The egg—irreducible complexity of creation's perfect package

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The anatomy and physiology of an amniotic egg was briefly reviewed to illustrate its irreducible design and the contrast between the amniotic egg type and egg designs for aquatic environments such as fish. The variations of the amniotic egg were also noted, stressing they all had the very same basic design, shape, colour, and size variations. Plausible means of the evolution of the amniotic egg type from fish eggs were explored, finding that almost no evolutionists have ventured to hypothesize evolution in this area largely because of lack of fossil or other evidence and the problem irreducible complexity presents. The egg is an excellent example of irreducible complexity because every component discussed in this review exists in all amniotic egg types, and are all required for the egg to function.

Bird and reptile eggs are irreducibly complex structures designed to enable the embryo to develop into a fetus, then into a fully formed animal outside of the mother's body. Bird eggs are "virtually self-contained life-support systems. All they require for the embryo to develop properly are warmth and oxygen."[1] The eggs in birds, reptiles, insects, mollusks, fish, and monotremes (mammals that lay eggs instead of giving birth to live young), contain an ovum. When the ovum is fertilized it is called a zygote. A zygote is thus a diploid cell resulting from the fusion of two haploid gametes.

The egg serves several functions, including protection and nourishment of the offspring while it develops from one cell to a fully formed young animal able to live in the outside world. The egg covered in this review is the amniotic egg type, named such because the embryo develops inside the amnion, the innermost membrane that encloses the embryo of mammals, birds, or reptiles. This review about amniotic eggs focuses on birds' eggs, but many of the observations also apply to reptile eggs.

The largest known egg of an existing bird is that of the elephant bird *(Aepyornis maximus)* which is about 10 kg, although some extinct dinosaurs had larger eggs. The bee hummingbird produces the smallest bird egg known, which weighs half a gram. Eggs laid by some reptiles and most fish can be even smaller, and those of insects and other invertebrates are much smaller still.

The jelly-like eggs of non-amniotes (aquatic and semiaquatic animals who lay their eggs in water, including fish, amphibians, frogs, and toads) do not have a hard-protective eggshell. Amniotes (animals whose embryo develop in an amnion) include mammals, birds, and reptiles. A few animals, as some turtles, lizards, and snakes, lay soft-shelled eggs, but most lay hard-shelled eggs consisting of hard mineral crystals of calcium carbonate.[1] This review covers only hard-shelled eggs.

A zygote results from the fertilization of an ovum, which develops into an embryo and then a shelled fetus. Animals that lay eggs are *oviparous,* and the study of eggs (and the hobby of collecting eggs, commonly bird eggs) is termed *oology*. The embryo develops from the small germinal disc located on the edge of the egg yolk. The egg's fluid-filled cavity not only buffers the embryo against short-term external temperature extremes, but also cushions it if it is bumped.[2]

After that the egg matures to the degree that it can be expelled, and in a short time, it is expelled from the mother's body.[3] If fertilized, the embryo further develops in the egg until the organism can survive outside. When adequately developed, the fetus breaks out of the egg's shell to begin its life in the outside world, a process called hatching. It may take longer than a day to break out of the egg shell.

The egg's shape

Both protection and nourishment of the offspring are achieved within a striking diversity of egg types and shapes. Hauber classified 600 of the world's bird eggs, noting that each egg is unique.[4] Furthermore, of the over 10,000 species of birds, many more bird eggs have yet to be described.[5] A problem is that: "Explanations for both the origin and function of this diversity have remained little more than anecdotal."[6] Spottiswoode in the journal *Science*, touts the results of research, in which she describes an egg as "the most perfect thing."[7] In short, she found: "changes in the forces experienced by the shell membrane as the egg develops in the female's oviduct are sufficient to generate the observed egg-shape diversity across all birds,"[7] a conclusion that only explains the results of the forces on the egg, not the genetics behind the oviduct design that produces the egg shape.

The need is to explain the *origin* of the oviduct design, which is the real issue and one for which no evolutionary

Figure 1. A variety of bird eggs, illustrating the variety existing in both size and colour

explanation is provided. Stoddard *et al.* admit that the "precise physiological mechanisms by which morphological adaptations for flight might affect egg shape are unknown". [7] Actually, how such adaptations might affect the shape is unknown, period.

The eggshell

All amniotic eggs have an outer covering called a shell consisting mostly of protein, calcium carbonate ($CaCO_3$), and various other minerals.The eggs of reptiles, birds, and monotremes (the few mammals that lay eggs, such as the platypus) are laid on dry land. All are surrounded by protective eggshells that can be either flexible, or hard and inflexible as is the familiar chicken egg. A bird's egg shell is a remarkable piece of engineering. It is very lightweight and has up to 17,000 microscopic pores that allow the chick to breathe oxygen and expel carbon dioxide, which is necessary for bird life.

