Reports of the National Center for Science Education

Reports of the National Center for Science Education is published by NCSE to promote the understanding of evolutionary science.

Vol 31, No 1 (2011)

Don Aguillard with another educator whose name is associated with a major court decision for evolution, Susan Epperson. Photograph: Eugenie C Scott.

ISSN: 2159-9270

Vol 31, No 1 (2011)

Table of Contents

Articles

Features

Reviews

ISSN: 2159-9270

REPORTS OF THE NATIONAL CENTER FOR SCIENCE EDUCATION

Published bimonthly by the National Center for Science Education

REPORTS.NCSE.COM
ISSN 2159-9270

ARTICLE

Recent Advances on the Origin of Life—Making Biological Polymers

Michael A Buratovich

The creationism–evolution debate almost always comes around to discussions about the origin of life. The enormousness of the problem of how organic chemicals (those compounds that contain the element carbon) reacted to synthesize biological molecules like proteins, nucleic acids, membrane lipids, and others, and how these self-replicated and assembled to form the first protocells, represents an attractive target for critics. In addition, the respectable degree of uncertainty that surrounds present answers to origin-of-life questions, and the large diversity of the proposed solutions, represent ample fodder for those who would question the validity of the entire origin-of-life research program. Consequently, creationists have said a great deal about origin-of-life research, and none of it is positive.

According to the doyen of recent (or "young-earth") creationist debaters, Duane Gish, the facts "establish beyond doubt that an evolutionary origin of life on this planet would have been impossible" (Gish 2007). In a review of the Miller-Urey experiment, prolific recent creationist author Jerry Bergman concluded that "this set of experiments—more than almost any other carried out by modern science—has done much more to show that abiogenesis is not possible on earth than to indicate how it could be possible" (Bergman 2004). "Intelligent design" proponent Stephen Meyer has written: "I have noted an increasing sense of futility and frustration arising among the scientists who work on the origin of life" (Meyer 2009:321).

Despite these depressing assessments, recent advancements in origin-of-life research provide a more positive perspective. To be fair to critics of this research, the origin of life is an extremely difficult problem. General models of the origin of life exist that are supported by a modicum of evidence, but there is at this time no detailed *explanation* of how life began that is satisfactorily supported by a large corpus of experimental data and is accepted by the majority of origin-of-life researchers.

We simply do not know the chemical mechanisms that brought forth life on earth. However, it is equally invalid that an evolutionary origin for life on earth is impossible. While the vast majority of origin-of-life researchers would agree with the former statement, few creationists would agree with the latter. It is also wildly incorrect to suggest that virtually no progress has been made in the six decades of research in this area. In fact, some criticisms of contemporary theories of the origin of life have been addressed by recent advances in this field.

Amino acid and polypeptide synthesis

In 1953, Stanley Miller published a short paper that detailed the synthesis of amino acids in a spark-discharge apparatus that contained reduced gases like methane (CH_4), ammonia (NH_3), hydrogen gas (H_2), and water (H_2O). This paper launched origin-of-life research, since it showed that the synthesis of amino acids (the building blocks of proteins), under what were thought to be reasonable prebiotic conditions, is remarkably simple (Miller 1953).

Miller concluded from the data available to him at the time that the early earth had a reducing atmosphere. Unfortunately, further geochemical research has shown that the atmosphere of the early earth probably consisted of neutral gases (for example, water vapor, carbon dioxide, and nitrogen) rather than reduced gases (for example, methane, ammonia, and hydrogen). While volcanoes and extraterrestrial impacts would have deposited reduced gases like methane or ammonia in the atmosphere, these gases would have been quickly destroyed by ultraviolet radiation from the sun. Therefore, a reducing atmosphere on the early earth almost certainly existed transiently (Schopf 1983; Zahnle and others 2010).

However, after Miller passed away on May 20, 2007, some of his former students found notebooks and vials that contained the results of experiments that were never analyzed. In particular, Miller ran a variation of his original experiment in which he used a water flask that had an aspirating nozzle at its top. This injected a steam jet into the spark chamber, and simulated lightning strikes in a steam-filled volcanic eruption (Miller 1955). Analyses of vials from this experiment revealed higher amounts and different types of amino acids than the original Miller experiment (Johnson and others 2008). This volcanic steam discharge experiment shows that even if the atmosphere was not reducing, amino acid synthesis on the volcanically active early earth still would have been very effective.

Making amino acids is possible, but what about forming peptide bonds between them to form polypeptides? Recent creationist Roger Patterson offered this criticism of prebiotic peptide synthesis: "Proteins do not form from piles of amino acids … Proteins cannot form in water, because the water breaks the bonds that hold the amino acids together—a process known as hydrolysis" (Patterson 2007:139). Patterson is *partly* correct, since peptide bonds, the bonds between amino acids in proteins, do not form spontaneously; amino acids must be activated in order for peptide bonds to form between them. Inside cells, amino acids are activated by attaching them to transfer RNAs (tRNAs), and the amino acyl-tRNA bond allows the formation of peptide bonds on the surface of ribosomes without the input of any further energy (Weaver 2008:522). However, proteins are synthesized inside cells, which are composed, largely of water. This renders Patterson's claim—namely that proteins cannot form in water—specious.

As it turns out, a simple gas expelled by volcanoes called carbonyl sulfide (Figure 1) can link amino acids together under very mild conditions that do not threaten their stability (Leman and others 2004). Thus, volcanic eruptions could have provided the means to make amino acids and link them together with peptide bonds to form simple proteins.

Another common criticism of Miller's experiment comes from the "handedness" of amino acids. Amino acids exist in "right-handed" or "left-handed" forms (Figure 2). Living organisms almost exclusively utilize the left-handed forms, and Miller's experiment produced

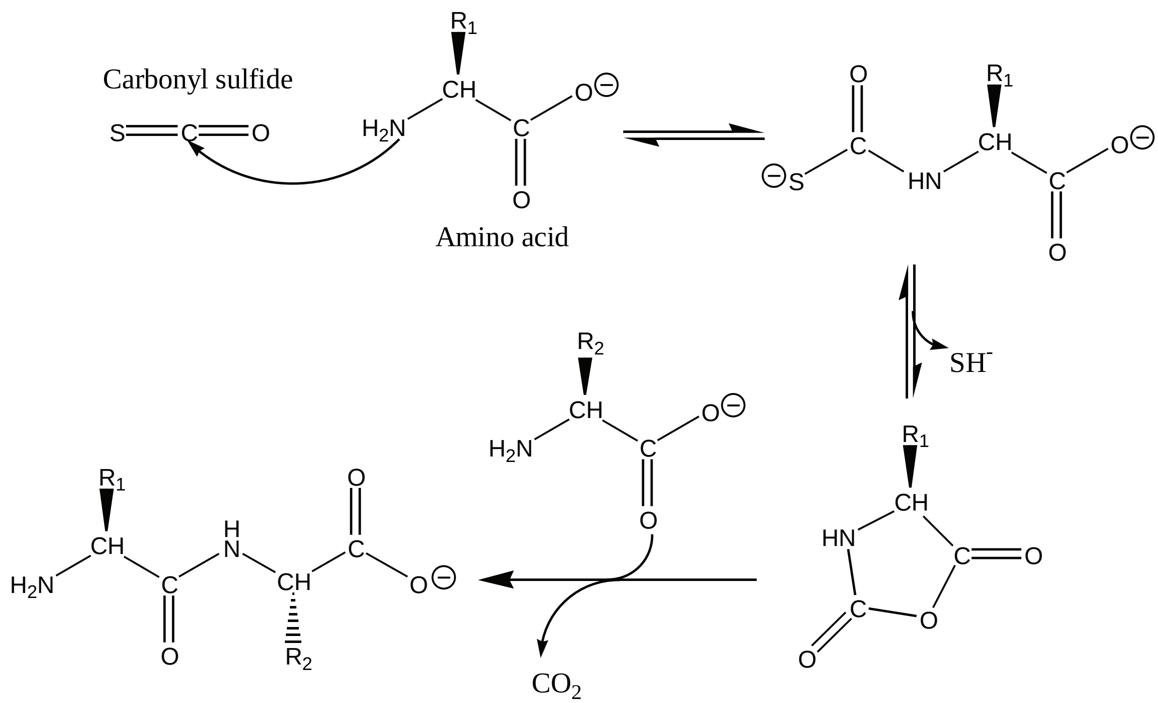

FIGURE 1. *Carbonyl sulfide, the most abundant sulfur-containing compound in the atmosphere, is released from volcanoes, the oceans and deep sea vents. Reaction of the carbonyl sulfide with amino acids generates an α-amino acid N-carboxyanhydride (NCA), otherwise known as a Leuchs anhydride. The NCA efficiently reacts with another amino acid or polypeptide to form a dipeptide, or a new polypeptide with one more amino acid at its amino-terminal end.*

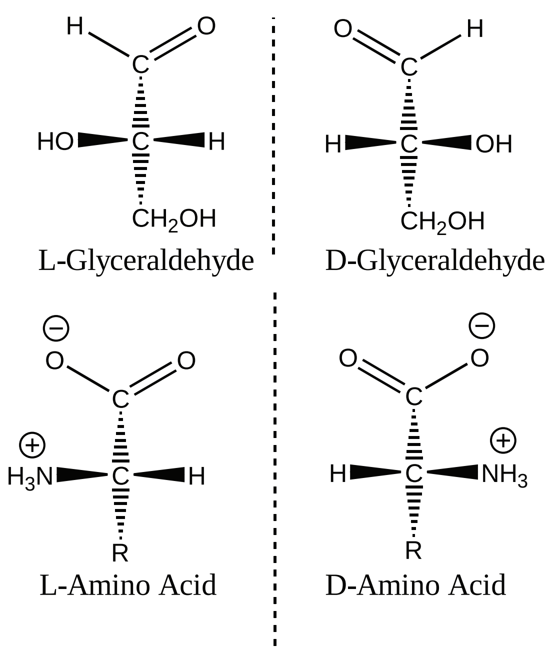

FIGURE 2. *Two different forms of a generalized amino acid in three-dimensional space relative to the absolute configuration of L- (left-handed) and D- (right-handed) glyceraldehyde. Chemical constituents attached to the central carbon by dark wedges extend above the plane of the paper, and those attached by faded-line wedges extend below the plane of the paper. The three-dimensional structure of the chemical groups attached to the central carbon is that of a tetrahedron, and this representation of the molecule is known as a Fischer projection. The composition of the "R" group differs between the twenty different amino acids. Amino acids are "chiral" molecules, which mean that they exist in non-super-imposable mirror images. The molecules are designated as "L" or left-handed or "D" or right-handed according how the substituent atoms are attached to the central, chiral carbon, relative to the absolute configuration of the three-carbon sugar glyceraldehyde. L-amino acids have their nitrogen-containing "amino groups" (NH_3^+-) on the left-hand side, and D-amino acids have their amino groups to the right side.*

mixtures of right- (D) and left-handed (L) amino acids. The synthesis of proteins that contain mixtures of right- and left-handed amino acids would, presumably, have generated non-functional proteins that could not have contributed to the origin of life. The only way to make truly functional proteins is to make polypeptides that consist solely of left-handed amino acids. This generates a problem for the origin of life because, according to Stephen Meyer: "Starting from mixtures of D-forms and L-forms, the probability of building a 150-amino acid chain at random in which all bonds are peptide bonds and all amino acids are L-form is, therefore, roughly 1 chance in 10^{90}" (Meyer 2009:207).

This is certainly a wildly improbable event, but, as it turns out, there are natural mechanisms that might have selected left-handed over right-handed amino acids. First, astronomers have discovered a special type of polarized light in our region of space that selectively destroys right-handed amino acids (Bailey 2001). This is precisely why slight excesses of left-handed amino acids have been found in several meteorites (Glavin and Dworkin 2009). Is it possible to amplify these excesses? Ronald Breslow at Columbia University has shown that evaporation of solutions of amino acids that have slight excesses of the left-handed form causes mixtures of the right- and left-handed forms of the amino acids to fall out of solution, which leaves a vast excess of left-handed forms of amino acids remaining in solution for further prebiotic reactions (Breslow and Levine 2006). Since the right-handed amino acids have been removed from solution (where chemical reactions occur), only the left-handed ones remain for further prebiotic chemistry. Another way to think about this amplification mechanism is to imagine that you have 40 black squirrels and 35 gray ones living in your backyard. The grays ones eat piñon nuts, but the black ones eat walnuts. If a disease equally wipes out both types of squirrels so that you only have four squirrels left, the remaining squirrels are almost certainly exclusively black because there were more black squirrels to begin with. Now the squirrels that frolic about in your backyard will be largely black and will eat walnuts and not piñon nuts. This illustrates how natural mechanisms can explain the tendency for left-handed amino acids in extant living organisms.

The "RNA first" hypothesis

While the prebiotic synthesis of amino acids and proteins represents an exciting advance in origin of life research, most scientists think that nucleic acids were some of the first molecules formed during the early history of the earth. Nucleic acids are the informational molecules in living organisms. Deoxyribonucleic acid (DNA) stores genetic information and ribonucleic acid (RNA) acts, largely, as an informational intermediate.

The prevalent theory in origin-of-life research postulates that RNA was the first biological molecule to achieve ascendency. There are two main strands of evidence for an "RNA first" view of the origin of life. First, the rich uses of RNAs in modern cells for such central cellular processes like translation (protein synthesis), RNA processing and splicing, maintenance of telomeres (structures that cap linear chromosomes), RNA editing, and regulation seem to represent remnants of an ancient RNA world (Gesteland and others 2006:287–467). Likewise, particular cellular processes are initiated by RNA. For example, RNA primers are necessary to prime DNA synthesis. In addition, the precursors for DNA synthesis (deoxyribonucleotides) are initially made as the precursors for RNA synthesis (ribonucleotides), but are converted by an enzyme into the precursors for DNA synthesis. These same nucleic acid precursors are part of enzymatic cofactors that are conserved throughout all living systems (Müller 2006). Second, discoveries in the 1980s that ribonucleic acid (RNA) molecules possess catalytic activity (Kruger and others 1982; Guerrier-Takada and others 1983; Zaug and Cech 1986) also argue that life began with catalytic RNAs that directed early biochemical reactions and later surrendered to more efficient and highly accurate protein catalysts.

Nevertheless, the "RNA world" hypothesis has received heavy criticism from a variety of corners. Stephen Meyer notes that "both synthesizing and maintaining these essential RNA building blocks, particularly ribose (the sugar incorporated into nucleotides) and the nucleotide bases, has proven either extremely difficult or impossible under realistic prebiotic conditions" (Meyer 2009:301). Recent creationist Brian Thomas writes, "In a pre-biotic chemical soup, the RNA portions of ribonucleoproteins would have broken down within minutes with exposure to ultraviolet radiation, oxygen, or water" (Thomas 2009). In fact, chemist Graham Cairns-Smith published a list of problems with the RNA world hypothesis (Cairns-Smith 1982). This list can be found on several creationist websites (for example, AiG nd). Honesty requires us to admit the formidable problems associated with the postulation of an RNA world, but recent discoveries have provided ways around some of the more common objections.

