

THE INTELLIGENT DESIGN CONTROVERSY IN SCIENCE (Is there scientific merit in the concept of "Intelligent Design" in Nature?)

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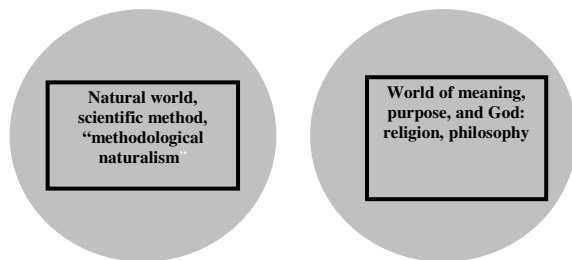
A. Introduction

For many years Western societies have allowed scientific and religious ideas to coexist by maintaining a separation between the two. The dominant opinion has been that human pursuits can be compartmentalized, with science based on experimental study and mathematics in one separated realm, and religion and the humanities in another separated realm.

The late Harvard paleontologist Stephen Jay Gould developed a term for this "live and let live" attitude, which separates the world of faith and religion from the world of measurable, observable real events or systems. He called the two realms "non-overlapping magisteria"¹. Figure 1 illustrates the concept. In our day this solution is being challenged by a set of ideas collectively labeled *intelligent design*, or, *the science of intelligent design*.

Most of us have noticed a strong conflict in Western societies, particularly in the USA and the UK, around this set of intelligent design (ID) ideas. A number of well-trained academic scientists in astronomy, astrophysics, and molecular biology² have been claiming that it is possible to identify objects that have been designed and result from the action of

Fig. 1: Steven Gould's "Non-Overlapping Magisteria."



¹ Gould, S.J., *The Hedgehog, the Fox, and the Magister's Pox : Mending the Gap Between Science and the Humanities*. Random House, New York, 2003.

² E.g. William Dembski, (Ph.D. in Math. from U. of Chicago, Ph.D. in Philosophy from U. of Ill. at Chicago, M. Div from Princeton Theological Seminary, postdoctoral study at Cambridge); Guillermo Gonzalez, Ph.D. in astronomy, U. of Wash., Asst. Prof. at Iowa State U.; Michael Behe, Ph.D. in biochemistry from U. of Penn., Prof. of biological sciences at Lehigh U.; Scott Minich; Jonathan Wells; Stephen Meyer, Ph.D. in history and philosophy of science from Cambridge, Assoc. Prof. of Philosophy at Whitworth College; and many others.

an Intelligence, called *the Designer*. They propose objective criteria, which they say are scientific, for drawing the conclusion that an object or system is intelligently designed. These arguments seem to imply intervention in the normal interlocking network or web of cause events and their effects that we observe in the world, because they focus on the action of an agent, the Designer, that differs from the combination of natural law, necessity, chance and sufficient time. Some people, who reject the possibility of a supernatural realm, accept the possible existence of a Designer, but they regard the Intelligence of this Designer as a collective phenomenon arising out of the whole of the physical universe. This was the concept of God that Einstein held. They would use as an analogy the physical human brain, out of which a mind or intelligence arises, even though it is a purely natural phenomenon.

Those promoting intelligent design usually avoid defining the Designer, and many will not call the Designer “God,” in a traditional sense. In writings of ID proponents the Designer is not clearly a supernatural realm. Some have suggested extra-terrestrial intelligent beings as the designers. However, all are unanimous that chance and necessity (environmental selection), as defined in Neo-Darwinism cannot carry out the design function for life in the time available. They explicitly reject “*The Blind Watchmaker*” concept advanced by Richard Dawkins of Oxford.³

Most scientists are suspicious of those who find design in nature, but fail to identify the Designer. They regard ID as a “Trojan Horse” to smuggle religious ideas and God-actions as explanations into the midst of scientific activity. They believe this would destroy the essence of science by inextricably mixing it with religious ideas and supernatural explanations. They usually react strongly, angrily rejecting intelligent design, and repeating endlessly, “Intelligent design is not science!” Professional power is used to marginalize and criticize ID researchers, by blocking publication of results in peer-reviewed journals, and preventing ID researchers from getting grants or faculty positions. These tactics resemble those of totalitarian societies, and should not be characteristic of an open-minded scientific community. Thus far mainstream science has not offered adequately reasoned answers.

