Biology and Philosophy* 11 (1996): 493-517.

<sup>19</sup>Augustine, early 5<sup>th</sup> C, *Enchiridion*, in M. Dods, ed., trans. J. F. Shaw, *The Works of Aurelius Augustinus, Bishop of Hippo* 9, (Edinburgh: T. and T. Clark, 1892), chap. 11.

<sup>20</sup>G. W. Leibniz, 1710, *Theodicy*, in A. Farrer, ed., trans. E. M. Huggard (London: Routledge and Kegan Paul, 1952).

<sup>21</sup>Job 38:1-42:6; Isaiah 45:9; Romans 9:14-21.

<sup>22</sup>John Calvin, 1559, *Institutes of the Christian Religion*, final ed., trans. H. Beveridge (Edinburgh: Calvin Translation Society, 1845), book III, chap. 22, sect. 1.

<sup>23</sup>Carl Wieland, "New Eyes for Blind Cave Fish?" [www.answersingenesis.org/docs2/4361news8-9-2000.asp](http://www.answersingenesis.org/docs2/4361news8-9-2000.asp) (Australia: Answers in Genesis Ministries International, 2000).

<sup>24</sup>Genesis 1:29-30, 2:16, 9:2-3; Isaiah 11:6-9, 65:25; Hosea 2:18.

<sup>25</sup>Isaiah 11:8-9.

<sup>26</sup>Genesis 3:18.

<sup>27</sup>Genesis 3:14.

<sup>28</sup>Collège Dominicain d'Ottawa, Footnote in GBWW 19, p. 511.

<sup>29</sup>Plato, 4<sup>th</sup> C. BC, *Timaeus*, trans. B. Jowett in GBWW 7, chap. 76.

<sup>30</sup>Aristotle, 4<sup>th</sup> C. BC, *On the Gait of Animals*, trans. A. S. L. Farquharson in GBWW 9, chaps. 2, 8, 11, 12; —, *On the Generation of Animals*, trans. A. Platt in GBWW 9, II:5-6, V:8; —, *On the Parts of Animals*, trans. W. Ogle in GBWW 9, II:13, III:1, IV:11-3; and —, *On the Soul*, trans. J. A. Smith in GBWW 8, III:9, 12.

<sup>31</sup>—, *On the Generation of Animals*, in GBWW 9, V:8.

<sup>32</sup>—, *On the Soul*, in GBWW 8, III:9.

<sup>33</sup>—, *On the Gait of Animals*, in GBWW 9, chaps. 2, 8, 12; —, *On the Generation of Animals*, in GBWW 9, III:10; —, *On the Parts of Animals*, in GBWW 9, II:14; and —, *On Youth and Old Age, on Life and Death, on Breathing*, trans. G. R. T. Ross in GBWW 8, chap. 4.

<sup>34</sup>—, *On the Parts of Animals*, in GBWW 9, IV:10.