Nucleic Acid Synthesis

RNA molecules are polymers of ribonucleotides. A "nucleotide" consists of three components: a sugar, nitrogenous base, and a phosphate (Figure 3). Ribonucleotides are a specific type of nucleotide whose sugar consists of a five-carbon molecule called ribose. Molecules that only have a sugar and a base are called "nucleosides." Synthesizing these three components and properly linking them together under prebiotically feasible conditions has proven to be problematic. Ribose is easily synthesized by means of the "formose reaction" that links formaldehyde molecules together in an alkaline environment. However, under these conditions ribose readily reacts with all the other molecules made by the formose reaction to form a brown, complex mixture of organic molecules. Therefore, despite its ease, the formose reaction is probably not a viable option for the synthesis of ribose under prebiotic conditions (Shapiro 1988). Yet another problem is the inherent instability of ribose in aqueous solutions, which, at neutral pH, has a half-life of only 73 minutes at 100°C and 44 years at 0°C (Larralde and others 1995). Finally, like amino acids, ribose comes in two three-dimensional forms, which are called D- and L-ribose (Figure 4). DNA and RNA from extant organisms are made from nucleotides that exclusively contain D-ribose (Nelson and Cox 2008:272), but prebiotic synthetic schemes for ribose consistently make mixtures of the D- and L-forms. Unfortunately, if nucleotides are produced with mixtures of the D- and L-forms of ribose, these nucleotides do not make RNA, since the polymerization reaction under these conditions is inhibited by "enantiomeric cross-inhibition" (Joyce and others 1987).

Even more problems arise when one considers the synthesis of nitrogenous bases. Nitrogenous bases come in two forms, purines and pyrimidines. There are two types of purine bases, adenine and guanine, which are found in both DNA and RNA. There are three types of pyrimidine bases, cytosine, thymine and uracil. Cytosine is found in DNA and RNA, but uracil only occurs in RNA, and thymine only occurs in DNA, with a few rare exceptions (Figure 5). In prebiotic reactions, dilute solutions of hydrogen cyanide (HCN) in ammoni-

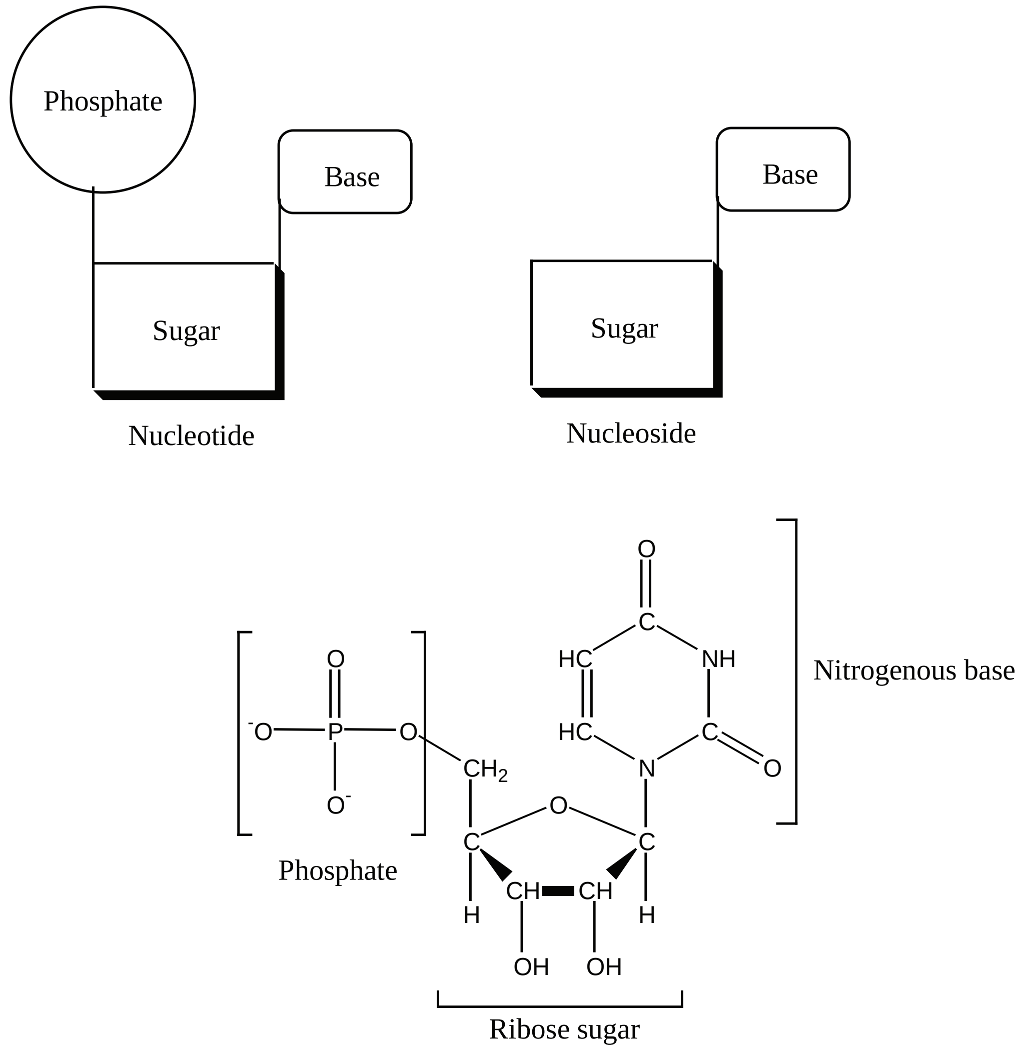

FIGURE 3. *The generalized structures of nucleotides and nucleosides. The sugars found in contemporary nucleic acids are the five-carbon sugar ribose in RNAs and 2'-deoxyribose in DNA. The structure shows the ribonucleotide uridylate, which is also known as uridine-5'-monophosphate (UMP), which has a phosphate, ribose and a pyrimidine-based nitrogenous base known as uracil.*

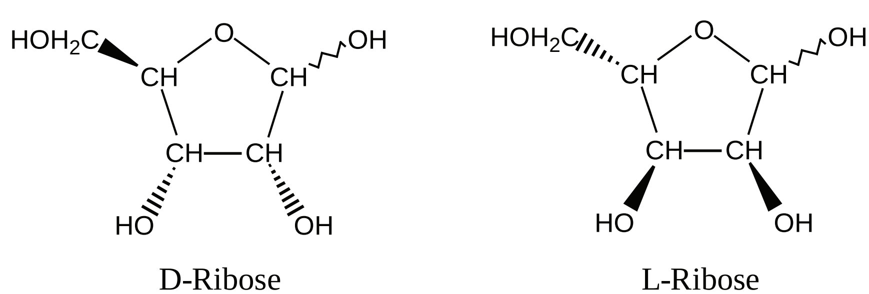

FIGURE 4. *Two different forms of the five-carbon sugar ribose, which is the sugar found in RNA. In extant organisms, only the D-form of ribose is used. In solution, ribose cyclizes to form the "furanose" ring form of the sugar. All nucleic acids and polynucleotides use the ribofuranose form of ribose rather than the linear form. The squiggly line indicates that the hydroxyl (-OH) group has a variable configuration and can project either above the plane of the paper or below it.*

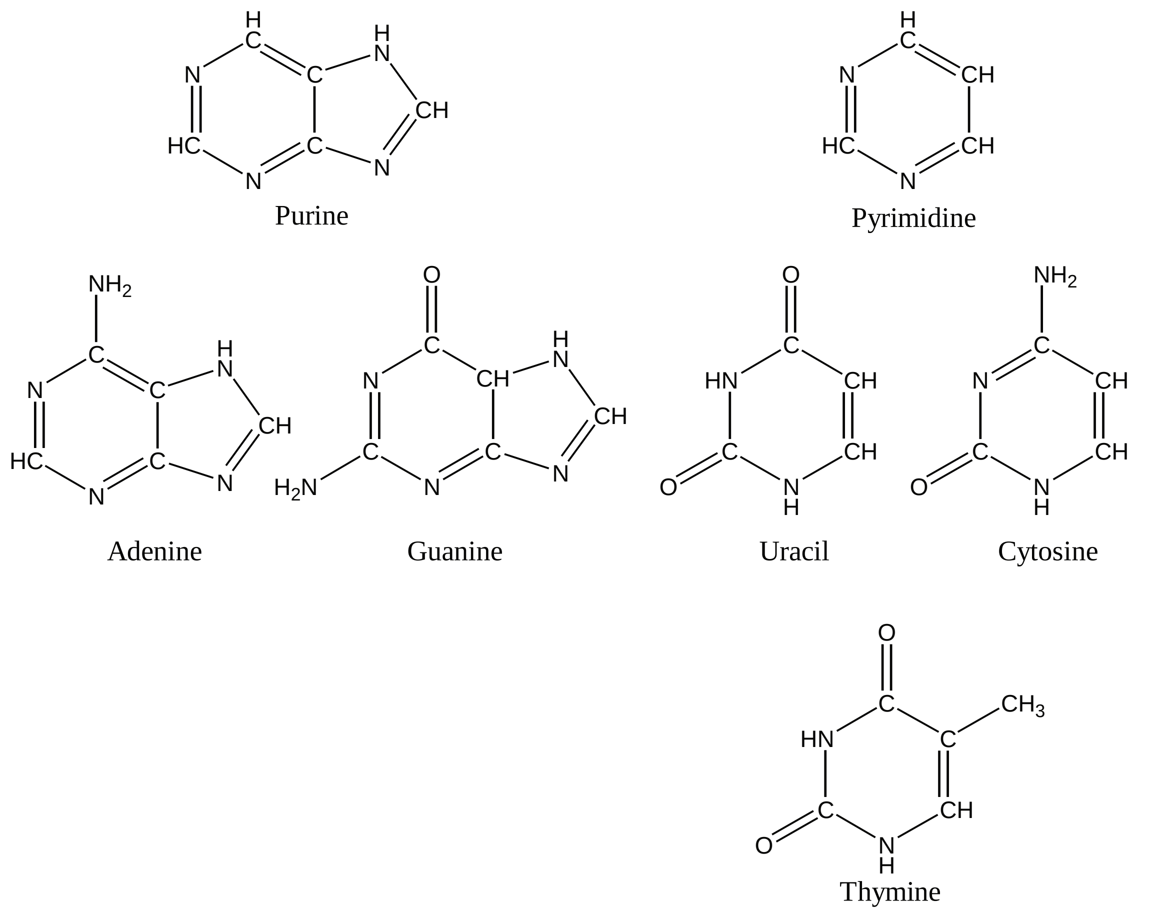

FIGURE 5. *The different nitrogenous bases found in extant nucleic acids. These bases are built on one of two parent compounds. Purine is the parent compound for adenine and guanine, which occur in both RNA and DNA. Pyrimidine is the parent compound for uracil, which is only found in RNA, thymine, which is only found in DNA, and cytosine, which is found in both DNA and RNA. The attachment of a sugar to a nitrogenous base forms a nucleoside, and the attachment of a phosphate group to a nucleoside converts it into a nucleotide.*

um hydroxide (NH_4OH) can easily synthesize adenine (Oró 1961). However, this generates further problems, since the presence of these nitrogenous substances would inhibit the formose reaction, which makes the concomitant synthesis of ribose and the nitrogenous bases rather improbable (Shapiro 1995).

A solution to this impasse for the synthesis of pyrimidine-containing nucleotides has been proposed by John Sutherland and his colleagues at the University of Manchester. Traditional ways of making ribonucleotides consisted of synthesizing ribose and a base in separate reactions, and then linking the two together. Unfortunately, the reaction that directly links ribose to the nitrogenous base to form a nucleoside does not work. Instead, Sutherland and his colleagues used stock prebiotic compounds that have been detected in solar nebulae and countless other prebiotic simulations to form intermediates in the presence of phosphate that efficiently formed pyrimidine-containing ribonucleotides (Figure

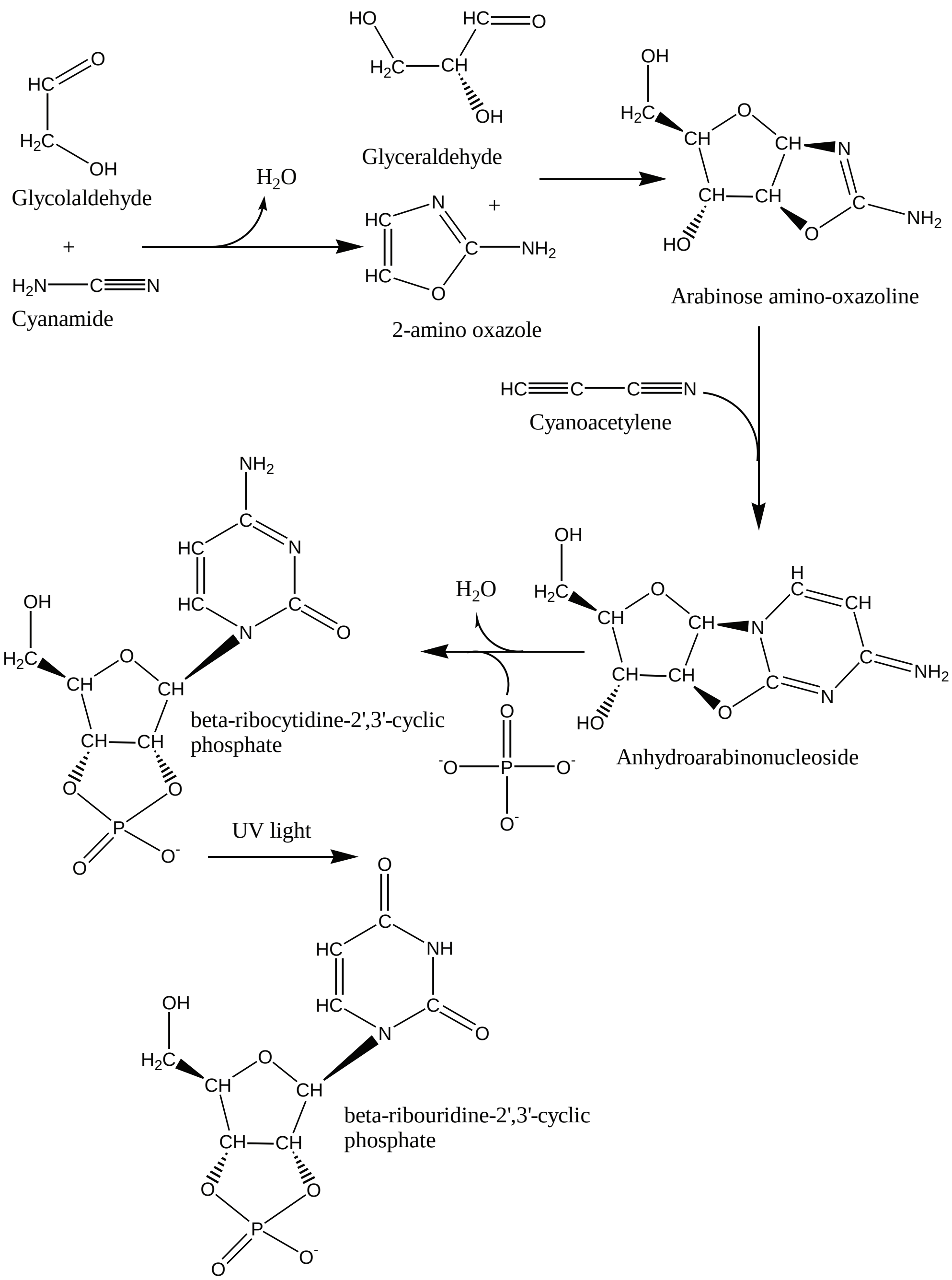

Figure 6. *Reaction scheme for the prebiotic synthesis of the two pyrimidine nucleotides. All steps in this reaction scheme show high efficiency and use chemicals that have been identified as stock prebiotic molecules. The reaction begins with glycolaldehyde and cyanamine, two stock prebiotic compounds, to form 2-amino-oxazole, which, in the presence of phosphate buffer, reacts with glyceraldehydes to form pentose amino-oxalines. The arabinose derivative of these pentose amino-oxalines was the one of the highest yields of this reaction and dehydration caused the crystallization of the side products, enriching the reaction for arabinose amino-oxaline. Arabinose amino-oxaline efficiently reacted with cyanoacetylene, another stock prebiotic compound in phosphate buffer, to form anhydroarabinonucleoside. In the phosphate buffer, this compound formed β-ribocytidine-2',3'-cyclic phosphate, but exposure to ultraviolet radiation not only degraded the undesirable side products, but also converted some of the β-ribocytidine-2',3'-cyclic phosphate into β-ribouridine-2',3' -cyclic phosphate, the other nucleotide required for RNA synthesis.*

6). Furthermore, the side products of these reactions are destroyed by ultraviolet light irradiation, resulting in two pyrimidine-containing ribonucleotides, cytidine monophosphate and uridine monophosphate (Powner and others 2009). Sutherland's solution clears several hurdles in the quest to synthesize pyrimidine-containing rubonucleotides under prebiotically plausible conditions.

