FEATURE ARTICLE

Vestigial Biological Structures: A Classroom-Applicable Test of Creationist Hypotheses

RECOMMENDED FOR AP Biology

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Abstract

Lists of vestigial biological structures in biology textbooks are so short that some young-Earth creationist authors claim that scientists have lost confidence in the existence of vestigial structures and can no longer identify any verifiable ones. We tested these hypotheses with a method that is easily adapted to biology classes. We used online search engines to find examples of 21st-century articles in primary scientific literature in which biological structures are identified as vestigial. Our results falsify these creationist hypotheses and show that scientists currently identify many structures as vestigial in animals, plants, and single-celled organisms. Examples include not only organs but also cells, organelles, and parts of molecules. Having students repeat this study will give them experience with hypothesis testing, introduce them to primary scientific articles, and further their education on vestigial structures.

Key Words: *Vestigial structures; vestigial organs; evolution; creationism; primary scientific literature.*

○ Introduction

Many organisms possess biological structures that are recognizable as degenerate versions of their homologs in related organisms and that do not perform the functions that those homologs perform. For example, degenerate eyes in blind cave fishes and cave salamanders are useless for vision (Eigenmann, 1900), and degenerate limbs in numerous lizard species are useless for locomotion (Moch & Senter, 2011). Such degenerate structures are called "vestigial structures" because they are vestiges (remnants) of ancestral structures. Biologists recognize vestigial structures as evidence for biological evolution (Starr & Taggart, 2004; Reece et al., 2011). For example, blind cave fishes and salamanders arguably have eyes only because they inherited them from sighted ancestors.

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Until recently the human and ape appendix has been considered a vestigial organ, a remnant of a much larger ancestral cecum. A cecum is a side branch of the large intestine that houses bacteria that break down cellulose, enhancing the digestion of plant matter in herbivorous mammals (Kardong, 2011). However, an anatomical study of primates showed that the appendix of humans and apes is not a remnant of a cecum but is instead an evolutionarily new structure with no homolog in lower primates (Scott, 1980). It appears to function as a protective reservoir for beneficial bacteria that inhabit the colon, a microbial "Noah's ark" from which beneficial bacteria can repopulate the colon if a disease decimates them (Bollinger et al., 2007).

The recognition of the appendix as vestigial ceased not because it has a function but because it is a newly evolved structure instead of a vestige of an ancestral structure. A structure does not have to be useless or functionless to be a vestige. Even so, scientists generally hesitate to use the term "vestigial" for a structure unless it has lost its most salient previous function. For example, the degenerate pelves of whales currently function as anchors for reproductive structures but are considered vestigial because they have lost their previous function as anchors for hindlimbs that are used in locomotion (Simões-Lopes & Gutstein, 2004). Likewise, the degenerate ink glands of certain marine snails store algal pigments but are considered vestigial because they have lost their previous function as organs of ink production (Prince & Johnson, 2006).

Anti-evolution authors in the young-Earth creationist (YEC) camp have long insisted that all structures previously identified as vestigial are actually misidentified as such (e.g., Morris, 1974; Koop & Schaeffer, 1987; Bergman & Howe, 1990; Bergman, 2000; Menton, 2010). According to the YEC argument, no truly vestigial biological structures exist. Rather, in each case, the structure is functional but its function was unknown when it was labeled as vestigial. Such authors fail to understand that a structure can have a function and yet be a vestige. Nevertheless, some of these YEC authors have noticed something that is worth noticing: Lists of vestigial structures in biology textbooks have dwindled through the

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decades. These authors use this as evidence that scientists have lost confidence in the existence of vestigial structures or that scientists cannot find more examples of valid vestigial structures (Koop & Schaeffer, 1987; Bergman & Howe, 1990; Bergman, 2000). As one YEC author puts it, "vestigial organs…have now been thoroughly discredited" (Bergman, 2010, p. 63).

Indeed, lists of vestigial biological structures in current biology textbooks are usually quite short, with only one to three examples (e.g., Starr & Taggart, 2004; Reece et al., 2011). This is the case even in textbooks for evolution classes (e.g., Ridley, 2004; Kardong, 2008), one of which does not mention vestigial structures at all (Volpe & Rosenbaum, 2000). It is therefore worth testing the YEC hypotheses that biologists have lost confidence in the existence of vestigial structures and that more examples than those in short textbook lists cannot be found. Both hypotheses make the same prediction: that a review of recent primary scientific literature will find only a small number of examples (or none) of biological structures that are identified as vestigial. This is because scientists primarily communicate via primary literature (technical journals, etc.), not textbooks. Here, we report a test of these YEC hypotheses.