These two positions are *a classic case of the possible overlap of supernatural and natural causes*. To focus the discussion, let us admit that if there is truly scientific evidence for design, then the traditional monotheistic God is the likely Designer. The question for objective investigation is whether God, the Creator, has left clear evidence of direct action in the universe that is not according to natural law. If a real Creator exists, we cannot necessarily relegate him to some ethereal “spiritual realm,” or “non-overlapping magisteria.” A Creator powerful and intelligent enough to make and maintain the universe could reasonably choose to intervene in that universe. To discuss clearly what is happening in the intelligent design controversy, we must set the stage with attempts to define two competing worldviews, which collide in this controversy: Naturalism, and the Biblical Worldview. We must discuss the difference between natural events or systems and supernatural events or systems.

B. Natural Events or Systems

For millennia humans have noticed that events seem to fit into a predictable pattern of cause and effect. In practical terms, this has given rise to the many technologies

³ Dawkins, R., *The Blind Watchmaker: Why the Evidence of Evolution Reveals a Universe Without Design*. W. W. Norton and Co., 1996.

humans have developed and used. During the Enlightenment this was codified into a system of natural laws that were general descriptions, often in mathematical terms, of these observable regularities. Newton’s laws of motion, including the law of universal gravitation, gave expression to an accurate description of motion that has proven reliable every time it has been tested in the realm of everyday sizes and speeds. At the same time, direct observations and experiments were increasingly emphasized as the means to discover and test the natural laws.

Philosophically, people began to think in terms of the world operating like a giant machine, with every event or system being the result of an unbroken network or web of cause and effect that occurred according to the natural laws that were discovered. Each new law that was found strengthened this impression, until today this naturalistic view of reality is embedded deeply in the consciousness of members of Western societies. We hear increasing claims that there are no events or systems that do not fit into the interlocking structure of natural laws. This defines the Worldview of Naturalism, as pictured on the left of Fig. 2.

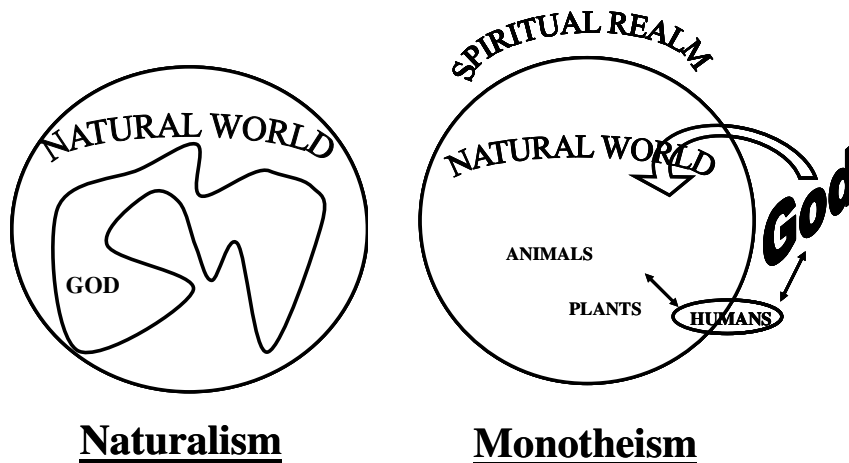


Fig. 2 Two Worldviews: One that includes only natural causes (Naturalism,) and one that includes natural and supernatural causes (Monotheism.)

This mechanistic view actually cannot be supported today in light of three major developments in science itself.