Although very thin, bird egg shells are extremely strong. They must be strong, otherwise they would collapse when the adult incubates them. The shell is often so strong that it takes some chicks longer than a day to chip their way through it to enter the outside world.[8] Chicken eggs must be strong enough to resist being fractured from the outside, but weak enough to be broken from the inside when the chick is ready to hatch. As we will now explain, how this is done is nothing short of ingenious.

Development of bird egg shells

The specific details of amniotic eggshell construction vary enormously. For example: duck eggs are oily and waterproof; cormorant (medium-to-large seabirds) eggs are rough and chalky; tinamou eggs are shiny and very colourful; and emu and cassowary eggs are rough, grainy, and heavily pitted.

Birds' eggs have a hard calcium-rich shell containing three main layers. As a chick develops in preparation for hatching, these layers become thinner from the inside to the outside. The shell's necessary strength and other qualities come from its nanostructural design.[9]

One source of the shell's strength is osteopontin protein which becomes embedded inside the crystal structure that generates the nanostructure to increase its hardness. Osteopontin in turn helps to form a scaffold that guides the development of the calcium-containing mineral assembly arrangement, generating the nanostructure that helps to produce the eggshell layer's hardness.

Osteopontin protein is also used in the bones of birds to help guide the biomineralization process to give these structures their specific properties. Without this protein, large calcite (calcium carbonate) crystals form. Higher concentrations of osteopontin produce a smaller nanostructure, and consequently a stronger overall structure.

The shell structure surrounding the embryo must be altered towards the end of development to allow the young to hatch. As the embryo develops, the egg shell slowly dissolves, and the calcium taken from the shell is then incorporated into the bird's skeleton.[10]

Focused ion beam research has revealed that the entire eggshell layers are formed from an array of tiny areas packed with the crystalline calcium-containing mineral.[11] The layers are smaller and more closely arranged in the outer egg shell layer. The nanostructure also increases in size toward the inner layers. The outside layer with the smallest nanostructure is harder but the inner layers become softer. This design feature was described in one study that stated an eggshell

> "… has an unusual combination of mechanical properties (low fracture toughness combined with high Young's modulus), making it ideally suited as a container for the developing chick, which must be stiff and rigid but also brittle enough to be broken when required."[12]

When a fertilized chicken egg was incubated for 15 days, the nanostructure of the outermost layer remained unchanged. But, the nanostructure of the inner layers had become smaller in size as a result of calcium carbonate being dissolved in acidic conditions so it could be used in the developing chick's skeleton. The process is aided by the nanostructure increasing the surface area of the calcium-containing mineral. Thus, the inner portion of the shell dissolves to provide mineral ions for the chick's body needs, while at the same time weakening the shell enough to be broken by the hatching chick. Some chicks have a temporary egg tooth with which to crack or break the eggshell. A few days after hatching, the egg tooth is no longer needed, and is absorbed by the chick's body.

The protoporphyrin markings on passerine (generally called perching or song birds) eggs function to reduce shell brittleness by acting as a solid-state lubricant. If insufficient calcium exists in the mother bird's feed, the eggshells may be too thin. Protoporphyrin speckling compensates for the brittleness caused by thin eggshells and varies inversely to the amount of calcium in a bird's diet. For this reason, eggs laid later in a clutch are more spotted than earlier ones because the female's calcium store is increasingly used up with each egg produced.

The egg anatomy

A membrane separates the eggshell from the albumen, or egg white, a gelatin-like substance providing food for the growing embryo. This membrane is a barrier to both desiccation and bacterial infection.[13] Two layers of albumen exist—a thick albumen layer near the yolk and a thinner layer near the eggshell. Depending on the egg size, albumen accounts for most of an egg's liquid weight, usually close to 66%. Albumen contains more than half the egg's total of 40 different kinds of protein, and a majority of the egg's niacin, riboflavin, magnesium, potassium, and sodium.

The cloudy appearance in the egg white is produced by carbon dioxide in the egg. As eggs age, the carbon dioxide escapes, so the albumen in older eggs is more transparent than that of fresher eggs. Albumen is opalescent until an egg is beaten or cooked which denatures the protein and produces the white colour seen when cooking an egg.