The test described below is one that can be employed as an assignment in a biology class to serve three purposes that are important for science students. First, it involves students in hypothesis testing, which gives them experience with scientific method. Second, it introduces students to primary scientific literature, so that they can see firsthand the ultimate sources of the information that ends up in textbooks and in secondhand reports in popular science magazines. Third, it expands their education on vestigial structures beyond the meager information found in textbooks. All three goals were in fact attained when this test was performed in a class taught by one of us (Senter), in which the rest of us were graduate students.

○ Methods

We used the search terms "vestigial" and "vestige" to search online databases of primary scientific articles such as JSTOR (http://www.jstor.org) and Science Direct (http://www.sciencedirect.com) for examples of articles in which biological structures are explicitly identified as vestigial. We counted such identifications only if the following five criteria were met: (1) The authors' wording indicates that they themselves consider the structure vestigial and are not merely citing previous opinions on vestigiality. (2) The authors use the word "vestigial" or "vestige," not just a synonym (e.g., "rudimentary" or "reduced"). (3) The authors are not describing a rare developmental anomaly. (4) The organism with the vestigial structure is extant. (5) The vestigial structures are not just mentioned in passing but are important to the main focus of the article. To avoid the appearance of "stacking the deck," we did not use any articles for which any of us was an author.

We used only articles published in the 21st century, to ensure that the identification of a structure as vestigial is recent enough to be considered current. We did not use articles from the year 2000, because that is actually the last year of the 20th century.

○ Results

In 21st-century articles from primary scientific journals, we found enough examples of biological structures that scientists identify as vestigial to place 64 entries in Table 1. Several of these entries include multiple species or supraspecific taxa. This falsifies the YEC hypotheses that scientists have lost confidence in the existence of vestigial biological structures and that scientists cannot find more than a few examples of vestigial biological structures in nature.

○ Discussion

To make our results more useful to others, we have included information on function in Table 1. A few vestigial structures are explicitly recognized as entirely useless in primary scientific literature (Table 1), but most are not.

It is probable that we have missed numerous examples of biological structures that scientists currently consider vestigial. This is because the online search engines cannot find every single scientific article published in the 21st century, because we examined no primary scientific literature from sources other than journal articles, and because we used only English-language articles. Table 1, therefore, should not be considered a complete list, and the absence of a structure therein does not necessarily mean that scientists do not currently consider it vestigial. Furthermore, we did not include the numerous examples of vestigial structures recognized in fossil taxa (e.g., Senter, 2010). These facts, in addition to the fact that Table 1 contains a plethora of examples despite its incompleteness, show that biological structures that scientists currently consider vestigial are common, not rare or nonexistent.

As Table 1 shows, some body parts are particularly prone to vestigiality in certain taxa or in organisms in certain ecological niches. For example, vestigial reproductive structures are common in plants. Vestigial limbs are common in lizards. Vestigial eyes are common in burrowing vertebrates. Vestigial mitochondria are common in microbes that inhabit anoxic environments.

Our results show that scientists recognize vestigiality at numerous levels of biological organization in addition to the organ level. In some cases, a major bodily region is vestigial (e.g., the abdomen of a barnacle; Blin et al., 2003). Structures smaller than organs can also be vestigial. Vestigial organelles have been identified in unicellular organisms (e.g., vestigial mitochondria in several species [Regoes et al., 2005] and vestigial chloroplasts in others [Sekiguchi et al., 2002]). Even parts of molecules can be considered vestigial. Researchers have recently identified vestigial genes in whales (McGowen et al., 2008) and a vestigial region in antibody molecules of wobbegong sharks (Streltsov et al., 2004).

It is rare for biology textbooks to mention vestigial structures other than organs and to list more than three examples. We therefore hope that our compilation in Table 1 will be useful to educators who wish to supplement meager textbook information with further examples. We also recommend that longer lists of vestigial structures be added to biology textbooks, to counter the YEC hypotheses that are falsified here.

Our study is easily adapted to biology classes as an assignment. If students are assigned to find a certain number of publications on vestigial structures in primary scientific literature, they need only be taught how to enter the term "vestigial" or "vestige" in an online search engine and to recognize primary scientific articles (e.g., by the presence of an abstract). The experience and knowledge gained during such an exercise would be a valuable addition to a student's biological education.

Table 1. Examples of biological structures that scientists have identified as vestigial in primary scientific journal articles published in the 21st century. N = no function listed by author(s). U = useless structure according to author(s).