The production of purine-based nucleotides has not yet been fully worked out, but here again; recent work has provided some remarkable possibilities. The purine adenine is easily made by hydrogen cyanide (HCN), but the ability of HCN to react depends on its concentration. At high concentrations, HCN polymerizes, but at low concentrations, HCN degrades to formamide. This probably explains why formamide is found in a variety of comets, asteroids, and interstellar clouds (Ehrenfreund and others 2004:17–31,179–203). Formamide is formed by several prebiotic compounds (Figure 7), is liquid under a wide range of temperature and pressure, and has a half-life in water of 200 years at 25°C and pH 7.0 (Costanzo and others 2007). Ernesto Di Mauro and his colleagues have shown that if formamide is exposed to heat (130°C) and UV radiation (<300 nm), it can form all the purine bases found in RNA (Barks and others 2010). Therefore, prebiotic synthesis of purine bases is extremely easy under relatively gentle conditions.

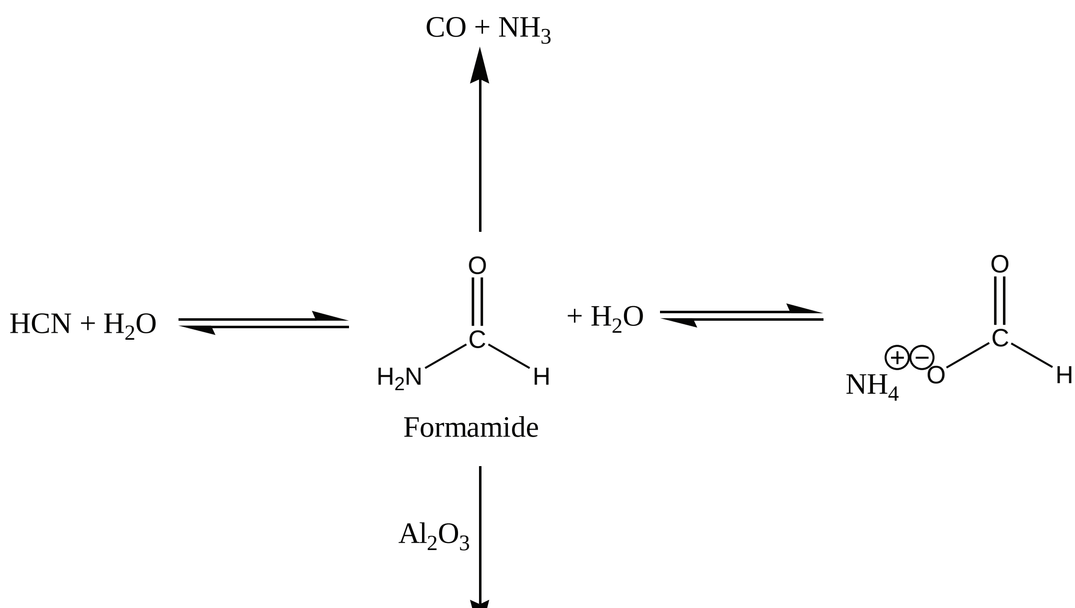

FIGURE 7. *Formamide chemistry. When exposed to water, hydrogen cyanide degrades to formamide (H_2NCOH), and while formamide can degrade to other more basic molecules, its stability and reactivity make it an excellent substrate for prebiotic reactions. The high dielectric constant of formamide also makes it an excellent solvent for metal oxides and inorganic salts that can act as catalysts for prebiotic reactions.*

What about linking these bases to ribose sugars? Once again, forming nucleosides from isolated ribose and purines is a highly inefficient reaction, but experiments in the laboratory of Hicham Idriss at the University of Auckland have shown that ultraviolet irradiation of formamide on the surface of titanium dioxide (TiO_2) can form nucleosides (Senanayake and Idriss 2006). Because TiO_2 is found in reasonable amounts on earth and stratospheric particulates, such catalysis is reasonable under prebiotic conditions.

The production of D-ribose–containing nucleotides over L-ribose nucleotides could result from two different mechanisms. First, workers in Ronald Breslow's lab made "saturated" solutions of nucleosides that contained cytosine, uracil, or adenine attached to either D- or L-ribose. Saturated solutions have molecules dissolved in a solvent at such a high concentration that they begin to "precipitate," or fall from solution. In these saturated solutions, L-ribose-containing nucleosides tended to precipitate preferentially, which greatly enriches the solution for D-ribose-containing nucleosides. This leads to solubility-based amplification of these D-ribose nucleosides (Breslow and Cheng 2009). Secondly, RNA molecules made from D-ribose-containing nucleotides are not as susceptible to degradation by ultraviolet light (Bolik and others 2007). These two mechanisms would selectively enrich D-ribose nucleosides and selectively degrade polynucleotides made from L-ribose nucleosides.

Linking phosphates (PO_4^{-3}) to these nucleosides to form nucleotides is problematic because most of the phosphorus in the early earth would have been present as apatites, which are quite insoluble in water, and therefore unavailable for prebiotic chemistry (Schwartz 2006). However, three different processes can overcome this phosphorus problem. First, lightening strikes during volcanic eruptions can reduce insoluble phosphates to phosphites (PO_3^{-2}), which are more soluble and show greater reactivity. Secondly, the combination of apatites with hot basalts in volcanoes can produce soluble forms of phosphate. Third, the mineral schreibersite ($(Fe,Ni)_3P$) from meteorites is a highly soluble form of phosphorus that readily forms phosphates when combined with water. Thus phosphate availability was probably not a problem on the early earth.

The addition of a phosphate to a nucleoside (phosphorylation) is not a favorable reaction, since it requires the input of a respectable amount of energy. However, particular phosphate-containing minerals, like libethenite ($Cu_2(PO_4)(OH)$) and hydroxyapatite ($Ca_5(PO_4)_3(OH)$), can readily phosphorylate nucleosides and convert them into nucleotides. Phosphate addition occurs on the surfaces of these minerals followed by nucleotide release (Costanzo 2007).

Finally, the linkage of nucleotides to form polynucleotides is yet another unfavorable reaction. As "intelligent design" advocates Mills and Kenyon note:

> nucleotides do not link unless there is some type of activation of the phosphate group. The only effective activating groups for the nucleotide phosphate group (imidazolides, etc.), however, are those that are totally implausible in any prebiotic scenario. For living organisms today, adenosine-5′-triphosphate (ATP) is used for activation of nucleoside triphosphate groups, but ATP would not be available for prebiotic synthesis. (Mills and Kenyon 1996)

Yet again, recent work has provided new insights. Workers in Ernesto Di Mauro's laboratory have shown that cyclic nucleotides like cyclic adenosine monophosphate (cAMP) and cyclic guanosine monophosphate (cGMP) readily formed RNA polymers in water after being heated. Polynucleotide chains over 120 bases long were observed in these experiments, and they were synthesized with simple precursors and without enzymes (Costanzo and others 2009).

The RNA world

The synthesis of RNA from ribonucleotides provides opportunities for catalytic RNAs to accelerate various reactions. What kinds of reactions can RNA-based enzymes, or ribozymes, catalyze? In the 1990s, workers in David Bartel's laboratory devised methods to generate pools of RNA molecules with random sequences and select individual RNA molecules from these pools that could act as RNA ligases (Bartel and Szostak 1993). RNA ligases catalyze the joining of two smaller RNA molecules to form a larger one, and Bartel's lab isolated 65 different RNA ligases and showed that 1 of 20 trillion RNA molecules that were at least 220 nucleotides long could catalyze RNA ligation reactions (Ekland and others 1995). Further work showed that these RNA ligases could be subjected to "in vitro evolution" to form RNA polymerases, or molecules that could catalyze the addition of nucleotides to the ends of RNA molecules. While this RNA-based RNA polymerase is quite accurate (96.7%), it binds the template quite weakly and only adds a maximum of 14 nucleotides before it undergoes self-degradation (Johnston and others 2001). Various innovations have been employed to create ribozyme RNA polymerases that bind the substrate much more tightly, but these ribozymes are also quite slow and can only add one nucleotide (McGinnes and Joyce 2003; Ikawa and others 2004).

Ribozymes can also catalyze the synthesis of ribonucleotides (Figure 8). Ribozymes can catalyze aldol condensations between glyceraldehyde and glycolaldehyde to form ribose (Fusz and others 2005). Ribose phosphorylation is trivial, since ribozymes can efficiently catalyze the transfer of phosphate groups (Wilson and Szostak 1999). The synthesis of nucleosides from phosphorylated ribose has also been demonstrated by ribozymes (Unrau and Bartel 1998; Lau and others 2004). Likewise several different ribozymes can transfer phosphates to polynucleotides or to individual nucleotides (Lorsch and Szostak 1994; Curtis and Bartel 2005). Therefore, the advent of ribozymes brought new and more efficient ways to make the precursors necessary for the synthesis of RNAs.

The synthesis of peptide bonds between amino acids, which is necessary for the production of proteins, is also catalyzed by ribozymes. The attachment of a nucleotide to the carboxyl group of the amino acid to activate it is catalyzed by ribozymes (Kumar and Yarus 2001), as is the aminoacylation of tRNAs (Saito and others 2001). The formation of peptide bonds between activated amino acids is also catalyzed by several different ribozymes (Zhang and Cech 1998; Illangasekare and Yarus 1999; Steitz and Moore 2003).

Protocells

In order to form something that resembles a cell, self-replicating RNA molecules had to assemble inside a membrane-like structure to form a "protocell" that could not only fuse with other protocells, but divide by budding into smaller protocells.

Biological membranes surround modern cells and act as the boundary for the cell interior. Contemporary cell membranes are bilayers of phospholipids. Phospholipids are fatty acid molecules to which phosphate groups are attached with a "head group" that differs according to the type of phospholipid. The bilayer consists of a layer of phospholipids that sit

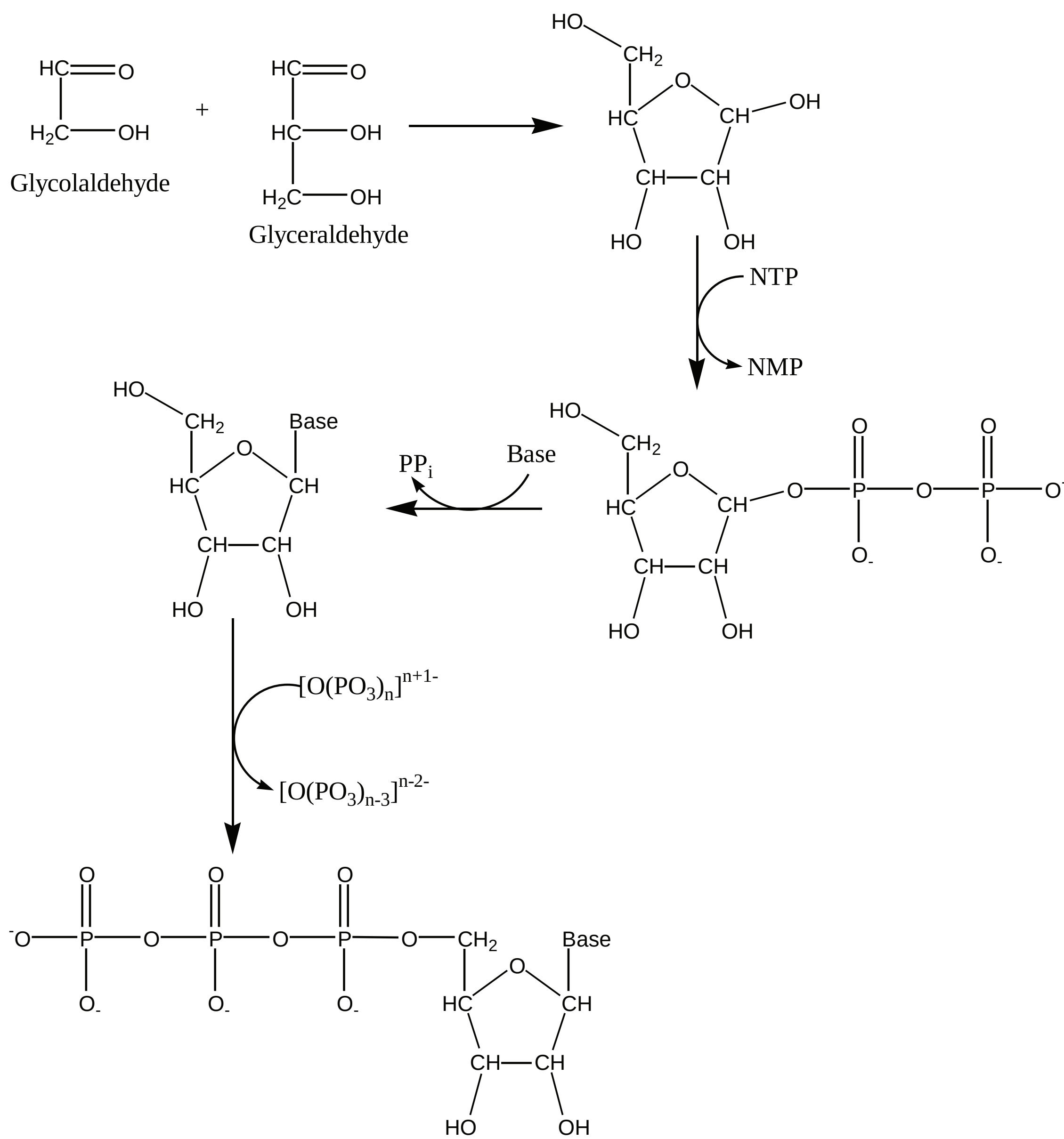

FIGURE 8. *Ribozyme catalyzed ribonucleotide synthesis. Each step in the synthesis of ribonucleotides has been shown to be catalyzed by ribozymes with the exception of the phosphorylation of free ribose and nucleosides. However, ribozymes can catalyze very similar reactions and prebiotic sources of phosphate have also been shown to phosphorylate nucleosides in the presence of clay minerals.*

upon a mirror image of itself. Therefore phospholipid bilayers have their phosphate groups pointed toward the cell interior and exterior and the water-hating, fat-loving fatty acid molecule pointing towards each other. Several molecules like free fatty acids or fatty alcohols, which are water-loving on one side and water hating on the other side (amphiphilic), have the ability to form bilayers, and the first protocells probably had membranes made from molecules simpler than phospholipids.