- (1) ***Godel’s proof*** showed that our logical systems themselves, including all of the mathematics we use to state the natural laws, are incomplete. They are powerful, but imperfect tools in the realm of logic and mathematics.
- (2) ***The quantum uncertainty principle*** states that though we can predict the motion of the probability wave of an electron, for example, deterministically, the actual motion of an electron described by that wave function is not deterministic. The problem is that ***the wave itself has the meaning of a probability distribution*** (when squared absolutely in the complex sense).
- (3) ***Most large scale systems are described by chaotic equations:*** For systems as large as those we live with at our size scale the uncertainties become so small as to be practically irrelevant. Motion becomes essentially deterministic for large systems. But another principle keeps us from actually making those deterministic predictions.

Coupled systems of nonlinear differential equations have been shown to have a property called chaos; they are chaotic systems of equations. The equations governing nearly all interesting systems are chaotic. Chaotic systems exhibit another type of uncertainty in their predictions that is essential, and cannot be avoided by refined measurements of initial conditions. In principle the solutions are deterministic, but actual predictions will deviate from reality as time progresses, no matter how well we know the starting conditions.

It seems to this author that these three results of modern science have not been fully factored into the thinking of scientists about the nature of the scientific description of nature. If there is a giant machine operating, we cannot apparently know it perfectly; much less prove in any specific case that the laws are followed perfectly. Still we know that modern science provides a very powerful and useful description of physical reality. But it would be honest and good if far more humility were expressed in assessing the completeness of scientific descriptions of the world. To be honest, science needs to project a much less triumphalistic attitude about its grasp of reality.

C. Supernatural Events and Systems

The existence of a supernatural world or realm has been accepted by humans as far back as our history is recorded. In particular, monotheistic religions picture an intelligent, personal Being with the power to plan and bring into existence the world we know. Most who believe in such a Creator accept that God has created natural laws, but that He has power to produce events or systems by direct, chosen action also. Many believe that God can appear in the natural realm as He chooses, but also can remain invisible.

The supernatural acts of such a Being occur as single, willed actions. They are not repeatable except as chosen by God, because they are acts of a personal, intelligent Being with special powers. Almost all of the early developers of modern Western science believed in the existence of such a God.⁴ Apparently, these religious beliefs did not keep Galileo, Kepler, Newton, Hooke, Maxwell and many others from developing the science we still accept today. They spoke of that belief very openly and integrated it with their science.

Galileo: *“It is true that the divine intellect cognizes mathematical truths in infinitely greater plenitude than does our own (for it knows them all), but of the few that the human intellect may grasp, I believe that their cognition equals that of the divine intellect as regards objective certainty, since man attains the insight into their necessity, beyond which there can be no higher degree of certainty.”*⁵

Johannes Kepler: *“I give you thanks, Creator and God, that you have given me this joy in thy creation, and I rejoice in the works of your hands. See I have now completed the work to which I was called. In it I have used all the talents you have lent to my spirit.”*

Isaac Newton: *“This most beautiful system of sun, planets, and comets could only proceed from the counsel and dominion of an intelligent and powerful Being.”* Also,

⁴ Barr, S.M., *Retelling the Story of Science*. First Things 131 (March 2003): 16-25.

⁵ The original quote is in Italian. This English translation uses uncommon, large words to express the ideas. A more accessible translation might be, *“God is a Mathematician and understands all mathematical truths, which are infinite in number. Our human minds can grasp only a few of them. But the few that we do grasp are just as true and certain to us as they are to God, because they are logically necessary. This is the highest level of certainty that exists.”*

“This Being governs all things, not as the soul of the world, but as Lord over all; ... and Deity is the dominion of God, not over his own body, as those imagine who fancy God to be the soul of the world, but over servants.”

Christian believers accept that the actual events in the world is a mixture of some which have natural causes, some which have supernatural causes, and some which have mixed causes. Most have accepted the existence of the network of cause and effect according to regular natural law that is studied by science. They also believe in a real Creator God, who can intervene miraculously if he chooses to do so. Creation of the universe itself and the resurrection of Christ are widely accepted as supernatural events, but most Christians accept other miracles as well, including some they believe they have witnessed. Christians have given reasons why miracles should be rare ⁶, but they accept the reality of intervention. Those who hold to a fully secular universe, who hold the worldview of naturalism, would deny that supernatural causes exist that can cause events in nature. But can there be an objective scientific method for deciding that an event or system has been intelligently designed, whether produced by natural or supernatural means, or a mixture?