- <sup>33</sup>Plato, *Sophist*, trans. B. Jowett in GBWW 7, chaps. 265–6; and —, *Timaeus*, in GBWW7, chaps. 41–7, 69–92.
- <sup>34</sup>Galen, C. 175, *On the Usefulness of the Parts of the Body*, trans. and ed. M. T. May, (Ithaca, NY: Cornell University Press, 1968), I:6.
- <sup>35</sup>*Ibid.*, II:55–113.
- <sup>36</sup>*Ibid.*, I:12.
- <sup>37</sup>John Wilkins, 1675, *Of the Principles and Duties of Natural Religion*, ed. J. Tillotson (London: J. Walthoe and Co., 1734), I:VI.
- <sup>38</sup>John Ray, 1691, *The Wisdom of God Manifested in the Works of Creation* (New York: Garland, 1979), 156–85.
- <sup>39</sup>William Paley, 1802, *Natural Theology, or Evidences of the Existence and Attributes of the Deity Collected from the Appearances of Nature*, in F. Ferré, ed., *Natural Theology: Selections* (Indianapolis, IN: Bobbs-Merrill, 1963), chap. 5.
- <sup>40</sup>"A Second Opinion on the Giant Panda's Thumb," [www.reasons.org/resources/connections/1999v1n1/](http://www.reasons.org/resources/connections/1999v1n1/) (Pasadena, CA: Reasons to Believe, 1999); Richard Deem, "Examples of Bad Design Gone Bad", [www.geocities.com/CapeCanaveral/Lab/6562/evolution/designgonebad.html](http://www.geocities.com/CapeCanaveral/Lab/6562/evolution/designgonebad.html) (God and Science, 2000); Casey Luskin, "Good Theology and Bad Design Or Bad Theology and Good Design?" [www.acs.ucsd.edu/~idea/badtheolgooddesn.htm](http://www.acs.ucsd.edu/~idea/badtheolgooddesn.htm) (San Diego, CA: Intelligent Design and Evolution Awareness Club, 2001); and John Woodmorappe, "The Panda Thumbs its Nose At the Dysteleological Arguments of the Atheist Stephen Jay Gould," [www.answersingenesis.org/home/area/magazines/tj/v13n1\\_panda.asp](http://www.answersingenesis.org/home/area/magazines/tj/v13n1_panda.asp) (Australia: Answers in Genesis Ministries International, 2001).
- <sup>41</sup>Aristotle, *On the Gait of Animals*, in GBWW9, chaps. 17, 19.
- <sup>42</sup>*Ibid.*, chap. 17.
- <sup>43</sup>Richard Dawkins, *The Blind Watchmaker*, 91–3; and Ecclesiastes 1:9.
- <sup>44</sup>Aristotle, *On the Gait of Animals*, in GBWW9, chap. 19.
- <sup>45</sup>Plato, *Statesman*, trans. B. Jowett, in GBWW 7, chaps. 269–70; and —, *Timaeus*, in GBWW7.
- <sup>46</sup>—, *Statesman*, trans. B. Jowett, in GBWW 7, chap. 273; and —, *Timaeus*, in GBWW7, 30.
- <sup>47</sup>*Ibid.*, 42–6, 69.
- <sup>48</sup>Aristotle, *Metaphysics*, trans. W. D. Ross, in GBWW8, I:2, XII:7.
- <sup>49</sup>D. M. Balme, "Teleology and Necessity," in *PIAB*, 277.
- <sup>50</sup>Aristotle, *History of Animals*, trans. D. W. Thompson, in GBWW 9; —, *On the Gait of Animals*, in GBWW9; —, *On the Generation of Animals*, in GBWW9; and —, *On the Parts of Animals*, in GBWW9.
- <sup>51</sup>—, *On Sleep and Sleeplessness*, trans. J. I. Beare, in GBWW8, chaps. 2, 9, 17; —, *On the Soul*, in GBWW8, II:4, III:12; —, *Physics*, trans. R. P. Hardie and R. K. Gaye, in GBWW8, II:8; and —, *Sense and the Sensible*, trans. J. I. Beare, in GBWW8, chap. 5.
- <sup>52</sup>A. Gotthelf, "Aristotle's Conception of Final Causality," in *PIAB*, section 13.
- <sup>53</sup>Aristotle, *Physics*, trans. R. P. Hardie and R. K. Gaye, in GBWW 8, II:8.
- <sup>54</sup>—, *On the Parts of Animals*, in GBWW9, I:1.
- <sup>55</sup>—, *On the Soul*, in GBWW8, chap. 4.
- <sup>56</sup>—, *On the Parts of Animals*, in GBWW9, I:1.
- <sup>57</sup>A. Gotthelf, "Aristotle's Conception of Final Causality," in *PIAB*.
- <sup>58</sup>D. M. Balme, "Teleology and Necessity," in *PIAB*.
- <sup>59</sup>J. M. Cooper, "Hypothetical Necessity and Natural Teleology," in *PIAB*.
- <sup>60</sup>Aristotle, *On the Parts of Animals*, in GBWW9, I:1.
- <sup>61</sup>Richard Dawkins, *The Blind Watchmaker*, 3–6.
- <sup>62</sup>Aristotle, *History of Animals*, in GBWW9, V:1, 15–6, 19, 31–2, VI:15; and —, *On the Generation of Animals*, in GBWW9, II:5–6, V:8, I:1, 16, II:1, III:9–11.
- <sup>63</sup>*Ibid.*, III:11.
- <sup>64</sup>Aristotle, *Meteorology*, trans. E. W. Webster, in GBWW8, I:14; —, *On the Heavens*, trans. J. L. Stocks, in GBWW 8, I:3, 9–12; and —, *Physics*, in GBWW8, VIII:1–2.
- <sup>65</sup>Empedocles, 5<sup>th</sup> C. BC, arr. H. Diels, in J. Burnet, trans., *Early Greek Philosophy* (London: Adam and Charles Black, 1948), fragments 57–62.
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- <sup>67</sup>Michael J. Behe, *Darwin's Black Box: The Biochemical Challenge to Evolution* (New York: Free Press, 1996).
- <sup>68</sup>Richard H. Thornhill and David W. Ussery, "A Classification of Possible Routes of Darwinian Evolution," *Journal of Theoretical Biology* 203 (2000): 111–6.
- <sup>69</sup>Richard Dawkins, *The Blind Watchmaker*, 91.

## Books Received and Available for Review

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