The encapsulation of ribozymes and other components by membrane-like structures not only protects them, but also constructs a protocell that can bud and divide. Fatty acids (linear hydrocarbons that end in –COOH) or fatty alcohols (linear hydrocarbons that end in –OH) can form membrane-like structures and are easily made by reactions between hydrogen gas and carbon dioxide under conditions that approximate hydrothermal vents (McCollum and others 1999; Rushdi and Simoneit 2001), or by electrical discharges into mixtures of methane and water (Allen and Ponnamperuma 1967). The fact that fatty acids and fatty alcohols are found in meteorites and comets underscores the ease of making these molecules (Yuen and Kvenvolden 1973; Dworkin and others 2001).

When vesicles are made by free fatty acids, free fatty alcohols, or glycerol esters of fatty acids (all of which can be made under prebiotic conditions), they not only grow by incorporating more membrane molecules, but also bud off to form new vesicles. These vesicles also allow the entry of precursors for polynucleotide synthesis and nicely support polynucleotide synthesis (Deamer 2008). These vesicles spontaneously form, bud and grow, and are leaky enough to allow the entry of nucleotides to support the synthesis of RNAs, and support the synthesis of polynucleotides (Mansy 2008).

Additionally, researchers in Jack Szostak's laboratory have shown that those protocells that support the best RNA replication expand and gobble up the more poorly performing-protocells that do not support RNA synthesis that is as robust as the larger protocells. This is an example of competition, or, if you please, Darwinian selection occurring between protocells (Chen and others 2004). Stephen Meyer has asserted that natural selection cannot occur in prebiotic systems (Meyer 2009:274–277), but origin-of-life research clearly shows that it can.

Conclusions

Much work remains to be done in origin of life research, and many burning questions remain. What was the first self-replicating ribozyme? Was the genetic system of the first protocells single-stranded RNA or double stranded RNA? What served as the unwinding enzyme for double-stranded RNA, and was this a ribozyme? Was there a pre-RNA world, and what was the nature of the informational molecule used in the pre-RNA world? What did the first protocell look like? When did proteins take over from ribozymes? What catalytic activities did the first ribozymes have? How were the cyclic nucleotides used for polymerization made? When did DNA take over from RNA? What role did proteins play in the RNA world? Despite the multitudes of questions that remain, origin of life research has made some remarkable advances in the last decade, and several standard problems have been satisfyingly answered.

Criticisms also remain. Stephen Meyer, for example, asserts that "ribozymes are poor substitutes for proteins." He continues:

> For this reason claiming that RNA could replace proteins in the earliest stages of chemical evolution is extremely problematic. To say otherwise would be like asserting that a carpenter wouldn't need any tools besides a hammer to build a house because the hammer performed two or three carpentry functions, but building a house requires many specialized tools that can perform a great variety of carpentry functions. (Meyer 2009:304)

What Meyer seems to forget is that at this stage in the history of life, you do not need a two-story house with central heating and plumbing; you only need a tent, and a hammer is all you need to put up a tent. Meyer also objects that "ribozyme engineering does not simulate undirected chemical evolution … Ribozyme engineers tend to overlook the role that their own intelligence has played in enhancing the functional capacities of their RNA catalysts" (Meyer 2009:318–319). However, ribozyme engineering experiments use randomly-generated RNA sequences for their experiments. Even in those experiments that begin with one ribozyme and then attempt to improve or change its activity, those sequences that are attached to or inserted into the ribozyme core are randomly generated. The "intelligence" in the experiments consists in the screening and detection of those molecules that show the desired activity. The fact that RNA molecules with randomly-generated sequences can display the activities that they do is a testimony to the versatility of RNA ribozymes and the possibilities available to prebiotic reaction schemes on the early earth. Furthermore, the fact that ribozyme and protein-based polynucleotide polymerases use the same enzymatic mechanism is certainly not a coincidence (Buratovich 2006), but is more satisfactorily explained by common ancestry.

These advances answer some of the standard stock objections against chemical evolution, and they might provide some comfort and relief to those in the mainstream scientific community. However, it is doubtful that these new data will win any converts from our creationist colleagues. People often adhere to creationism for reasons that go beyond scientific considerations and convincing our opponents of the veracity of our viewpoint will probably take a much more complicated and multifaceted approach.

References

[AiG] Answers in Genesis. nd. Evolutionist criticisms of the RNA World conjecture. Petersburg (KY): Answers in Genesis [Internet]; [cited 2011 Feb 1]. Available from: http://www.answersingenesis.org/home/area/tools/Quotes/cairns-smith_RNA.asp.

Allen WV, Ponnamperuma C. 1967. A possible prebiotic synthesis of monocarboxylic acids. *Currents in Modern Biology* 1:24–28.

Bailey J. 2001. Astronomical sources of circularly polarized light and the origin of homochirality. *Origins of Life and Evolution of Biospheres* 31:167–183.

Barks HL, Buckley R, Grieves GA, Di Mauro E, Hud NV, Orlando TM. 2010. Guanine, adenine, and hypoxathine production in UV-irradiated formamide solutions: Relaxation of the requirements for prebiotic purine nucleobase formation. *Chembiochem: A European Journal of Chemical Biology* 11:1240–1243.

Bartel DP, Szostak JW. 1993. Isolation of new ribozymes from a large pool of random sequences. *Science* 261:1411–1418.

Bergman J. 2004 Why the Miller-Urey research argues against abiogenesis. *CEN Technical Journal* 18(2):28–36, August.

Bolik S, Rübhausen M, Binder S, Schulz B, Perbandt M, Genov N, Erdmann V, Klussmann S, Betzel C. 2007. First experimental evidence for the preferential stabilization of the natural D- over the nonnatural L-configuration in the nucleic acids. *RNA* 13:1877–1880.

Breslow R, Levine MS. 2006. Amplification of enantiomeric concentrations under credible prebiotic conditions. *Proceedings of the National Academy of Sciences USA* 103(35):12979–12980.

Breslow R, Cheng Z-L. On the origin of terrestrial homochirality for nucleosides and amino acids. *Proceedings of the National Academy of Sciences USA* 2009; 106(23):9144-9146.

Buratovich MA. 2006. A common, conserved mechanism for all polynucleotide polymerases. *Reports of the National Center for Science Education* 26(3):32–37.

Cairns-Smith, AG. 1982. *Genetic Takeover: And the Mineral Origins of Life*, Cambridge: Cambridge University Press.

Chen IA, Roberts RW, Szostak JW. 2004. The emergence of competition between model protocells. *Science* 305:1474–1476.

Costanzo G, Saladino R, Crestini C, Ciciriello F, Di Mauro E. 2007. Formamide as the main building block in the origin of nucleic acids. *BMC Evolutionary Biology* 7(Suppl 2):S1.

Costanzo G, Saladino R, Crestini C, Ciciriello F, Di Mauro E. 2007 Nucleoside phosphorylation by phosphate minerals. *Journal of Biological Chemistry* 282(23):16729–16735.

Costanzo G, Pino S, Ciciriello F, Di Mauro E. 2009. Generation of long RNA chains in water. *Journal of Biological Chemistry* 284(48):33206–33216.

Curtis EA, Bartel DP. 2005. New catalytic structures from an existing ribozyme. *Nature Structural Molecular Biology* 12:994–1000.

Deamer DW. 2008. How leaky were primitive cells? *Nature* 454:37–38.

Dworkin J, Deamer D, Sandford S, Allamandola L. 2001. Self-assembling amphiphilic molecules: Synthesis in simulated interstellar/precometary ices. *Proceedings of the National Academy of Sciences USA* 98:815–9.

Ehrenfreund P, Irvine WM, Owen T, Becker L, Blank J, Brucato JR, Colangeli L, Derenne S, Dutrey A, Despois D, Lazcano A, Robert F, editors. 2004. *Astrobiology: Future Perspectives*. New York: Springer.

Ekland EH, Szostak JW, Bartel DP. 1995. Structurally complex and highly active RNA ligases derived from random RNA sequences. *Science* 269:364–370.

Fusz S, Eisenfuhr A, Srivatsan SG, Heckel A, Famulok M. 2005. A ribozyme for the aldol reaction. *Chemical Biology* 12:941–950.

Gesteland RF, Cech TR, Atkins JF, editors. 2006. *The RNA World*. 3rd ed. Cold Spring Harbor (NY): Cold Spring Harbor Laboratory Press,

Gish D. 2007. A few reasons an evolutionary origin of life is impossible. *Acts & Facts* 36(1).

Glavin DP, Dworkin JP. 2009. Enrichment of the amino acid L-isovaline by aqueous alteration of CI and CM meteorite parent bodies. *Proceedings of the National Academy of Sciences USA* 106(14):5487–5492.

Guerrier-Takada C, Gardiner K, Marsh T, Pace N, Altman S. The RNA moiety of ribonuclease P is the catalytic subunit of the enzyme. *Cell* 1983; 35(3 Pt2):849–857.

Ikawa Y, Tsuda K, Matsumura S, Inoue T. 2004. De novo synthesis and development of an RNA enzyme. *Proceedings of the National Academy of Sciences USA* 101:13750–13755.

Illangasekare M, Yarus M. 1999. A tiny RNA that catalyzes both aminoacyl-RNA and peptidyl-RNA synthesis. *RNA* 5:1482–1489.

Johnson AP, Cleaves HJ, Dworkin JP, Glavin DP, Lazcano A, Bada JL. 2008. The Miller volcano spark discharge experiment. *Science* 322:404.

Johnston WK, Unrau PJ, Lawrence MS, Glasner ME, Bartel DP. 2001. RNA-catalyzed RNA polymerization: Accurate and general RNA-templated primer extension. *Science* 292:1319–1325.

Joyce GF, Scwartz AW, Miller SL, Orgel LE. 1987. The case for an ancestral genetic system involving simple analogues of the nucleotides. *Proceedings of the National Academy of Sciences USA* 84:4398–4402.

Kruger K, Grabowski PJ, Zaug AJ, Sands J, Gottschling DE, Cech TR. 1982. Self-splicing RNA: autoexcision and autocyclization of the ribosomal RNA intervening sequence of Tetrahymena. *Cell* 31(1):147–157.

Kumar RK, Yarus M. 2001. RNA-catalyzed amino acid activation. *Biochemistry* 40:6998–7004.

Larralde R, Robertson MP, Miller SL. 1995. Rates of decomposition of ribose and other sugars. Implications for chemical evolution. *Proceedings of the National Academy of Sciences USA* 92: 8158–8160.

Lau MW, Cadieux KE, Unrau PJ. 2004. Isolation of fast purine nucleotide synthase ribozymes. *Journal of the American Chemical Society* 126:15686–15693.

Leman L, Orgel L, Ghadiri MR. 2004. Carbonyl sulfide-mediated prebiotic formation of peptides. *Science* 306:283–286.

Lorsch JR, Szostak JW. 1994. In vitro evolution of new ribozymes with polynucleotide kinase activity. *Nature* 371:31–36.

Mansy SS, Schrum JP, Krishnamurthy M, Tobé S, Treco DA, Szostak JW. 2008, Template-directed synthesis of a genetic polymer in a model protocell. *Nature* 454:122–126.

McCollum TM, Ritter G, Simoneit BR. 1999. Lipid synthesis under hydrothermal conditions by Fischer-Tropsch-type reactions. *Origins of Life and Evolution of the Biosphere* 29:153–166.

Meyer S. *Signature in the Cell*. 2009. New York: HarperOne.

Miller SL. 1953. A production of amino acids under possible primitive earth conditions. *Science* 117:528–529.

Miller SL. 1955. Production of some organic compounds under possible primitive earth conditions. *Journal of the American Chemical Society* 77(9):2351–2361.

Mills GC, Kenyon D. 1996. The RNA world: A critique. *Origins and Design* [Internet] 17(1). [Cited 2010 Aug 21]. Available from http://www.arn.org/docs/odesign/od171/rnaworld171.htm.

Müller UF. 2006. Re-creating an RNA world. *Cellular and Molecular Life Sciences* 63:1278–1293.

Nelson DL, Cox MM. 2008. *Lehninger Principles of Biochemistry*. New York: WH Freeman and Company.

Oró J. 1961 Mechanisms of synthesis of adenine from hydrogen cyanide under possible primitive earth conditions. *Nature* 191:1193–114.

Patterson R. 2007. *Evolution Exposed, Biology*. Hebron (KY): Answers in Genesis.

Powner MW, Gerland B, Sutherland JD. 2009. Synthesis of activated pyrimidine ribonucleotides in prebiotically plausible conditions. *Nature* 459:239–242.

Rushdi AI, Simoneit BR. 2001. Lipid formation by aqueous Fischer-Tropsch-type synthesis over a temperature range of 100 to 400 degrees C. *Origins of Life and Evolution of the Biosphere* 31:103–118.

Saito H, Kourouklis D, Suga H. 2001. An in vitro evolved precursor rRNA with aminoacylation activity. *EMBO Journal* 20:1797–1806.

Schopf J. 1983. *Earth's Earliest Biosphere: Its Origin and Evolution*. Princeton (NJ): Princeton University Press.

Senanayake SD, Idriss H. 2006. Photocatalysis and the origin of life: Synthesis of nucleoside bases from formamide on TiO_2(001) single surfaces. *Proceedings of the National Academy of Sciences USA* 103(5):1194–1198.

Schwartz AW. 2006. Phosphorus in prebiotic chemistry. *Philosophical Transactions of the Royal Society of London, Series B, Biological Sciences* 361(1474):1743–1749.