D. Inference to Intelligent Design: A Common Human Activity

We humans frequently carry out an activity called “inferring to intelligent design.” On a rock by the lake we see a heart in some red shiny substance with the words “Susan loves Peter” inside the heart, and perhaps an arrow through it. We immediately assume that either Susan or Peter or both or another human drew this symbol. We infer from the evidence that the symbol was not produced by any natural process, but that intelligent agents made the drawing. Or in a court case the judge hears evidence as a set of facts and arguments. That judge must decide whether the accused human (intelligent agent) produced this evidence in committing a crime, or whether the evidence only seems to prove that the defendant did the crime, and is really an accidental alignment of facts.

E. Adequate Evidence of Intelligent Design: The Explanatory Filter.

Dr. William Dembski has detailed the process he believes we use in making a logical inference to intelligent design as the best explanation.⁷ He calls it “the explanatory filter,” and it contains three steps. In simplified form, they are the following:

- 1) The object or situation must be CONTINGENT.
- 2) There must be a very large number of alternatives so that this one is HIGHLY IMPROBABLE.
- 3) The object or situation must SERVE A PRE-SPECIFIED PURPOSE.

⁶ Lewis, C. S., *The Problem of Pain*. Macmillan, New York, 1961, pp. 21-22.

⁷ Dembski, W., *The Design Revolution*. InterVarsity Press, Downers Grove IL, 2004, p. 75.

F. An Example of Application of the Explanatory Filter

As an example, consider the object pictured in Fig. 3. What is it? Most people quickly identify it as a stone-age tool made by humans by chipping flint. Let's apply the *explanatory filter* to show how it leads to this conclusion.

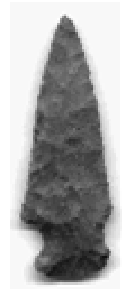


Fig. 3

Firstly, a piece of flint stone can have other shapes than this one. The shape is not required by physical laws like that of a crystal or a falling drop of water. The object is CONTINGENT. Let the reader note that this condition requires that we MUST RULE OUT NATURAL CAUSES FIRST.

In fact, a piece of flint can have any of a huge number of shapes within the laws of nature. This is the second requirement. The shape shown in Fig. 3 is HIGHLY IMPROBABLE. But *any* piece of flint satisfies these two conditions.

The third condition determines the intelligent design of this object by someone with a human-like intelligence. The object is clearly an arrowhead or spearhead. The indentations are for wrapping leather thongs around the head placed in a slot in a wooden shaft to hold it firmly in place. The sharp edges and pointed shape make the object perfect for penetrating the flesh of an animal. The object SERVES A PRE-SPECIFIED PURPOSE as a hunting weapon.

With this explanatory filter Dembski helps us understand that our inference to intelligent design and production by a human is not arbitrary, but results from meeting these three conditions. You might try applying them to another example, like a court case, to test them further.

G. Two Main Areas Where Scientists are Claiming There is Evidence of ID

A number of scientists working mainly in the two areas of astronomy/astrophysics and molecular biology have found situations where they believe the explanatory filter gives a “yes” answer that the physical universe with our earth and a number of biological systems within it have been intelligently designed. The first class of scientists use some form of *the anthropic principle*, which has been developed by physicists such as Paul C. W. Davies⁸ and others to explain how the structure of the universe is highly improbable and ideally suited for intelligent carbon-based life. The biologists say they find a property they call *irreducible complexity* (IC) in a number of molecular machines and sequential molecular processes, like blood clotting. We will discuss these two ideas and try to evaluate where the science stands.