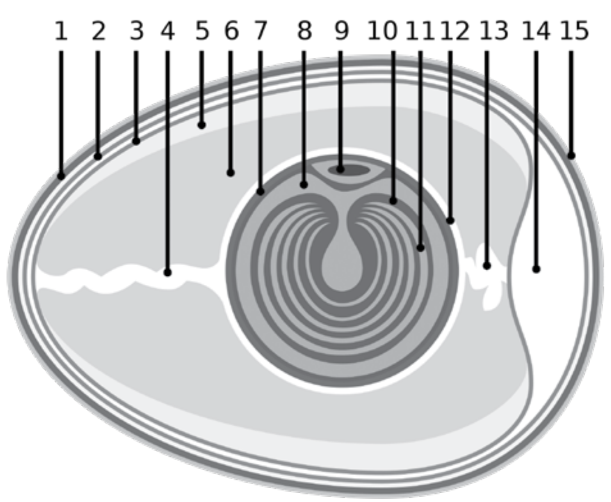

Figure 2. Interior structure of an egg showing its basic parts: 1. eggshell; 2. outer membrane; 3. inner membrane inner membrane; 4. chalaza; 5. exterior albumen (outer thin albumen); 6. middle albumen (inner thick albumen); 7. vitelline membrane; 8. nucleus of pander; 9. germinal disk (blastoderm); 10. yellow yolk; 11. white yolk; 12. internal albumen; 13. chalaza; 14. air cell; and 15. cuticula.

In the centre of the egg is the yolk, a yellow liquid consisting of proteins, fat, cholesterol, vitamins, minerals, and the germ spot, the zygote.[14] Two string-like structures called *chalazae* are located on opposite ends of the egg to anchor the yolk in the thick egg white.[15] The chalazae insure the yolk remains in the same position in the centre of the thick egg white no matter how the egg is turned.[15]

The chalazae are in turn attached to the membrane lining the eggshell. Since eggs often roll around and may be turned by the mother, this anchoring system is required to insure the yolk remains on top and so it does not become attached to the shell which would create problems. Otherwise the embryo would slosh around in the liquid albumen which could be detrimental.

How does a chick breathe in the egg?

The small pores in eggshells allow the embryo to obtain oxygen and expel carbon dioxide. The domestic hen's egg has around 7,500 microscopic pores and some other species have as many as 17,000. The pores also allow pathogens to enter, a problem solved in most vertebrate eggs by the production of a rich amount of an antibacterial enzyme called lysozyme. Between the eggshell and the shell membrane is a space called an *air chamber* designed to hold air, allowing the embryo to obtain oxygen. The membranes surrounding these eggs are typical of all amniotes.

As the embryo grows, its primary food at first is the yolk. When the fatty yolk is broken down for energy, water is produced as a by-product to be used by the embryo. When these nutrients are exhausted, the food source becomes the thin albumin. Waste products, such as urea, are collected in a sack called the allantois. The albumin is located around the yolk and consists of two layers. The first is the stringy layer called the thick layer; the second is the more watery layer called the thin layer which supplies the water developing fetuses require.

Eggshell colouration

Eggshell colours exist in an amazing variety ranging from white to bright blue, purple, and even black.[16] Eggshells also display a mixture of colours called spotting. The colour of individual eggs is both environmentally influenced and genetically inherited through the mother, suggesting the gene responsible for egg pigmentation is on the sex-determining W chromosome (female birds are WZ, males ZZ). It was once believed the colour was applied to the shell immediately before laying, but research has shown that colouration is an integral part of shell development, and the same protein is also responsible for depositing calcium carbonate, or the protoporphyrins, when a lack of that mineral exists.

The default colour of all vertebrate egg shells is white, produced by the calcium carbonate from which shells are constructed. The green or blue colour comes from the pigment known as biliverdin, also found in human bile. A blood breakdown product, it is responsible for the sometimes greenish colour of bruises. A brown, 'earth' colour comes from zinc chelate. Protoporphyrin is an organic compound that produces a reddish-brown colour or a spotting paint colour to the egg.

Many ground-nesting birds use egg markings for camouflage. In species which nest in large groups, such as the guillemot (*Uria aalge*), each female's eggs have very different markings to allow them to identify their own eggs on the crowded cliff ledges on which they breed. Examples include the Charadriiformes, a diverse order of small to medium-large birds that includes gulls, terns, plovers, and sandpipers, most of which live near water.

Brood parasitism

When one bird species lays its eggs in the nest of another it is called bird brood parasitism. Some brood parasitic birds, such as cuckoos, have egg colouration that matches the passerine host's eggs. Passerines are perching birds or, less accurately, songbirds which include more than half of all bird species. In some cases, the host's eggs are removed or eaten by the female, or expelled from the nest by her chicks. Brood parasites include the cowbirds and many Old-World cuckoos. Most passerines lay coloured eggs, even if there is no camouflage requirement for cryptic colours (colouration designed for camouflage, from *crypsis* meaning hiding).