Shapiro R. 1988. Prebiotic ribose synthesis: A critical analysis. *Origins of Life and the Evolution of the Biospheres* 18:71–85.

Shapiro R. 1995. The prebiotic role of adenine: A critical analysis. *Origins of Life and the Evolution of the Biospheres* 25:83–98.

Thomas B. 2009. Did ribonucleoproteins spark life? [Internet]. Daily Science Update. [Cited 2009 June 15].Available from http://www.icr.org/article/did-ribonucleoproteins-spark-life.

Unrau PJ, Bartel DP. 1998. RNA-catalyzed nucleotide synthesis. *Nature* 395:260–263.

Weaver RF. 2008. *Molecular Biology*, 4th ed. New York: McGraw-Hill.

Wilson DS, Szostak JW. 1999. In vitro selection of functional nucleic acids. *Annual Reviews of Biochemistry* 68:611–47.

Yuen GU, Kvenvolden KA. 1973. Monocarboxylic acids in Murray and Murchison carbonaceous meteorites. *Nature* 246:301–303.

Zahnle K, Schaefer L, Fegley B. 2010.Earth's earliest atmospheres. [Internet]. *Cold Spring Harbor Perspectives in Biology* [Cited 2010 Jan 6]. Available from http://cshperspectives.cshlp.org/doi:10.1101/cshperspect.a004895.

Zaug AJ, Cech TR. 1986. The intervening sequence RNA of Tetrahymena is an enzyme. *Science* 231(4737):470–475.

Zhang B, Cech TR. 1998. Peptidyl-transferase ribozymes: Trans reactions, structural characterization and ribosomal RNA-like features. *Chemical Biology* 5:539–553.

About the author

Michael Buratovich is Professor of Biochemistry at Spring Arbor University. He is also *RNCSE*'s associate editor for biochemistry.

Author's address

Michael Buratovich
Spring Arbor University
106 E Main Street
Spring Arbor MI 49283
michaelb@arbor.edu

REPORTS OF THE NATIONAL CENTER FOR SCIENCE EDUCATION

Published bimonthly by the National Center for Science Education

REPORTS.NCSE.COM
ISSN 2159-9270

FEATURE

How to Humanize Knowledge, or CSI: Evolution and Climate Change

Kevin C Armitage

One of the great paradoxes of our time is that the more science influences our lives, the less we understand it. We live in a country in which about 45% of our fellow citizens believe the earth is less than 10 000 years old. As biologist Richard Dawkins has pointed out, this temporal confusion is as wrong as believing that the distance between New York and San Francisco is 7.8 yards. More important than lack of basic scientific knowledge is the widespread misunderstanding over the way science works and why: how the quantification, testing, and revision of hypotheses creates new knowledge. Consequently, scientific understanding only minimally impacts our public debate.

Worry about this problem is not new, of course. Speaking to the American Association for the Advancement of Science in June 1922, the historian James Harvey Robinson (1922:94) noted that the discoveries of science have "succeeded in unfolding to our gaze so new a world in its origin, development [and] workings … that practically all of the older poetic and religious ideas have to be fundamentally revised or reinterpreted." When viewed in the abstract, science, indeed most intellectual work, can appear to the untutored as trivial, an assault on tradition, or simply weird.

Robinson's primary example of how ignorance about science harms civic debate is also shockingly familiar: he decried the "strong and threatening opposition" to "organic evolution." Robinson understood that the human "affinity and obvious relationship with the rest of the organic world" was disturbing to many people. Soon after Robinson spoke, these issues exploded onto the national consciousness in the form of the Scopes trial. Things have little improved since. In the early 21st century, a third of Americans fully reject the science of evolution, with many others unsure about evolution or uneasy about how to reconcile evolution with religious belief. Two-thirds of Americans agree that public school biology classes should teach both evolution and "intelligent design"—the new clothing worn by the old creationism—as if there were scientific evidence for creationism.

Evolutionary science in everyday life, or at least on television

Happily, there are also signs that the public may be more open to evolutionary science than is commonly thought. Indeed, debates over evolution may reflect the stigmatization of the term "evolution" but not the fact itself. For example, 78% of adults find perfectly acceptable an evolutionary description of plants and animals if it highlights natural selection but omits the word "evolution". And how many fans of popular television shows such as *CSI: Crime Scene Investigation* would be surprised to learn that the very same genetic information used to unravel the weekly crime is also revolutionizing evolutionary science—indeed, giving modern researchers an unparalleled understanding of evolutionary history? How many American citizens know that the same DNA that solves paternity suits in a court of law deciphers the evolutionary heritage of species in the court of scientific evidence?

Combining the criticism of James Harvey Robinson with the success of science as represented in *CSI* points us, I believe, to a way to spread knowledge about the basics of modern biology that will help the public understand some of the most crucial issues it faces. Civic-minded educators should work to remove evolution from theological debates (while recognizing that fundamentalist readings of biblical texts and science are incommensurable) and insert it into its proper place: as an explanation of how organisms respond to environmental change—particularly climate change—and thus the likely effects on our society of a warming planet .

How would this help educate the public? Television programs such as *CSI* succeed in making science sexy and fun because, in the words of Robinson, they humanize science. "Once it was well to dehumanize science," argued Robinson; "now it must be rehumanized." By "dehumanize" he meant that science proceeds by carefully regulating human interest; in Robinson's words, science advances through its "stubborn refusal to consider natural phenomena in terms of human impulse". To "rehumanize" science—and especially evolutionary science—is to demonstrate how it applies to the entirety of life—the "essential interweaving and mutual dependence of all things"—rather than boxing it into a category of knowledge removed from the problems of day to day existence. Educators should follow this lead and emphasize to the public how evolution helps us understand—and thus respond intelligently—to one of the greatest challenges facing humanity: global climate change and its attendant problems.

Making it personal

As with evolution, the public is largely misinformed about the science of climate change. Also like evolution, climate change appears isolated from day-to-day life, an abstract concept easily dismissed because of its supposed remoteness. Unlike DNA evidence used to apprehend a murderer, evolution and climate change do not seem urgent—one seems to describe the distant past, the other the distant future. Yet bringing them together can vitalize both concepts. Many of the changes brought about by climate change can only be explained by evolution: the process of organisms adapting—or failing to adapt—to changing environments.

These adaptations can be seen by anyone who looks. Weeds such as the field mustard are thriving in California because they evolved to flower earlier and hence escape drought conditions. Yellow-bellied marmots are weaning their young earlier, because during the past ten years, the average time of spring snowmelt has come earlier. Red squirrels in the Canadian Yukon are reproducing at an earlier time, giving them a head start on gathering spruce cones. Pine beetles, newly able to thrive in Canada due to warmer winter weather, have denuded vast swaths of forest, turning those forests from something that removes atmospheric carbon (a "sink") into a contributor of carbon dioxide and other greenhouse gases. The pitcher-plant mosquito has shifted toward shorter, more southern climates to initiate its larval dormancy. Nor are these changes merely behavioral; as William Bradshaw and Christina M Holzapfel (2006) argued in *Science*, "recent studies show that over the recent decades, climate change has led to heritable, genetic changes in populations of animals as diverse as birds, squirrels, and mosquitoes."

The changing fitness of insects such as mosquitoes provides one of the most vivid and worrisome examples of species evolving in response to climate change. Mosquitoes have long been devastating to human health. They are excellent vectors—that is, disease transmitters—for the protozoan parasites of the genus *Plasmodium* that cause malaria. Prevention of malaria usually centers on killing local mosquito populations, often with DDT, a nerve poison lethal to mosquito larvae. Yet this treatment is only effective for a short time because DDT resistant strains of mosquitoes quickly evolve. As spraying kills the individual mosquitoes most vulnerable to DDT, those that have resistance to the poison are the only ones left to reproduce. Soon, by the process of simple inheritance, mosquito populations can become largely DDT resistant. Indeed, in some areas previously treated with DDT, resistant mosquitoes resurge within months of new spraying. Nor is this a trivial issue: malaria affects between 300 and 500 million people each year, killing over one million annually.

Moreover, the problem of malaria is spreading due to the effects of climate change. The World Health Organization already suspects that climate change is responsible for increased rates of malaria in industrialized countries. Studies have correlated rising temperatures with growing numbers of mosquitoes, and hence increases in the diseases they carry.

Evolution and the effects of climate change are inseparable subjects because disease vectors survive and reproduce within specific climatic conditions. Temperature and precipitation are the most important climatic factors influencing the spread of disease vectors, though others such as elevation, wind, and hours of daylight are also important. The WHO estimates that global temperature increases of 2–3°C would enlarge by hundreds of millions the number of people at risk for malaria infection. Furthermore, the seasonal variation of malaria in its endemic regions would also likely intensify. Mosquitoes, then, are both evolving to produce new strains and are responding to the new opportunities provided by a changing climate.

Disease is not the only way that evolution and climate change affect each other. One of the great worries about a heating planet is the effect of increased temperatures upon agriculture. Like diseases and their vectors, food production depends upon climatic factors such as temperature and rainfall. Global climate change will increase rainfall in some areas, decrease it in others; it is likely to be more variable as a rule.

Temperature may be the most important factor. One published study showed that rice yields decline by 10% for every single degree Celsius increase in nighttime temperature. Nor is this a problem confined to countries dependent upon rice. As Biever (2003) reports, crop yields drop 17% for every 1°C increase in temperature. Moreover, higher temperatures generally mean greater amounts of weeds and insects—and the diseases they spread. Greater temperatures will thus probably increase farmer dependence on pesticides, which will impose a large financial burden and add to groundwater contamination. Many pesticides derive from fossil fuels, exacerbating the ecological and economic vicious cycle. Heartland agriculture, in other words, will decline dramatically if climate change produces new environments for which corn and wheat are not well adapted.

All of this points to the fundamental role of educators in a democratic society: to give the public the information and tools it needs to grapple with the problems of its time. If our society is to meet the great challenges of climate change—and the very existence of our society may depend upon it—the public must have a basic understanding of evolution. Given the history of the reception to evolution in this country, that is no easy task.

The moral imperative

To wield this tool effectively, then, it is vital that educators humanize evolution by removing it from theological debates in favor of putting it to use understanding and solving environmental problems. To do this we must combat the grossly unfair association of evolution with immorality. It will not be easy to disassociate evolution from such connotations—and fundamentalist religionists will surely continue to use this idea to justify their opposition to basic science—so it is vital that educators continue the struggle to make evolution the center of biological education. Those of us trained in the humanities and social sciences—by definition the humanizers of knowledge—have a special duty to use our training to show the vital role of evolutionary thought in problem solving.

To succeed at this we must insist—and demonstrate—that evolution is not a conspiracy to kill God, or to promote naïve materialism, or to deny moral dialogue. Rather it is a tool of fundamental importance if our society, indeed our world, is to successfully respond to the most profound problems it faces. Indeed, using evolution to solve problems is deeply moral and a social justice issue: poor, nonwhite people are subject to the worst affects of climate change. Conversely, denying this essential tool for understanding our ecological predicament is gravely immoral. Public-spirited educators, then, need to speak out with forceful urgency. Our future depends upon our ability to humanize this knowledge, making it a vital tool of public debate.

References

Biever C. 2003. America's bumper harvests will wither away if the temperature keeps rising. *New Scientist* 177:16.

Bradshaw WE, Holzapfel CM. 2006. Evolutionary response to rapid climate change. *Science* 312:1477–8.

Robinson JH. 1922. The humanizing of knowledge. *Science* 56:89–100.

About the author

Kevin C Armitage teaches in the Western Program at Miami University. He is the author of *The Nature Study Movement: The Forgotten Popularizer of America's Conservation Ethic* (Lawrence [KS]: University Press of Kansas, 2009).

Author's address

Kevin C Armitage
Western Program
111 Peabody Hall
Miami University
Oxford OH 45056
armitakc@muohio.edu

REPORTS OF THE NATIONAL CENTER FOR SCIENCE EDUCATION

Published bimonthly by the National Center for Science Education

REPORTS.NCSE.COM
ISSN 2159-9270

FEATURE

People & Places: Don Aguillard

Randy Moore

> I knew that this was important. I was not ready to pretend that "creation science" was legitimate or that evolution didn't matter.

Donald W Aguillard (Figure 1) was born in Ville Platte, Louisiana, on June 20, 1954. After graduating in 1975 from the University of Southwest Louisiana (now the University of Louisiana at Lafayette), he began teaching biology at Acadiana High School in Lafayette, Louisiana. There, in 1980, Aguillard saw an advertisement in *The American Biology Teacher* asking teachers to call the ACLU if they wanted to challenge the Louisiana law requiring "balanced treatment" for evolution and creationism in public schools. Aguillard, who knew that he "couldn't stand by and do nothing," became the lead plaintiff in a lawsuit that later became known as *Edwards v Aguillard* (the defendant, Edwin Edwards, was governor of Louisiana at the time). Many of Louisiana's biology teachers were prepared to avoid teaching evolution rather than teach creationism, but fewer than ten biology teachers agreed to participate in the lawsuit.

On January 10, 1985, US District Judge Adrian Duplantier ruled that Louisiana's "balanced treatment" law was unconstitutional. Duplantier's ruling, which blocked Louisiana from implementing the law, noted that

> (1) creationism is a religious belief "tailored to the principles of a particular religious sect";
>
> (2) there can be no valid secular reason for banning the teaching of evolution; and
>
> (3) the statute's avowed purpose of protecting academic freedom was inconsistent with the statute's legislative history and its requirement for teaching of creation science whenever evolution is taught.

When Louisiana appealed the decision, the US Court of Appeals for the Fifth Circuit—noting the ongoing influence of William Jennings Bryan and the Scopes trial—affirmed Duplantier's ruling by a vote of 8–7. Although the dissenting opinion by Judge Thomas Gee (1925–1994) that "there are two *bona fide* views" of origins was the first published judicial support for creationist claims since the Scopes trial, the case was not over, for when a federal court rules that a state law is unconstitutional, the US Supreme Court must consider hearing the case.

Edwards v Aguillard was heard before the US Supreme Court on December 10, 1987. Although Wendell Bird (representing the state of Louisiana) admitted that "some legislators had a desire to teach religious doctrine in the classroom," he claimed that the law had a primary secular purpose based on "fairness" and "academic freedom."

Figure 1. *Don Aguillard (left) with another educator whose name is associated with a major court decision for evolution, Susan Epperson. Photograph: Eugenie C Scott.*

On June 19, 1987, in a 7–2 decision, the Supreme Court—noting that evolution has been "historically opposed by some religious denominations"—affirmed that

> (1) Louisiana's "balanced treatment" law was unconstitutional because it impermissibly endorsed religion by advancing the religious belief that a supernatural being created humankind;
>
> (2) it is unconstitutional to mandate or advocate creationism in public schools, for creationism is a religious idea;
>
> (3) the contention "a basic concept of fairness" for requiring the teaching of creation science is "without merit";
>
> (4) banning the teaching of evolution when creation science is not also taught undermines a comprehensive science education; and
>
> (5) the law is "facially invalid as violative of the Establishment Clause of the First Amendment, because it lacks a clear secular purpose."