H. The Anthropic Principle Derived From the Structure of the Universe as a Whole

In the Middle Ages people thought that the Earth was **The Privileged Planet** at the Center of the Universe. Then Copernicus and Galileo showed that the Sun was at the center of the Solar System, and the planets rotated around it. Earth was demoted from its

⁸ Davies, P. C. W., *The Accidental Universe*. London: Cambridge University Press, 1982 (the first of many books by various authors to introduce the anthropic principle.)

privileged status. That our Earth is nothing special is called “The Copernican Principle.” It is a truly insignificant planet in a solar system around a medium-sized star far out near a spiral arm of our galaxy, one galaxy among billions. This view has dominated for centuries. Recently, Carl Sagan expressed this by saying

*The Earth is a very small stage in a vast cosmic arena...Our posturing, our imagined self-importance, the delusion that we have some privileged position in the Universe, are challenged by this point of pale light.*⁹

But in the last 30 years, as the “Standard Model” of Big-Bang Cosmology has become widely accepted, astronomers and astrophysicists have realized how many fundamental properties of the laws of nature must be “just so” for a planet to exist that can support human intelligent life. They speak of the value of the electron charge, the neutron/proton mass difference, the strengths of the gravitational, strong nuclear and weak forces, the specific inhomogeneities in the early hot Big Bang, the precise properties of the Collider that hit the Earth to produce just the right kind of Moon, and many other parameters, in making this point. Astronomers and astrophysicists are increasingly speaking of the anthropic principle: *the laws of nature and the initial conditions of the Universe are exactly as they must be for humans to arise, flourish and observe the structure of the Universe.* The Universe seems designed specifically as an excellent home for us and for us to have a good platform to study and understand how it is made.

On this view, the explanatory filter for intelligent design of the Universe is satisfied. The constants and laws of nature can be adjusted, and you still get a Universe. The Universe is **CONTINGENT**. Since many of these parameters are continuous variables, there are very many distinct Universes you can construct from the laws. The Universe is **HIGHLY IMPROBABLE**. By satisfying the purpose of being a suitable home for humans within extremely narrow limits (i.e. a good human home itself has many detailed requirements) the Universe fulfills a **PRE-SPECIFIED PURPOSE**. Therefore, Dembski would claim, the Universe and our Earth are intelligently designed and produced as a suitable home for humans.

Now, instead of thinking that there are many planets in the universe suitable for life, astronomers are arguing that the Earth is likely to be the only suitable place in the Universe for intelligent carbon-based life to exist. (We know of no other type of intelligent life.) Further, the probability that a suitable planet like our Earth could result is itself exceedingly improbable. Gonzalez and Richards have summarized much of the necessary science in their recent book, in which they restore the Earth to its previous status as “The Privileged Planet.”¹⁰ This book has been given the status of a key monograph in astronomy by a number of well-known reviewers.

I. Irreducible Complexity in Biology

The biologist Michael Behe¹¹ has authored the concept of **irreducible complexity** (IC) in biology. He has advanced several molecular machines and several reaction cascades in living systems that he says cannot be built up in small steps from simpler systems. If you change any part of the machine or cascade, the whole thing ceases to

⁹ Sagan, C., *Pale Blue Dot*. Random House, New York, 1994.

¹⁰ Gonzalez G., Richards, J., *The Privileged Planet: How Our Place in the Cosmos is Designed for Discovery*. Regnery Publishing, Inc., 2004, ISBN: 0895260654

¹¹ Behe, M., *Darwin's Black Box*. The Free Press, Simon & Schuster, New York, 1996.

function. Therefore, the system cannot be produced by the small changes of Neo-Darwinism. The very last step in building the system would fail. It seems that IC systems must be produced whole and functioning. Dr. Behe does not reject common descent, but believes that Neo-Darwinism is a failed theory in the light of these systems.

One hotly-debated example is that of the flagellar motor in certain bacteria, shown in Fig. 4. It is a complex molecular machine with 40 distinct sub-assemblies that rotates to generate propulsion for the bacteria. This motor has been studied extensively. To date no complete proof has been given yet, showing no way to assemble it in steps within our knowledge of mechanisms of genetic change. Examining the system, it certainly appears as a candidate for IC.