Taxon	Structure	Structure's Function in Unreduced State	Structure's Function in Vestigial State	Reference(s)
Unicellular Organisms				
Amoebozoa				
Entamoeba histolytica	mitochondria	ATP synthesis	N	Regoes et al., 2005
Apicomplexa				
Cryptosporidium parvum	mitochondria	ATP synthesis	N	Regoes et al., 2005
Plasmodium falciparum	chloroplast	photosynthesis	N	Sekiguchi et al., 2002
Toxoplasma gondii	chloroplast	photosynthesis	N	Sekiguchi et al., 2002
Diplomonadida				
Giardia lamblia	mitochondria	ATP synthesis	Fe-S cluster synthesis	Regoes et al., 2005
Euglenozoa				
Astasia longa	chloroplast	photosynthesis	N	Sekiguchi et al., 2002
Fungi				
Trachipleistophora humanis	mitochondria	ATP synthesis	N	Regoes et al., 2005
Heterokontophyta				
Anthophysa vegetans	chloroplast	photosynthesis	N	Sekiguchi et al., 2002
Blastocystis humanis	mitochondria	ATP synthesis	N	Regoes et al., 2005
Ciliophrys infusionum	chloroplast	photosynthesis	N	Sekiguchi et al., 2002
Pteridomonas danica	chloroplast	photosynthesis	N	Sekiguchi et al., 2002
Paraphysomonas	chloroplast	photosynthesis	N	Sekiguchi et al., 2002
Spumella	chloroplast	photosynthesis	N	Sekiguchi et al., 2002
Multicellular Organisms				
Plantae				
some Arecoideae (a subfamily of palms)	male flowers	pollen production	N	Ortega-Chávez & Stauffer, 2011
Gethyum and *Gilliesia* (South American allioids)	stamens	pollen production	N	Rudall et al., 2002
Schiedea (Hawaiian schiedeas)	stamens	pollen production	N	Golonka et al., 2005
Consolea spinosissima (a cactus)	androecium [in female plants]	pollen production	N	Strittmatter et al., 2002
Consolea spinosissima (a cactus)	gynoecium [in male plants]	sperm reception; ovule and fruit production	N	Strittmatter et al., 2002
Fragaria virginiana (strawberry)	stamens	pollen production	N	Ashman, 2003
Nemophila menziesii (Baby Blue-eyes)	anthers	pollen production	N	Gomez & Shaw, 2006
Penstemon centranthifolius (Scarlet Bugler) and *P. rostriflorus* (Beakflower Penstemon)	stamen	pollen production	U	Walker-Larsen & Harder, 2001

Table 1. continued

Taxon	Structure	Structure's Function in Unreduced State	Structure's Function in Vestigial State	Reference(s)
Penstemon ellipticus (Rocky Ledge Penstemon)	stamen	pollen production	increases duration of pollinators' visits by hindering nectar access	Walker-Larsen & Harder, 2001
Penstemon palmeri (Palmer's Penstemon)	stamen	pollen production	acts as a lever that increases stigma contact with pollinator	Walker-Larsen & Harder, 2001
Epifagus americana (Beechdrops)	chloroplasts	photosynthesis	N	Sekiguchi et al., 2002
Bryozoa				
Calloporidae (a bryozoan family)	ooecium	protects brood chamber	N	Ostrovsky et al., 2006
Mollusca				
Dolabifera dolabifera (a sea hare)	ink gland	defensive ink production	algal pigment storage	Prince & Johnson, 2006
Octopus vulgaris (common octopus)	shell	external protection	N	Napoleão et al., 2005
Teuthida (squid)	phragmocone	buoyancy	muscle and fin attachment	Arkhipkin et al., 2012
Arthropoda				
Cirripedia (barnacles)	abdomen	multiple functions	N	Blin et al., 2003
Carabus solieri (a ground beetle)	hind wings	flight	U	Garnier et al., 2006
Formidicae (ants) [workers]	spermathecae	sperm storage	N	Bowsher et al., 2007; Gotoh et al., 2013
Formicidae [workers of most species]	wing imaginal discs	wing production	N	Bowsher et al., 2007
Diacamma (a genus of wingless ants) [workers]	wings	flight	social display of reproductive status	Miura, 2005
Apis cerana (eastern honeybee) and *A. mellifera* (European honeybee) [workers]	spermathecae	sperm storage	N	Gotoh et al., 2012
Lepidoptera larvae (caterpillars)	crop	food storage	defensive regurgitation	Grant, 2006
Chondrichthyes				
Orectolobus maculatus (wobbegong shark)	complementarity-determining region of IgNAR antibody	adhesion to antigen	N	Streltsov et al., 2004
Actinopterygii				
Actinopterygii	vertebral arches of posterior tail	muscle attachment	N	Bensimon-Brito et al., 2012
Acipenseriformes (paddlefishes and sturgeons)	pulmonary artery	blood transport to gas bladder	blood transport elsewhere	Longo et al., 2013