Invoking the Scopes legacy, *Time* magazine described the *Edwards* decision as "a major setback for fundamentalist Christians". When he heard of the decision, Aguillard said

> I hope my case made a difference. Biology teachers have to speak up. In-service programs are not the answer, nor are better textbooks; neither of those things will make any difference if teachers refuse to teach evolution thoroughly and unapologetically.

Although *Edwards* diminished subsequent attempts to pass "balanced treatment" laws, many creationists were encouraged by a part of Justice Brennan's majority opinion:

> Teaching a variety of scientific theories about the origins of humankind to school children might be validly done with the clear secular interest of enhancing the effectiveness of science instruction.

They were also encouraged by the dissenting opinions of Justices Antonin Scalia and William Rehnquist, who argued that

> the people of Louisiana, including those who are Christian fundamentalists, are quite entitled, as a secular matter, to have whatever scientific evidence there may be against evolution presented in their schools, just as Mr Scopes was entitled to present whatever scientific evidence there was for it … The body of scientific evidence supporting creation science is as strong as that supporting evolution. In fact, it may be stronger. Evolution is merely a scientific theory or "guess". … Although creation science is educationally valuable and strictly scientific, it is now being censored from or misrepresented in the public schools … Teachers have been brainwashed by an entrenched scientific establishment composed almost exclusively of scientists to whom evolution is like a "religion". These scientists discriminate against creation scientists so as to prevent evolution's weaknesses from being exposed.

After his trial, Aguillard continued to stress evolution in his classes, and in 1998 he earned a PhD from Louisiana State University. Aguillard, an award-winning school administrator, is currently the superintendent of St Mary Parish schools in Louisiana.

About the Author

Randy Moore is the HT Morse–Alumni Distinguished Professor of Biology at the University of Minnesota.

Author's address

Randy Moore
University of Minnesota, MCB 3-104
420 Washington Avenue SE
Minneapolis MN 55455
rmoore@umn.edu

REPORTS OF THE NATIONAL CENTER FOR SCIENCE EDUCATION

Published bimonthly by the National Center for Science Education

REPORTS.NCSE.COM

ISSN 2159-9270

REVIEW

Why Evolution Works (and Creationism Fails)

by Matt Young and Paul K Strode

New Brunswick (NJ): Rutgers University Press, 2009. 224 pages

reviewed by Mike Klymkowsky

This book is part of a grand tradition, with ambitious and laudable goals, namely to clarify for the curious reader what distinguishes science from non-science. Young (a physicist) and Strode (a high school and college teacher) have a specific audience (college students), a particular science (evolutionary biology), and a uniquely vocal "opposition movement" (creationist ideologues) in mind. Like a textbook, their book include a number of "thought questions" at the end of each chapter, a clear effort to provoke readers to clarify their thinking through introspection and metacognition (why do I think what I think?) Overall, their approach succeeds, but with two provisos: readers must take the time to consider their questions seriously, and they must have enough of an understanding of the basic concepts involved to produce clear answers for themselves. Thus the book could well serve as a foundational text for courses that compare and contrast scientific and non-scientific approaches to biological questions.

As befitting their goals, Young and Strode present a broad array of examples of how a scientific approach makes sense of biological systems. (Perhaps because of its ambitious scope, the authors make a few mistakes that I hope will be corrected in a second edition: for example, *E coli* is not a "purple bacterium" and Darwin produced lineage trees before Haeckel.) Their writing is largely jargon-free and accessible, but herein lies a potential problem—jargon is often shorthand for specific, complex, and not infrequently counterintuitive ideas, and as such it can be useful. For example, it is unclear how compelling their readers will find their critique of Dembski's probability arguments (chapter 10), precisely because their avoidance of jargon necessitates a longer, and more confusing (at least to me), treatment of a difficult subject. Their use of boxes to present material also strikes me as problematic, since material presented in boxes is often recognized by students as "skippable". In particular, the discussion of HJ Muller's explanation of apparent (but not real) irreducible complexity (p 73) should have escaped the text box and been elaborated on further.

There are tricky issues associated with the presentation of any scientific topic, particularly one as publicly controversial as evolutionary biology. While simplification is necessary, it can lead to a situation in which the reader is asked to accept various statements essentially on faith, while leaving them without the knowledge needed to confirm for themselves the reasonableness and validity of these assertions. This is one reason that the common creationist tactic of questioning well-established science works—the general public (understandably) does not have the knowledge or confidence to dismiss frivolous objections, they cannot easily identify the absurd (Skrabanek 1986). How many could profitably read

Lynch's (2005) critique of Behe and Snoke's (2004) flawed reasoning, or appreciate the role of historical contingency in the in vitro evolution of citrate utilization in *E coli* (Blount and others 2008)? It is perhaps not entirely clear what foundational ideas must be grasped in order for evolutionary mechanisms to be compelling, and it is unfair to expect Young and Strode to remediate the failings of our educational system, but there are points in their book where it would have been helpful and more persuasive if more of the scientific background had been explained.

As an example from molecular evolution, Young and Strode (p 116) note that lampreys, which are thought to share similarities with the ancestral vertebrate, have a receptor protein that can interact with aldosterone, even though they do not make aldosterone themselves. But they fail to explain how such a thing is possible. The explanation relies on an understanding of the factors that mediate intermolecular interactions and can lead to "promiscuous" interactions. In fact, molecular promiscuity, together with gene duplication and the effects of molecular chaperones (which stabilize proteins), combine to facilitate evolutionary adaptation (Copley 2003, Tokuriki and Tawfik 2009a,b). One can argue that ignorance of life's molecular mechanisms led to what has been called the "eclipse of Darwinism" (Bowler 1992, 2005) and that our deepening molecular understanding provides the most compelling evidence for accepting evolutionary mechanisms. The difficulty in imagining how random mutation could produce useful adaptation has driven many, including Darwin and Wallace, to seek various alternatives, such as orthogenesis, neo-Lamarckian mechanisms, and even divine intervention. Young and Strode's relative neglect of molecular-level mechanisms may leave their readers unable to grasp how modern discoveries have removed the need for metaphysical explanations, and allowed Darwinian theory to reappear, essentially intact (albeit more subtle in its details).

A larger question is whether any presentation of the logic of the scientific enterprise can be compelling to those who have embraced an anti-scientific mind-set? Probably not, but that is not Young and Strode's target audience. They are after the open-minded, rational, and intellectually curious, and I think that for such an audience their presentation of how science works will be particularly compelling. In contrast to its dogmatic opposition, the scientific community displays a remarkable level of intellectual honesty, flexibility, and humility. As captured by the words of Richard Feynman, "Scientific knowledge is a body of knowledge of varying degrees of certainty—some most unsure, some nearly sure, but none *absolutely* certain … Now we scientists are used to this, and we take it for granted that it is perfectly consistent to be unsure, that it is possible to live and *not* know" (2000:146, emphasis in original). Science has produced a logical, testable, robust, and increasingly accurate model of the world around us, but this progress was possible only because of its willingness to abandon supernatural stories since, if permitted, they make any model possible and progress impossible. Creationists, of whatever ilk, rarely display a similar level of intellectual candor—their foundational assumptions are carved in stone (or perhaps the rock of ages).

The playing field is therefore biased in favor of the supernaturalist, for whom all things are possible (a 6000-year–old earth? No problem!) Science, in contrast, embraces its vulnerability—it could well be that rigorous naturalistic laws do not exist because the world requires constant divine interventions to exist. While this latter scenario posits a rather inept designer, it is nevertheless logically possible. But amazingly enough, no matter how hard or esoteric the problem, this does not appear to be the case. Notwithstanding the claims of various religious biologists (most notably at the moment, Francis Collins), an unbiased view of the world as a whole, and biological systems in particular, fails to reveal any need for, or examples of, supernatural intervention. The authors' discussion of the biological origins of morality speak to this point, a point strengthened by recent observations on the role of "mirror neurons" in learning and empathy (reviewed by Iacoboni 2009).

Young and Strode argue against the notion that science and religion occupy distinct domains, and point out that scientific and religious beliefs can directly contradict one another. But these conflicts exist only for the dogmatic. It seems to me that a religious perspective can be reconciled with a scientific one, once we accept that science has essentially nothing to say about what we should do, but only provides insights as to what might be possible, and if possible, how our goal might be achieved. In that light, it is important to reject scientism, the belief that science provides ultimate truth. Science requires us, like the White Queen in *Through the Looking-Glass*, to think "impossible things", such as quantum entanglement, bent space, wave-particle duality, and the creative effects of random mutations. Unlike religion, however, it provides us clear and testable reasons that such impossible things (or something quite like them) must be in play. This book provides compelling examples of how science works. With any luck, it will entice its readers to delve further into these impossible, yet compelling and empirically-based, ideas, and help them to recognize what distinguishes the "impossible" ideas of science from the impossible ideas of religion and other ideologies.

References

Behe MJ, Snoke DW 2004. Simulating evolution by gene duplication of protein features that required multiple amino acid residues. *Protein Science* 13:2651–2664.

Blount ZD, Borland CZ, Lenski RE 2008. Historical contingency and the evolution of a key innovation in an experimental population of *Esherichia coli*. *Proceedings of the National Academy of Sciences* (USA) 105:7899–7906.

Bowler PJ. 1992. *The Eclipse of Darwinism: Anti-Darwinian Evolution Theories in the Decades around 1900*. Baltimore: The Johns Hopkins University Press.

Bowler PJ. 2005. Revisiting the eclipse of Darwinism. *Journal of the History of Biology* 38:19–32.

Copley S. 2003. Enzymes with extra talents: Moonlighting functions and catalytic promiscuity. *Current Opinion in Chemical Biology* 7:265–272.

Feynman R. 2000. The value of science. In: Feynman R. *The Pleasure of Finding Things Out*. New York: Da Capo Press. p 141–149.

Iacoboni M. 2009. Imitation, empathy, and mirror neurons. *Annual Review of Psychology* 60:653–670.

Lynch M. 2005. Simple evolutionary pathways to complex proteins. *Protein Science* 14:2217–2225.

Skrabanek P. 1986. Demarcation of the absurd. *The Lancet* 1(8487):960–961.

Tokuriki N,.Tawfik DS. 2009a. Protein dynamism and evolvability. *Science* 324:203–207.

Tokuriki N, Tawfik DS. 2009b. Chaperonin overexpression promotes genetic variation and enzyme evolution. *Nature* 459:668–73.

About the author

Mike Klymkowsky is Professor of Molecular, Cellular, and Developmental Biology at the University of Colorado, Boulder, where he also co-directs CU Teach, Colorado's innovative secondary mathematics and science teacher education program.

Author's address

Mike Klymkowsky
MCDB / CU Teach
University of Colorado, Boulder
Boulder CO 80309
michael.klymkowsky@colorado.edu

REPORTS OF THE NATIONAL CENTER FOR SCIENCE EDUCATION

Published bimonthly by the National Center for Science Education

REPORTS.NCSE.COM

ISSN 2159-9270

REVIEW

Am I a Monkey? Six Big Questions about Evolution

by Francisco J Ayala

Baltimore: The Johns Hopkins University Press, 2010. 104 pages

reviewed by Joel W Martin

The difficulty that we face in working to convince the public of the validity of evolutionary biology cannot be attributed to a paucity of information or evidence. The last few years have seen a plethora of comprehensive and excellent books, most of them aimed at a non-scientific audience, detailing the abundant and overwhelming evidence in support of evolution. Rather, our problem is how to summarize and package that information in a form that is accessible to, and even attractive to, the general public. And if we are assuming that the most resistant public sector is composed of people who feel that their religion is threatened by evolution, and we are hoping to change their minds, it is unlikely that an adversarial or condescending tone will help achieve that goal. Francisco J Ayala's latest book *Am I a Monkey?* is not the first to present the case for evolution to a lay audience in a genteel, inviting, and non-threatening format, but it is one of the better ones, and it should go a long way in helping move us in the right direction.

It's hard to imagine someone more qualified to write about the interaction of evolution and faith than Francisco Ayala. Ayala, an evolutionary geneticist, is currently University Professor and Donald Bren Professor of Biological Sciences, Ecology, and Evolutionary Biology (School of Biological Sciences), Professor of Philosophy (School of Humanities), and Professor of Logic and the Philosophy of Science (School of Social Sciences) at the University of California, Irvine. On the scientific side, he has served as past president of the American Association for the Advancement of Science, is a member of the National Academy of Sciences, and in 2001 was awarded the National Medal of Science. Few in the field of biology will ever scale those heights. On the religious side, he is a former Dominican priest, and in 2010 he was awarded the Templeton Foundation's Templeton Prize (formerly called the Templeton Prize for Progress in Religion), given annually to someone who "has made an exceptional contribution to affirming life's spiritual dimension, whether through insight, discovery, or practical works." Scientists who adamantly oppose the idea of compatibility of science and faith (there are not terribly many of them, but they tend to be quite vocal) will sometimes suggest that real scientists, good scientists, would not succumb to such primitive needs and emotions; the rational, they argue, will have moved past the age where mankind depends on invisible deities to give meaning to life. Implied in this line of reasoning is that the best scientists could not possibly also be persons of faith. But this argument runs aground when someone with Ayala's credentials and accomplishments is considered, and I have always suspected a bit of envy among his most vociferous critics. Similarly, critics of evolution hoping to pin their arguments on their old nemesis "atheistic science" will have trouble brushing aside Ayala's theological background and the religious sensitivity of his writing. His credentials and accomplishments make it virtually impossible to criticize him as being either unsympathetic to religion or a mediocre scientist; quite clearly he is neither. And this puts him in an enviable, and possibly unique, position to write about the interface of science and faith for a lay audience, something he has done often in the past (Ayala 2006, 2007).

In *Am I a Monkey?* Ayala distills the anti-evolution arguments down to "six big questions about evolution," with each addressed in its own chapter. It's not clear how these six were selected, but presumably they are the questions that the author feels are foremost in (or perhaps most difficult to grasp by) the mind of the public; in his words, they are questions "that arise in the minds of people who are only vaguely familiar with the notion of evolution." Although arguments could be made for choosing other "big questions," these six are certainly worth addressing, as several of them are posed regularly on creationist websites and blogs. At 104 pages, the book is amazingly (and appealingly) short, an important advantage for reaching a general audience.

In the introduction, Ayala makes two important points that preface his treatment of evolution and set the tone for his conclusion. First, "science is a wondrously successful way of knowing the world, but it isn't the only way. Knowledge also derives from other sources, such as common sense experience, imaginative literature, music and artistic experience, philosophical reflection, and, for people of faith, religion and revelation" (p xiii). And second, "a scientific view of the world is hopelessly incomplete. Matters of value and meaning are outside science's scope. In order to understand the purpose and meaning of life, as well as matters concerning moral and religious values, we need to look elsewhere" (p xiii). Thus, the introduction will be immediately appealing to those who wade into this discussion somewhat reluctantly, fearful of where science, and this book, might lead them. These issues are then tabled for the first five chapters of the book while Ayala addresses other questions about evolution in a direct and unapologetic style; his writing throughout these chapters is brief, accurate, and hard-hitting (for example, "The 'missing link' is no longer missing," p 4). I liked the approach, but it did make me wonder whether persons only "vaguely familiar with the notion of evolution"—especially persons of faith looking for assistance in grappling with this subject—would make it to the end.