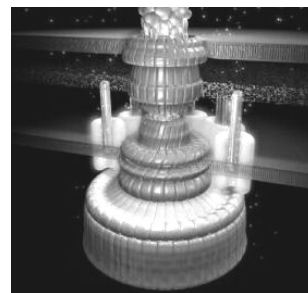


Fig. 4: The flagellar motor

The explanatory filter may also apply to this complex system to indicate design, but the “*no way to assemble in small steps*” property must be shown first.

J. “God as Creator”: Fact or Ethereal Opinion?

A key question for humans in any age is, “Did a supernatural, powerful, intelligent God create the whole Universe out of nothing so that time, space, and matter all came into being together in a creation event?” People who hold to Naturalism (no reality beyond the physical world) answer “no.”

They often say that religious views are valid, but private. They say that science deals with the real, measurable world of facts. Naturalists are willing to grant religious belief validity so long as it has no factual, real-world presence. Ideas about the supernatural are opinions that are not testable in the real world.

In their view science, which studies real things by methods of precise observation, can then concentrate on the unbroken network of natural cause and effect. Naturalists ask religious believers to practice “methodological naturalism.” They should do science as if naturalism were true. Many scientists who are Christian believers accept this request as defining the scientific enterprise for them also. Supernatural causes, such as an intervention by a Designer that violates natural law, are strongly avoided. The insistence on methodological naturalism in science has become very coercive and strident in the scientific cultures of the USA, the UK, and Western Europe.

K. For Believers Reality Includes Both Natural and Supernatural.

What if supernatural intervention in the creation of the universe or the creation of life is historically factual? We must ask whether God, the spiritual realm, and religious belief are real and factual parts of Reality. There is substantial evidence in holy books of monotheistic religions that miracles have, in fact, occurred. Events that do not happen within the unbroken network of cause and effect (natural law) appear to really happen. The scientific method is powerless to study singular actions of a personal Intelligence that are a single act of will and are not repeated. Science cannot disprove miracles.

Other methods, including the methods of historical inquiry and forensics critically examine accounts of miracles, to establish their reality or non-reality. If we find strong evidence that a miracle has happened, then we have “Warrant” for a belief in the supernatural invading the natural world.

The difficulty for biology arises if a supernatural Creator exists and decided to create certain life forms all at once outside of natural law processes. Then real organisms would exist that cannot be scientifically explained within the worldview of naturalism. The anthropic principle correlates with an original creation event, and there is relatively little argument that one can view the source of that creative event as a personal Designer God. It is in biology where the intense and heated debate rages.

It is difficult in science to prove a negative. To prove that a complicated system is IC is a large effort, and may be impossible. That is why some researchers are abandoning systems as complicated as the flagellum, and are studying much smaller systems that they believe are IC. Dr. Doug Axe¹², who did 14 years of postdoctoral work at Cambridge, is studying much simpler protein domains at the Discovery Institute, which he believes are IC. His results should be available soon.

L. Is Intelligent Design Anti-Darwin?

If biologists can show that life forms are intelligently designed as the best explanation, it would replace Darwin's explanation for the change of life over time in some cases. In other cases Neo-Darwinism already seems to provide a convincing, detailed, and mathematically correct explanation.¹³ But Neo-Darwinism is questioned by many biologists for reasons of scientific evidence without any reference to ID. Biologists who question Neo-Darwinism often expect to see it replaced by a new theory of "natural" evolution, rather than explanations with any reference to supernatural events.

Some of those who now doubt Neo-Darwinism expect biologists to find an eventual natural explanation, but others do not. For example, Michael Behe holds the Biblical Worldview, but he still believes that common descent happened by some means. He is open to the possibility that the full story of the development of life may have to include supernatural events, but accepts that part of the story of how life developed and changed on this planet happened by natural means.

M. Is Intelligent Design Science?

This question needs to be broken down into several more specific questions to understand the current situation.