The egg shape design

Most bird eggs have an oval shape, with one end rounded and the other end slightly more pointed. This shape results from the egg being forced through the bird's oviduct by muscles that contract behind the egg, pushing it forward. The egg's wall is often still slightly malleable even when expelled, and the more pointed end forms at the back. Cliff-nesting birds often have highly conical eggs because this egg design makes it less likely to roll off the cliff. Instead, they roll around in a tight circle. In contrast, many hole-nesting birds tend to have nearly spherical eggs.

Egg development in the hen

The details of the egg development in the body of the chicken are largely unknown except that it is a complex, delicate process. The general steps are known, but few details are. The chicken egg begins as an oocyte produced by the hen's ovary in a process called ovulation. The hen has two

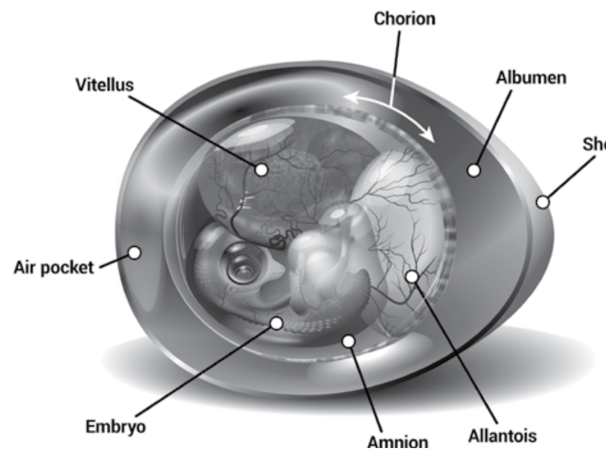

Figure 3. The development of the chick at its 9th day

ovaries with the right ovary producing hormones and the left one producing eggs. This ovary contains all the undeveloped eggs the hen was born with, limiting the maximum number of eggs she can lay in her lifetime.

The oocyte is released into a long, spiralling tube in the hen's reproductive system called the oviduct where it may be fertilized internally by a sperm. The two-foot-long oviduct consists of several compartments, each with a different function; the two main ones will be described here. The oviduct performs various duties throughout the process similar to an assembly line with different sections performing different tasks. The first section of the oviduct assembly line, called the magnum, is where the first layer of egg whites that cover the yolk are formed. Whether or not it is fertilized, it continues down the oviduct where it is coated with the vitelline membrane, structural fibres, and added layers of albumin.

The egg is also plumped up with fluid until it achieves the approximate shape required. The next stop on the line is the isthmus where the inner and outer membranes of the shell are formed around both the yolk and the two white layers described above. As the egg travels down through the oviduct, it is continually rotating within the spiralling tube. At this part of the journey antibiotics are produced to protect the egg yolk and the 'whites' from bacteria.

In the shell gland, the egg is sealed within a hard shell just before it is laid. The shell consists primarily of calcium carbonate crystals as covered above. Also, just before the egg is laid, a natural antibacterial coating is added to the outer shell. This antibacterial substance called the 'bloom' protects it from potentially harmful bacteria.

A hen's body temperature is about 41^0C, so when the warm egg is laid it rapidly cools to ambient temperature, creating an air space between the two shell membranes. Because of this a fresh egg will sink in water, while older eggs with larger air spaces will float—providing a good way for determining if an egg is fresh. This egg formation system will not produce viable eggs unless all of these steps are in place. If any step is defective, the entire system will fail and the hen will not be able to reproduce.

Dinosaur eggs

Many types of dinosaur eggs exist, based mostly on their shell traits such as size, texture, shape, and even their microscopic traits.[17] An evaluation of the many thousands of dinosaur eggs so far discovered shows they are of similar or even greater complexity than modern bird eggs. Stereo electron microscope study was able to determine that their shell, as is true of all birds, consists of a minimum of two layers. Many studies of dinosaur eggs show no evidence of evolution from ancient shelled eggs to modern eggs.[18]

No evidence of animal egg evolution

The most authoritative compendium on the science of hard-shelled eggs notes this "highly functional reproductive system … is a compact and adaptable product of evolution engineering" but in 565 pages not only includes no evidence of its evolution, but never even mentions the theory again.[19] Although no evidence exists for the evolution of animal eggs from non-eggs or even ancient eggs to modern eggs, some speculation exists. Packard and Packard postulate:

> "Evolution of the avian egg from the naked, amniotic egg of ancestral reptiles probably was the outcome of intense predation by soil invertebrates and microbes on a highly integrated and coadapted complex of characters. The calcareous shell, which from its inception afforded a measure of protection to eggs against attacks by soil organisms, became progressively thicker and more complex in the face of continuing selection for antipredator devices."[20]

The authors note a problem with what they admit is only a plausible conceptual model, one which they acknowledge dates back to 1928 and is limited by "the meager body of evidence presently available".[21] This model was proposed to account for the evolution of cleidoic (amniotic) eggs. It is part of the theory of how birds evolved from reptilian progenitors, and includes the problem that

> "… increases in thickness and complexity of eggshells led to simultaneous reductions in the amount of liquid water that could be absorbed by incubating eggs from the substrate. Because embryos initially were dependent upon uptake of substantial quantities of water from the environment to satisfy their needs for this solvent, adaptive increases in thickness of the eggshell required coupled increases in the amount of water contained by eggs at oviposition."[22]

Other problems include that the egg shell alone would not offer much protection because, for the chick to survive, it must be able to take in oxygen and expel carbon dioxide. Critical to protection from bacteria are the antibacterial defences which now exist in egg design. I was not able to locate any other attempt to explain the evolution of amniotic eggs, nor could I find a follow-up to the Packard article.

The evidence of sexual reproduction involving the production of eggs has "continued, unaltered in essentials, almost since animal life began".[22] Other than this, little else can be said about egg evolution except: "Whatever the reason for the evolution of sex, it is found at all levels of the animal kingdom and the egg in its many forms is its manifestation."[23]

Many fossil eggs have been found, especially dinosaur eggs, but as noted, as far as can be determined from the abundant number of fossils found, eggs have always been close to identical to modern egg types. Chicken eggs are clearly Irreducibly Complex. All of the parts including the shell system, the air cell, the outer and inner membranes, the albumen, the vitelline membrane, and even the chalazae, and of course the embryo, must exist as a unit for the first egg system of life to survive.

Theories of bird egg evolution have been limited to attempting to explain the evolution of small details, such as a theory of the evolution of the egg size, the egg shell colour or nesting traits appearance.[24] Although these theories all begin with an existing fully developed egg, even here not much success has been achieved. After an extensive study testing various theories put forth to evaluate bird shell colour variations, one researcher concluded it is difficult

> "… to account for the evolution of egg pigmentation and difficult to judge the extent to which pigmentation is constrained by phylogeny. There is little indication that specific egg colours evolved primarily to signal their noxiousness to predators, or female quality to birds that will assist with chick rearing, though it is possible that particular egg colours have been co-opted secondarily by individual species to serve these functions. Nor does it seem likely that brood parasitism favours the evolution of either specific egg colours or elaborate patterning. The most plausible general explanation for egg pigmentation remains Wallace's (1889) hypothesis, that deviations in egg colour and patterning from the ancestral white have been selected primarily for their cryptic appearance."[25]

It is even difficult to create a just-so-story of the evolution of the bird egg. In the evolution of the vertebrate eye design that included an iris, a circular lens, a gel-filled vitreous cavity, pigment, and photoreceptor cells which are connected by the optic nerve to the brain, at least a possible scenario can be created, although when examined in detail it utterly fails.[26] Taylor postulated the bird egg evolved from reptile eggs, which he notes are only slightly different.[27] He then opines the reptile egg in turn evolved from fish eggs which consist of millions of complex cells that are structurally close to large blobs of jelly, producing a major gap between them and amniotic eggs.[28]

Fish eggs are designed to thrive in water, but the yolk of land animals must be protected and nourished by a privately contained pool of water and nutrients surrounded by a shell that allows gas exchange to take place. Thus, evolutionists believe the amniotic egg evolved, but "evolutionists have no idea how the" avian

> "… egg could have evolved. All they can tell us is the reptile egg is similar to it and it is supposed to have appeared first. This, of course, only throws the problem back one stage. They cannot even say *when* the evolution of the egg might have happened … the fossil record is blank just when we need it."[28]

The egg innovation was a critical step for Darwinism because it allowed life to move from the water onto the land. From there, modern evolutionists argue, evolved reptiles, dinosaurs, and mammals. Thus, here we have a chasm for which, as Taylor noted, we have no idea how and when this drastic change occurred.

Hayward has reviewed the attempts to explain this gap and concluded the existence of a bird's egg is a big miracle, and just as much of a problem for Darwinists as the origin of its wings.[29] Prof. Marc McKee commented on the egg design, noting "we should be making materials that are inspired by nature and by biology because … it is really hard to beat hundreds of millions of years of evolution in perfecting something."[30] Of course, no evidence exists of its evolution but enormous evidence exists of its irreducible design.

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