The first chapter (Am I a Monkey?) seemed at first an unnecessary throwback to the confusion over monkeys, apes, and their (and our) ancestors. An uninformed reader could assume that this question is indeed at the heart of the issue, when instead it is something of a canard, since apes (not monkeys) are the primates closest to humans, and I wondered why someone would choose a somewhat misleading question for the book's title (see also the recent article by Meikle and Scott 2010). But Ayala dispenses with the monkey-ape confusion at the start, and indeed does a fine job recounting the evidence for the evolution of apes and man from a common primate ancestor. The chapter serves as a nice summary of what we know of human origins, including the fossil and molecular evidence underlying human evolution.

In chapter 2 (Why is Evolution a Theory?), Ayala attempts to clear up the seemingly ever-present confusion between scientific and everyday uses of the word theory. Like many others before him, he describes evolution as "both theory and fact," which is understandable to those of us who study evolution but almost guaranteed to be confusing to a lay reader. His definition of a "scientific fact" as "an observation that has been observed again and again" and as something different from our everyday use of the word seems unwieldy to me. Facts are facts, as they say.

Chapter 3 (What is DNA?) presents a concise overview of what we know about that all-important molecule. It's up to date and well-written, possibly his best chapter. But here I found myself asking: is this really one of the six most burning questions about evolution? More to the point, is the lack of knowledge about DNA really one of the major stumbling blocks that keep people from understanding and accepting evolution? Given that most high school students can give you a decent definition of DNA, I question whether it is. Indeed, several creationist authors point to DNA as evidence of design, so most readers will be aware of it. Still, there's certainly no harm in giving the public a clear description and explanation of DNA and how it functions, and how it enhances our understanding of evolution, especially for those who have been out of high school or college for a few years (and/or slept through much of Biology 101), and Ayala has certainly done that.

Chapter 4 (Do All Scientists Accept Evolution?) is more about the additional evidence—from embryology, molecular biology, paleontology, and so on—that supports our understanding of evolution, and only the first three sentences of the chapter have to do with the number of scientists who accept it. Stating that the overwhelming majority of biologists accept evolution, which is true, but providing very little evidence to support that statement is in some ways no more convincing than the creationist claim that there are many who doubt it. A broader discussion, admitting that there are indeed a handful of scientists (but only a handful) who are at odds with the enormous scientific community, might have been more helpful here in dispelling the notion of widespread scientific disagreement. But if I am applauding the book for its brevity, I cannot simultaneously criticize it for being too brief here.

Chapter 5 (How Did Life Begin?) struck me as out of place. It's obviously a fascinating question, but it's never been at the heart of biological evolution; traditionally it's been a question for the field of biochemistry, although there are arguments for including it in an evolution curriculum (e.g. see Lazcano and Peretó 2010). But the public seems to feel that this question is part and parcel with evolution, so I suppose its inclusion here is legitimate on those grounds. Even if it is not a question of evolutionary biology *per se*, it is among the most important (and potentially most troubling) from a theological perspective.

The final chapter (Can One Believe in Evolution *and* God?) serves as a bookend for the introduction and stresses the compatibility of science and faith. Ayala lays out his reasons for believing that science poses no threat to persons of faith, and indeed why science and faith cannot be in contradiction and are in fact complementary because of their different approaches, combining some of his personal philosophy with historical considerations, statements on the compatibility of faith and science from religious organizations, and scriptural exegesis. This chapter is his most important contribution (in part because the topics of other chapters are covered in more depth elsewhere), and it will be well received by persons of faith searching for how to reconcile science and religion. It will also, predictably, draw the most flak from those, whether creationist or evolutionist, opposed to any such reconciliation.

An index would have been nice; without it readers will have a hard time finding if and where Ayala discusses creationism or "intelligent design" (he doesn't), or Genesis, or David Hume. Similarly, references might have helped readers know where to turn for more information on, for example, *Ardipithecus*, Cech and Altman's Nobel Prize-winning work on ribozymes, *Tiktaalik,* the FOXP2 gene and its relationship to human language, or other topics. There are eight illustrations inserted between chapters 3 and 4, but although they are relevant to the text, they are not referred to or numbered, which is a bit of an inconvenience that could have been easily corrected. But these are minor quibbles. The book is well-written, accurate, and concise, and it covers the main points of biological evolution likely to be questioned by non-specialists. More importantly, it is accessible and easy to digest for the audience for whom it is written. Because of that strength, I suspect that it will, in the long run, play a larger role in promoting the acceptance of evolution than so many contemporary but longer and more detailed treatises. And that is its most important contribution.

References

Ayala FJ. 2006. *Darwin and Intelligent Design*. Minneapolis: Fortress Press.

Ayala FJ. 2007. *Darwin's Gift to Science and Religion*. Washington (DC): Joseph Henry Press.

Lazcano A, Peretó J. 2010. Should the teaching of biological evolution include the origin of life? *Evolution: Education and Outreach* 3:661–667.

Meikle WE, Scott E. 2010. Why are there still monkeys? *Evolution: Education and Outreach* 3:573–575.

About the author

Joel W Martin is Chief of the Division of Invertebrate Studies and Curator of Crustacea at the Natural History Museum of Los Angeles County, and the author of *The Prism and the Rainbow: A Christian Explains Why Evolution is Not a Threat* (Baltimore: The Johns Hopkins University Press, 2010).

Author's address

Joel W Martin
Division of Invertebrate Studies
Natural History Museum of Los Angeles County
900 Exposition Boulevard
Los Angeles CA 90007
jmartin@nhm.org

REPORTS OF THE NATIONAL CENTER FOR SCIENCE EDUCATION

Published bimonthly by the National Center for Science Education

REPORTS.NCSE.COM
ISSN 2159-9270

REVIEW

Chronology of the Evolution–Creationism Controversy

by Randy Moore, Mark Decker, and Sehoya Cotner
Santa Barbara (CA): Greenwood Press, 2010. 454 pages

reviewed by David A Reid

The authors of this accessible and endlessly fascinating introduction to the evolution/creationism controversy have undertaken an ambitious project—to chronicle all aspects of the controversy from the earliest known creation stories of the ancient Egyptians to the 2009 announcement of the discovery of *Ardipithecus ramidus*. While the development of scientific and religious ideas constitutes the central theme of the *Chronology*, the book's broader aim is to present the manifold ways in which science and religion have interacted with society, popular culture, politics, and law. As informative as the *Chronology* is, however, the comprehensive nature of the work is both its strength and its weakness as the authors, all of whom are biologists at the University of Minnesota, push the limits of their historical understanding of the issues.

To their credit, the authors attempt to remain neutral with respect to all sides of the many controversies involved. Their goal is to "explain what happened, what was said, and what it meant" (p x). They acknowledge that both evolutionary science and creationist thinking encompass complex intellectual traditions and social phenomena, and identify wherever adherents have engaged in vigorous argument both within their ranks and across the evolution/creationist divide. Those who are unfamiliar with the history of either science or Christianity will find much that surprises, particularly since the popular media still tends to rely on clichéd, one-dimensional images of science and religion as engaged in perpetual conflict, largely ignoring the internal complexities of either. The authors also address developments in sciences like astronomy and physics that at first glance might not seem directly relevant to the evolution-creationism controversy but nevertheless involved important science–religion issues or contributed to intellectual assumptions that were important to later controversies (for example, the debate over geocentric and heliocentric models of planetary motion).

As a reference work, the chronology is laid out as a series of topical entries divided by year. And this together with the lengthy, although not exhaustive, index and bibliography makes finding particular topics relatively easy. For those who are familiar with little more than the most famous primary sources (for example, Darwin's *Origin of Species*), the *Chronology* is a veritable treasure trove of well-known and less well-known works as well as choice quotations from many of them. It will serve teachers and students well, particularly high-school and college students looking for potential research topics. Unfortunately, at a cost of $85, the book's primary consumer market will likely consist of libraries rather than individual readers, but the authors have written the book to appeal to a general audience, something it does quite well (information about an eBook version is available from the publisher).

Despite the book's strengths, the authors have been rather unsuccessful in balancing their desire to make individual entries self-sufficient with trying to tell stories that require several entries spread out over decades or even centuries. This unfortunately leads to unnecessary repetition, as some individuals and topics are introduced several times throughout the text (a most egregious example of this comes on page 10, where we are told twice that in 1542 Pope Paul III established the Supreme Sacred Congregation of the Roman and Universal Inquisition). The recreational reader will find this repetition useful, while a more thorough reader will find it an annoyance, especially when extensive introductions are provided for individuals at the time of their birth, later in the context of their most important work, and sometimes at the time of their death.

A more problematic historical issue arises, however, when the authors attempt to explain how individual events contributed to long-range developments. We are told on several occasions, for instance, that particular statements or theories "influenced," "anticipated," or "hindered" later ideas. While the introduction stresses that readers should not judge past ideas by their similarity or dissimilarity to accepted ideas of today, the frequent appeal to "influences," "anticipations," and "hindrances" has the effect of doing just this. It also leads to a serious misunderstanding of the historical record. Although most intellectuals want their ideas to contribute significantly to the future development of thought, those ideas are always formulated in the context of contemporary problems and had appeal precisely because people believed them to provide adequate or, at least, interesting solutions to those problems. By emphasizing how ideas "anticipated" and "influenced" future thinking, the authors frequently miss opportunities to explain how and why particular ideas were deemed useful in their own historical present.

One example of this will suffice. Early in the *Chronology*, following a discussion of Plato's *Republic* and Aristotle's *Physics*, the book claims that Aristotle's theory of purpose in nature (or teleology) "combined with Plato's essentialism, restricted the development of evolutionary thought for centuries" (page 3). The implication, deliberate or not, is that if it was not for Plato and Aristotle, evolutionary theory would have been accepted long before Darwin. What it ignores is that Plato and Aristotle were struggling to explain how and why change could occur in an ordered universe. Material atomism, a coherent competing theory, could not explain either the harmonious order of planetary motion or the complex behavior of living organisms, although it could explain how change occurs. Plato and Aristotle both saw "life" as a fundamental organizing principle in nature—indeed, it was the principle that made order sustainable. In his dialogue *Timaeus*, Plato theorized that the creator-god gave the world a soul in order for it to have a living essence. Christians of the Middle Ages easily synthesized this aspect of Platonic natural philosophy with their interpretations of the creation story of Genesis 1 (strangely, the *Chronology* does not discuss either Plato's *Timaeus* or the origins of the two creation stories told in Genesis). Unless one understands the underlying problems that Aristotle, Plato, and their medieval followers were dealing with, opposition to evolutionary theory will seem irrational. Furthermore, it will be harder to understand why the rise of the mechanical worldview during the Scientific Revolution of the sixteenth and seventeenth centuries was such a remarkable event.

Given how quickly evolutionary theory continues to develop and how rapidly the political and legal strategies of creationists change, I hope that the *Chronology* will be updated in future years, giving the authors opportunities to remedy some of the book's weaknesses.

About the author

David A Reid is an adjunct professor of history at Joliet Junior College. A historian of science, he has regularly offered a course on the history of evolution and creationism.

Author's address

David A Reid
Department of Social and Behavioral Sciences
Joliet Junior College
1215 Houbolt Road
Joliet IL 60431-8938
dreid@jjc.edu

REPORTS OF THE NATIONAL CENTER FOR SCIENCE EDUCATION

Published bimonthly by the National Center for Science Education

REPORTS.NCSE.COM
ISSN 2159-9270

REVIEW

Evolution, Creationism, and Intelligent Design

by Allene S Phy-Olsen
Santa Barbara (CA): Greenwood Press, 2010. 171 pages

reviewed by Robert H Rothman

Evolution, Creationism, and Intelligent Design is part of a Greenwood Press series entitled *Historical Guides to Controversial Issues in America*. Allene S Phy-Olsen is Professor Emeritus of English at Austin Peay State University and this is her second contribution to the series, the first being a book on same-sex marriage. According to the publisher's website, the series examines the historical roots of hot-button issues and "provides the tools for the readers to sharpen their own thinking and take an informed position." Unfortunately, Phy-Olsen's book falls short of that mark.

The book is laid out in nine chapters, beginning with a historical overview of science and religion, a discussion of Darwin and the Darwinian revolution, a chapter on social Darwinism and eugenics, and another on theistic evolution. Next come two chapters on arguments for creationism and intelligent design, and the responses to those arguments. The final three chapters deal with religion and the courts, religion in the public schools, and finally a return to themes in the first chapter, but now projecting the relationship between science and religion into the future. Overall, this is a logical unwinding of the history of the conflict and the ideas that fuel it. The book concludes with an appendix of personalities involved in the debate and a very helpful fifteen-page annotated bibliography.

The book's 171 pages include the two appendices as well as an index. Thus the effective length of the book is only 128 pages, a very short space to tell a complicated story and to achieve the ambitious goals laid out in the book's introduction and the series's mission statement. A serious problem with the book, then, is the long and often irrelevant digressions that the author frequently takes. The worst example is a five-page discussion of Teilhard de Chardin, the Jesuit priest and anthropologist, in her chapter on theistic evolution. Teilhard was an interesting and intriguing character, but I don't think that he is central to the debate, and we don't need a discussion of his relationships with women or of the letters that recount the interesting details of his life.

On the other hand, in the chapter on religion and the courts, Phy-Olsen presents a very interesting discussion of the Scopes trial. It did not escape my notice that Austin Peay State University is named after the governor who signed the Butler Act into law, precipitating the Scopes trial. However, Phy-Olsen does not even mention *Epperson v Arkansas*, the case that led to the repeal of the Butler Act and other anti-evolution laws. Nor does she describe the events that returned evolution to the classroom and set the stage for *Epperson*. In 1968, the Supreme Court in *Epperson* found the exclusion of evolution to be a violation of the First Amendment. This, in turn, led to the burgeoning of the scientific creationism movement. In a book that is trying to present the history of the conflict, this is a serious omission. The remainder of that chapter is rounded out by quick discussions of *McLean v Arkansas Board of Education* (1982) and the recent *Kitzmiller v Dover Area School District* (2005), which blocked the introduction of "intelligent design" into the classroom. *McLean* is presented through the eyes of Norman Geisler and Langdon Gilkey, who took opposite views of the proceedings. Rather than clearly describing the case, the section reads more like a "he-said she-said." And Phy-Olsen doesn't even mention *Edwards v Aguillard* (1987), a follow-up case to *McLean* that went to the Supreme Court and banished creationism from the classroom but opened the door to the "intelligent design" movement. As with *Epperson*, this is a serious omission.