1. Are the methods of inference to intelligent design as the best explanation scientific?

As we showed above, the explanatory filter is very empirical and objective. In fact, the first step is to rule out a natural explanation for the structure of the event or system. The methods are fully compatible with scientific practice. As we have also shown, the real problem is that ID is open to causes outside the natural world. Intelligent design qualifies as science in its methods.

2. Is intelligent design a useful paradigm for science?

¹² Axe, D., Extreme Functional Sensitivity to Conservative Amino Acid Changes on Enzyme Exteriors, *J. Mol. Biol.*, 301, 2000, pp. 585-595.

¹³ Behe, M., *The Edge of Evolution: The Search for the Limits of Darwinism*. The Free Press, Simon & Schuster, New York, 2007, ISBN: 0743296206.

It is a useful paradigm to assume that life forms are intelligently designed, because it would quickly and directly have guided biologists to a number of truths that were finally established over initial opposition. In the mid-20th Century, the appendix and tonsils were regarded as vestigial organs, which they are not. Also, as recently as 2 years ago, 95% of human DNA was considered by most biologists as leftover junk from the process of evolution. It was two years ago when key journals began to publish contrary conclusions, like the article *Gems Among the Junk* in Scientific American. Now the dominant opinion among biologists is that most of human DNA probably has important functionality. One can assemble a number of other examples.

Will ID lead to a better predictive scheme? This author has an open mind on this, but it is far from obvious. Let those who want to study intelligent design have freedom to do research, get funding, and write articles to try to develop it as a useful predictive scheme.

3. Have any biological systems been proven to be irreducibly complex?

In a word, no. But research to do so on reasonably simple systems is well advanced.¹²

4. Would it ruin science to allow for possible supernatural causes for natural events or systems?

This author thinks not. Rather, it would allow for a scientific enterprise that could approach reality more fully and in a more integrated fashion. No case has yet been clearly proven that the origin of a life form or some subsystem of a life form has a cause beyond natural phenomenon.

The biggest challenge is to explain how so much detailed and interlocking information as exists in living organisms can arise from natural law, chance, necessity, and time. High levels of information are usually produced by intelligence, however. Still, no carefully formulation of information content of living things and no clear laws about how much information can arise by law, chance, necessity, and time have been offered to date.

If it could be proven, for example, that all life forms within a *genus* developed by some natural process like Neo-Darwinism, but the original *genus* representatives were produced discontinuously by supernatural intervention, we would then have a blended explanation of the development of life. This could include a proper timetable for the appearance of each *genus* representative. It could also allow for speciation by natural means.

N. Recommendations: An Open Mind and an Open Hand Toward ID Researchers

Shouldn't science be about following the logical, mathematical, and experimental evidence where it leads? If Neo-Darwinism is shown to be inadequate to explain the development of new life body plans, and no new mechanism that is adequate is discovered, then supernatural intervention to produce new life forms becomes a possible explanation. Special creation by God of certain life forms could become the best explanation. In that case, within science the search for new natural mechanism would surely continue. If such a mechanism were found, then the claim of special creation of those life forms would no longer be the best explanation. Naturalists would then say, "You see, your God is just a God of the gaps, and we will eventually close all of the gaps." Actually, we welcome this process in any scientific effort. Explanations are always subject to further examination.

Just like a famous soccer player who falls on hard times and begins to play poorly for a long time, the team will no longer use that player.

We should open science to the category of possible supernatural causes at the level of philosophy of science, and we should carefully discuss how to handle this expanded definition of science. We should keep an open mind on these questions, and not try to stifle ID research before it has developed enough to show its potential or lack of it.

Recent work by Jonathan Wells on certain molecular turbines¹⁴ show how ID concepts may be able to guide biological research in valuable directions to definite results. This author advises patience and asks mainstream science to give ID researchers reasonable professional resources and opportunities to pursue their work. If it is not a fruitful idea, it will fade away from the landscape of science, as many unfruitful ideas have in the past.

¹⁴ Wells, J., *Do Centrioles Generate a Polar Ejection Force?*, *Rivista di Biologia/Biology Forum*, 98, 2005, pp. 71-96.