Table 1. continued

Taxon	Structure	Structure's Function in Unreduced State	Structure's Function in Vestigial State	Reference(s)
Astyanax mexicanus (blind cavefish)	eyes	vision	regulation of circadian rhythms	Espinasa & Jeffery, 2006; Franz-Odendaal & Hall, 2006; Yoshizawa & Jeffery, 2008
Echidna nebulosa (snowflake moray) and *Muraena retifera* (reticulate moray)	pectoral girdle	support for pectoral fin	N	Mehta & Wainwright, 2007
Actinistia				
Latimeria (coelacanths)	lung	gas exchange	N	Longo et al., 2013
Latimeria	pulmonary vein	blood transport from lung to heart	N	Longo et al., 2013
Amphibia				
Plethodon cinereus (red-backed salamander) and *Eurycea* (brook salamanders)	fourth epibranchial	gill support	N	Kerney et al., 2012
Sirenidae (legless salamanders)	pectoral girdle	forelimb support	N	Bejder & Hall, 2002
Gegenophis ramaswamii (a caecilian)	fourth epibranchial	gill support	N	Müller et al., 2005
Squamata				
Pygopodidae (flap-footed lizards)	hindlimbs	locomotion	N	Brandley et al., 2008
Ophisaurus apodus (European legless lizard)	hindlimbs	locomotion	N	Bejder & Hall, 2002; Brandley et al., 2008
Bipes (a genus of worm lizarda)	pelvic girdle	hindlimb support	N	Kearney, 2002
Bipes	hindlimbs	locomotion	N	Kearney, 2002
Rhineura floridana (Florida worm lizard)	eyes	vision	N	Kearney et al., 2005
Rhineura floridana	jugal bone	forms lower border of eye socket	N	Kearney et al., 2005
Blanus (a genus of worm lizards)	hindlimbs	locomotion	N	Kearney, 2002
Feylinia (a skink genus)	sternum	forelimb muscle attachment	N	Kearney, 2002
Jarujinia bipedalis (a skink species)	forelimbs	locomotion	N	Chan-ard et al., 2001
some Serpentes (snakes)	hindlimbs	locomotion	N	Kearney, 2002; Brandley et al., 2008
Aves				
Apterygidae (kiwis), Casuariidae (cassowaries), and Dromaiidae (emus)	wings	flight	U	Maxwell & Larsson, 2007

Table 1. continued

Taxon	Structure	Structure's Function in Unreduced State	Structure's Function in Vestigial State	Reference(s)
Mammalia				
Cetacea (whales)	pelvic girdle	braces hindlimb against vertebral column	support for reproductive organs	Bejder & Hall, 2002; Simões-Lopes & Gutstein, 2004
Mysticeti (baleen whales)	hindlimbs	locomotion	N	Bejder & Hall, 2002
Odontoceti (toothed whales)	olfactory receptor subgenomes	genes for olfactory receptors	N	McGowen et al., 2008
Monodon monoceros (narwhal)	molariform teeth	food processing	U	Nweeia et al., 2012
Felidae (cat family)	clavicle	braces scapula against sternum	N	Hartstone-Rose et al., 2012
Mus musculus (house mouse)	incisor tooth bud	production of incisor	N	Peterková et al., 2002, 2006
Spalax ehrengergi (Middle East blind mole rat)	retina	image formation	regulation of circadian rhythms	Zubidat et al., 2010
Primates (primates)	Harderian gland	eye socket lubrication	N	Rehorek & Smith, 2006
Perodicticus potto (potto)	index finger	prehension	N	Tague, 2002
Ateles geoffroyi (Geoffroy's spider monkey) and *Colobus guereza* (mantled guereza)	thumb	prehension	N	Tague, 2002
Catarrhini (humans, apes, and Old World monkeys)	vomeronasal organ	pheromone reception	N	Liman & Innan, 2003; Zhang & Webb, 2003
Homo sapiens (humans)	sinus hair muscle	whisker movement	N	Tamatsu et al., 2007

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