In general, I found a lack of focus in many of the chapters. The chapter on arguments for creationism and intelligent design is seventeen pages long, while the following chapter on responses to intelligent design is only five and a quarter, and the last one and a quarter pages deal with atheism, particularly Dawkins's. As in several other chapters, the arguments are mostly a list of positions by leading proponents. The two chapters taken together do not really present the balanced point/counterpoint that should be the heart of this book. She also seems to accept some creationist arguments at face value, such as claims of gaps in the fossil record. In the first chapter on science and religion, Phy-Olsen raises important issues, such as the link between George McCready Price's flood geology and Seventh-Day Adventism, and Whitcomb and Morris's *The Genesis Flood*, and the Discovery Institute's Wedge Document, but fails to tie them into the chapters on creationism and responses to it. In the chapter on theistic evolution, she introduces a series of "influential voices from within the scientific community" and explains each person's viewpoint on religion and evolution. The views are diverse and interesting, but they are not tied together in a coherent way. A reader would not come away with a clear understanding of theistic evolution and how it relates to other views of evolution. There are many other instances of lack of focus throughout the book.

Finally, I need to address some errors in the book, some of which are minor and may merely be editorial glitches. For example, in *Kitzmiller*, the lead plaintiff was Tammy, not Timmy, Kitzmiller. George McCready Price is sometimes referred to as Price, and at other times as McCready. In the Darwin story, Phy-Olsen describes how Captain FitzRoy repatriated a Fuegian who had been educated in England and was returning as a missionary. There were actually three Fuegians, and there was a missionary, but he was an Englishman. She credits Herbert Spencer with the phrase "struggle for existence." That was the title of chapter 3 of *On the Origin of Species*. Spencer coined the phrase "survival of the fittest." Elsewhere she criticizes Darwin for accepting a Lamarckian view of genetics. This either is a cheap shot or indicates a lack of understanding. Darwin worked on the problem of heredity, and like everyone else of his generation, he failed. In the face of a variety of critiques, Darwin began to lose confidence in natural selection. The Lamarckian view was the most coherent alternative available until Mendel's work came to light. That can hardly be seen as a criticism.

Also, Phy-Olsen criticizes Darwin for not having read the paper that Mendel had sent him. This is an oft-circulated rumor for which there is no evidence. Mendel's paper, read or unread, has not been found in Darwin's library. In discussing the work of Haeckel, who demonstrated the similarity of embryos of different classes of vertebrates, she accuses him of faking his data. This is a blatant creationist claim. Haeckel was guilty of overidealizing his embryo drawings, but the point that he was making was then, and still is, correct. In her description of Asa Gray in the appendix, Phy-Olsen states that "Gray obtained an admission from Darwin that evolutionary theories were not antithetical to religious faith." Again this is either a cheap shot or a lack of understanding. Gray was Darwin's friend and chief proponent in the United States, and a deeply religious man who should have been prominently included in the chapter on theistic evolution. Darwin had very conflicted views about religion brought about in part by his skeptical mind but more by the tragic death of his daughter Annie at age ten. At the end of his life he identified himself as an agnostic but did not appreciate others using his work as evidence either for or against God. While Darwin did not agree with Gray's view that God necessarily guided evolution, for him to say that "evolution is not antithetical to religious faith" would hardly be an "admission."

About the author

Robert H Rothman is Professor of Biology in the School of Biological and Medical Sciences at the Rochester Institute of Technology. He teaches courses in genetics, genetic engineering, evolution and creationism, vertebrate evolution, bioethics, and a field course in the Galápagos Islands.

Author's address

Robert H Rothman
School of Biomedical Sciences
Rochester Institute of Technology
Rochester NY 14623
rhrsbi@rit.edu

REPORTS OF THE NATIONAL CENTER FOR SCIENCE EDUCATION

Published bimonthly by the National Center for Science Education

REPORTS.NCSE.COM
ISSN 2159-9270

REVIEW

God vs Darwin: The War between Evolution and Creationism in the Classroom

by Mano Singham
Lanham (MD): Rowman & Littlefield, 2009. 192 pages

reviewed by Stephen P Weldon

Mano Singham's most recent book, *God vs Darwin*, relates the eighty-year history of legal battles over the teaching of evolution in public schools from the Scopes trial until the *Kitzmiller* trial. In a market that has become saturated with discussions of the American obsession over the teaching of evolution—especially since *Kitzmiller* in 2005 and the celebratory events during Darwin's 200th birthday in 2009—Singham has still managed to write a succinct introduction to the subject. I cautiously recommend this book for that reason. Yet the book has some serious problems that make it less useful than I might have hoped.

The outline and intention of the book is clear. Singham writes in an accessible prose for general readers, and his short chapters and occasional sidebars clearly mark this book as one intended for people new to the subject. Singham is a theoretical nuclear physicist by training, and his interest in the topic arose from his own direct participation as a member of the state advisory board for K–12 science standards in Ohio in 2001, at a time when the ID controversies were boiling. Singham brings no new research to bear, nor does he introduce any radically new perspectives. The book mostly synthesizes and distills the accounts presented from other sources.

One of the most useful parts of the book is Singham's ability to rapidly capture the legal complexities in a few short chapters (nearly all of his chapters are 10 pages or under). He provides a concise overview of the major Supreme Court decisions from mid-century that set the stage for wrangling over the place of evolution in the school curriculum. Though the stories have been told before, here the reader can digest the meat of case law in a few minutes. Even the baffling three prongs of the *Lemon* test become clear.

There are problems with this book, however, that could have been remedied by a surer footing in the recent historical research that is readily available on this topic.

First of all, the book is somewhat lopsided in its presentation of the subject. Singham spends over one-third of the book on the Scopes trial, a singularly important event in American cultural history, but one of scant significance to the legal history of creation/evolution battles, a point which he understands and acknowledges. Singham, nonetheless, notices influences of the Scopes trial's legacy reverberating well into the present time, which helps explain his emphasis on it. Singham presents this entertaining story accurately, getting both Bryan and Darrow as well as the overall history of the trial by and large correct.

This is not surprising since his account is drawn directly from the Pulitzer-Prize–winning book by Edward Larson, *Summer for the Gods* (1997).

What is surprising, however, is the lack of even one citation to Larson's extensively researched legal history of the evolution-creation debate in American public education, *Trial and Error* (2003), a work that covers both the same period and the same broad topical focus of the book currently under review. This omission is indicative of a consistent problem with the book, which is its very light bibliography, especially of secondary sources.

A greater problem with this book lies in Singham's imprecision when it comes to his use of the term *religion*. Too often *religion* appears as a synonym for conservative religion or even fundamentalism. This is unexpected since the book is touted as helping to show the way for peaceful coexistence between science with religion. Nonetheless the terminological blunder slips out frequently—as, for example, when he erroneously states that "religious people have always been uncomfortable with the theory of evolution" (p 153)—and the damage is done. Singham's efforts to demonstrate that religion doesn't have to be at war with science is undermined by his allegiance to Daniel Dennett's perspective that Darwinism is a universal acid that eats away at religious belief.

I also find that Singham's portrayal of intelligent design as merely stealth creationism misrepresents or misinterprets the actual state of affairs. On this point, Singham is in good company, however. The idea that ID is merely gussied-up creationism goes back at least to the well-researched and helpful book by Barbara Forrest and Paul R Gross, *Creationism's Trojan Horse* (2004). That book traces the promotion of ID to people connected with Christian Reconstructionism and evangelical Christianity. Singham follows that line and brings it up to date with the Dover trial, which appears to be another smoking gun in favor of this interpretation: the unambiguous religious motivations of conservative Christians on the Dover Area School Board were shown to be behind the promotion of a pro-ID biology textbook in the district. Singham characterizes ID promoters as intellectuals who are trying to get the ignorant masses of fundamentalists to adopt a stealth strategy that will yield the same ends that they are too impatient to wait for.

There's clearly some truth to this characterization, but I don't find it convincing as a guiding framework. It is only part of the story and cannot explain the emergence of ID as a more broad-based scholarly movement—not a legal strategy—among people as diverse as the agnostic David Berlinski and the Catholic Michael Behe, neither of whom could conceivably be linked to Christian fundamentalism. Critics of ID acknowledge these people, but depict them as outliers. The bigger picture, however, shows attacks on evolution to be increasingly common phenomena among intelligent people around the world from many religious traditions, who are disenchanted with a contemporary secularism that often seems to have dehumanized the world in which we live. (See the second edition of Ronald Numbers's *The Creationists* [2006], in which he talks about this global creationism.)

In summary, Singham's book is a short introduction to a complex topic. It has some advantages as such but ought to be read in conjunction with other texts.

References

Forrest B, Gross PR. 2004. *Creationism's Trojan Horse: The Wedge of Intelligent Design*. New York: Oxford University Press.

Larson EJ. 1997. *Summer for the Gods: The Scopes Trial and America's Continuing Debate over Science and Religion*. New York: Basic Books.

Larson EJ. 2003. *Trial and Error: The American Controversy Over Creation and Evolution*, third ed. New York: Oxford University Press.

Numbers RL. *The Creationists: From Scientific Creationism to Intelligent Design*. Cambridge (MA): Harvard University Press.

About the author

Stephen P Weldon is Assistant Professor of History of Science at the University of Oklahoma.

Author's address

Stephen P Weldon
Department of History of Science
University of Oklahoma
601 Elm, Physical Sciences Room 618
Norman OK 73019-3106
spweldon@ou.edu

REPORTS OF THE NATIONAL CENTER FOR SCIENCE EDUCATION

Published bimonthly by the National Center for Science Education

REPORTS.NCSE.COM

ISSN 2159-9270

REVIEW

The Prism and the Rainbow: A Christian Explains Why Evolution Is Not a Threat

by Joel W Martin

Baltimore (MD): The Johns Hopkins University Press, 2010. 170 pages

Reviewed by Matt Young

I love the rainbow, not only because of its beauty but also because it has so many fascinating physical features — supernumerary arcs, secondary rainbow, bright sky inside the primary rainbow and outside the secondary rainbow, and dark sky between them. I can explain all these features on the basis of physical or geometrical optics. Joel Martin, the author of *The Prism and the Rainbow*, loves the rainbow not only because of its beauty but also because it reminds him of God.

Martin, an evolutionary biologist and an ordained Presbyterian elder, cleverly uses the rainbow and the prism as analogies for religious and scientific explanations. The religious explanation, which Martin would freely admit is not an empirical explanation, for the existence of the rainbow is that God put it there as a symbol of his covenant with humanity. For Martin, the Biblical story of the rainbow is a good yarn, and he argues that even "people today who fully understand the physics behind rainbows [can easily] think of the hand of God behind such a wondrous spectacle. In fact, it is hard for many people (and I am one of them) to conceive of a world that does not have God in it when confronted with such unbridled glory" (p 16).

The prism, by contrast, represents science; Newton used the prism to demonstrate that white light is composed of all the colors of the rainbow and thereby explained the visible spectrum.

Martin thus sets us up for what amounts to a viewpoint similar to Stephen Jay Gould's nonoverlapping magisteria: that there are two explanations does not necessarily mean that one of them is wrong. In short, he sees no reason why a natural phenomenon cannot on the one hand be explained by science and on the other hand be a sign from God. The Biblical story of the rainbow "has to do with God's forgiveness, grace, and promise"; it is not diminished because we understand the physics of the rainbow. The same, says Martin, is true of the theory of evolution: his appreciation of the deity is not diminished by his understanding of natural selection.

Although it does not say so anywhere, the book appears to be written for young adults, that is, in high school or college. Martin begins with an anecdote about two students who belonged to his church but were completely unaware that the church's official position accepted the theory of evolution. Indeed, Martin estimates that most Christians in the United

States belong to churches that consider evolution compatible with their beliefs; unfortunately, not all members of those churches share their churches' official positions.

In early chapters, Martin describes the nature of science and the meaning of the word "theory" in science. His defense of science is good, but I cannot agree that science does not address "such important human issues as our sense of morality or the value of beauty" (p 34). Indeed, I am mildly surprised that an evolutionary biologist does not even consider the possibility that our sense of morality is an evolved trait; we have observed cooperation and reciprocal altruism in the animal kingdom, and our sense of morality may well be similarly evolved and therefore addressable by science. Likewise, although Martin obviously rejects religious beliefs that conflict with known scientific fact, he inconsistently argues that science cannot address matters of faith. The chapter on the meaning of "theory" is likewise a little muddled and may not be clear to people who do not already have some appreciation of the terms he defines.

Subsequent chapters describe evolution, creationism, and "intelligent design" (ID) creationism. I wish that the chapter on evolution had been a bit longer and provided clearer evidence in favor of evolution, rather than just stating that the evidence is overwhelming. The chapter on creation science was clear, but the chapters on ID creationism were marred somewhat because the author has conflated ID creationism with old-earth creationism. Specifically, many old-earth creationists reject macroevolution and claim that there has been only variation within "kinds". While ID creationism is officially neutral about macroevolution, its most prominent scientific advocates, Michael Behe and William Dembski, accept macroevolution but do not think it could happen unaided, at least in certain cases. Contrary to Martin, ID creationism does not necessarily restrict evolution to microevolution within kinds.

Martin explains clearly that there is no affirmative evidence for ID creationism, that disagreement in science is to be expected, and that evidence against one theory is not necessarily evidence in favor of another. He also describes "the fear that evolution somehow removes God from the picture … It is mostly the 'randomness' of mutations that seems to concern creationists here, since this [randomness] would seem to imply pure chance over the hand of a designer" (p 71). He goes on to explain that randomness simply means unpredictability and, unarguably, that much of life is unpredictable.

After a couple of chapters on religion and the Bible, Martin concludes by asking what Christians are to believe. He states flatly that the Bible was written at different times and by different people; it is not a textbook but rather "enduring messages passed down from generation to generation." He advises wise readers of the Bible not to "get caught up in the details and lose the important message." Second, he does not think that any finding of science should make them question their faith. Third, he advises them to study evolutionary theory and biology. Finally, and to my mind the most important, he urges them not to "fear knowledge"; science, which he sees "as a gift from God, is the most direct way we have of learning about the natural world. … [S]cience itself is not remotely anti-Christian or anti-religious. … [W]e have nothing to fear from learning about the world around us" (p 101). In an unfortunate epilogue, however, Martin simply begs the question about how we know God is with us today and unconvincingly holds up evolution as evidence "that God's work is still being done."

Finally, three quibbles. The book has far too many detailed notes. If the material in the notes was worth reading, it should have been incorporated into the text; if it was not worth reading, it should have been eliminated. Second, the short glossary contains terms that appear nowhere in the book. And, finally, the author's description of the formation of the rainbow is inaccurate; although the color in the rainbow depends on dispersion (the variation of index of refraction with wavelength or color), the formation of the rainbow is not at all like the formation of a spectrum by a prism.

About the author

Matt Young is Senior Lecturer in the Department of Physics at the Colorado School of Mines and the author, with Paul K Strode, of *Why Evolution Works and Creationism Fails* (New Brunswick [NJ]: Rutgers University Press, 2009).

Author's address

Matt Young
Senior Lecturer
Department of Physics
Colorado School of Mines
Golden CO 80401
theopticist@gmail.com