normal production of glucose and towards the desired biofuel or electricity.

Fortunately, evolution has provided a good starting point with the hydrogenase enzyme protecting against damage when the Calvin cycle is unable to mop up all the electrons produced by the light-harvesting process. This can happen just after sunrise when light harvesting kicks in but the Calvin cycle has not yet 'woken up' from its night's rest. Under these circumstances, hydrogenase guides the electrons directly to the protons produced by splitting water to form hydrogen. The enzyme is eventually inhibited by oxygen liberated from the Calvin cycle as it gets going to allow normal photosynthesis to resume for the day.

There is also the hope of going further to bioengineer microalgae to produce biofuels or electricity directly...

Research has therefore focused on holding back this oxygen feedback mechanism to increase production of hydrogen. The first breakthrough came in 2000 when Melis and Seibert reported that reducing sulphate levels in algal cultures would cut the rate of photosynthesis (Melis *et al*, 2000). The result was a 90% reduction in oxygen production, sufficient to allow the hydrogenase enzyme to continue diverting electrons towards protons to yield hydrogen for a longer period.

Although it was a considerable step forward, it did not solve the problem because the *C. reinhardtii* cells soon died when deprived of sulphate. Melis, Seibert and others have since worked on various methods to achieve the same effect at a molecular level without depriving the cells of sulphate ions, by diverting electrons away from the Calvin cycle while maintaining overall levels of photosynthesis. This involves getting a number of things right and will probably require tuning several genes at the whole genome level to achieve the desired objectives.

The recent announcement by Craig Venter that he has created a synthetic bacterium by transplanting the genome from another species of bacteria (Gibson *et al*, 2010) has therefore added a new twist to the story. Venter's technology could enable scientists to make changes

to algae at the level of the whole genome, custom-building a suite of enzymatic tools to redirect the energy produced by photosynthesis. Venter's team took bacteria from the genus *Mycoplasma mycoides* and re-engineered its genome from digitized sequence information. The resulting genome was then transplanted into bacterial cells of another genus, *Mycoplasma capricolum*, which then acquired all the phenotypic properties of *M. mycoides* and was capable of self-replication.

Venter's development might prove a significant step on the road towards algae-derived biofuels, according to Ryu. "I think it is a smart move and look forward to hearing what would come out in the near future," he said. "Regardless of whether it works or fails, we will always learn something. For our approach, genomic manipulation can help greatly." A key target, Ryu explained, will be the ferredoxin proteins that act as biological capacitors in photosynthesis by accepting electrons from the chlorophyll antennae and carrying them to the Calvin cycle. "In genetically-modified algae, ferredoxin stops delivering the photosynthetic electrons to the Calvin cycle [...] Then we have a better chance of stealing the electrons," Ryu said.

Such exciting prospects stoke further optimism that science could at last provide a significant and sustainable source of energy that could be delivered in a variety of forms that might include transportation fuels, hydrogen, large-scale electricity production and possibly self-charging organic batteries.

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The separation of church and science

Science and religion offer different worldviews, but are they opposite or complementary?

Melissa Suran

Science and religion have long thought themselves mutually exclusive, despite science finding its roots in a theological view of the world. Since 1633, when Galileo Galilei faced the Roman Inquisition to answer for his discovery that the Earth revolves around the sun, there has been an often uneasy relationship between church and science. Religion has found itself ceding more and more ground to science as scientists have succeeded in explaining more about the Universe and the things within it. Although many scientists and religious

people disagree about fundamental 'truths' and what their own worldview can say about them, moderate voices on both sides of the divide agree there is a role for both science and religion in the modern world.

This year, evolutionary biologist Francisco Ayala from the University of California at Irvine (UCI), USA, was praised for his view on this issue and honoured with the prestigious Templeton Prize. The prize is an award of £1 million granted each year by the John Templeton Foundation (West Conshohocken, PA, USA) to an individual

who has made significant contributions to the spiritual dimension of life; the first recipient was Mother Teresa in 1973. In March this year, the foundation recognized Ayala, who has contributed important research to science while maintaining the value of religion. Ayala donated his prize to UCI, where he teaches evolution and the philosophy of science.

...science and God cannot stand as substitutes for each other

Ayala is originally from Madrid, Spain, where he was ordained a Catholic-Dominican priest in 1960, although he never practiced as a member of the clergy. Instead, he began to study genetics and evolution, which led him to a career as an academic scientist. According to Ayala, who has written many books including *Darwin and Intelligent Design* (Ayala, 2006), science and religion are two different windows through which we see the world (Ayala, 2007). "Suppose I give you an exact

physical description of a painting," he said. "The physical description does not answer questions [about the aesthetics or meaning]. It has to be answered a different way [...] the physical description is like science and the meaning and purpose of the painting is like religion." For Ayala, science and God cannot stand as substitutes for each other. "When some scientists come to the conclusion that science is contrary to the existence of God, that's when conflict arises," he said. One such scientist is British evolutionary biologist Richard Dawkins, with whom Ayala has been friends for nearly three decades. "While [Dawkins] argues that science cannot demonstrate the existence of God, and I agree [...], he should agree that science cannot prove that God does not exist," Ayala explained. "Science has nothing to do with the supernatural."

Massimo Pigliucci is a native Italian who has been working in the USA for the past two decades. Now a professor of philosophy at Lehman College of the City University of New York, he spent

...religious views are more prevalent in the USA than in European countries that have a less strict separation of church and state

much of his career as an evolutionary biologist and has had direct experience with the cultures of both the USA and Europe. In 2002, he wrote a book titled *Denying Evolution: Creationism, Scientism, and the Nature of Science*, which traces the roots of why the clash between science and religion in the Western world is worse in the USA than in Europe (Pigliucci, 2002).

"Americans are very distrustful of intellectuals and there's a prevalence of fundamentalist belief, which is much rarer in Europe these days," Pigliucci said. An atheist since his high-school days, he remains sceptical of anything biblical. "I'm an atheist in the same way in which I am an 'aunicornist'—I don't believe in unicorns," he explained. "I cannot claim positive knowledge that there are no unicorns,

but I've never seen a unicorn; I've never seen evidence of unicorns; and moreover, I know a lot about the mythology of unicorns and know why there is good reason to think it's a human-made story." Accordingly, Pigliucci, who also wrote *Nonsense on Stilts: How to Tell Science from Bunk* (Pigliucci, 2010), argues that it is not possible to reconcile science and religion. "I disagree that [they] work well in their own areas. [Religion is] providing people with an illusion that makes it easier to cope with mortality and the lack of social integration."

The distinction between science and religion is certainly not straightforward in the USA. The past years have seen political and legal battles between scientists and religious fundamentalists over the attempted introduction of religious beliefs—under the guise of 'intelligent design'—into science curricula in schools. Keith Fox, a molecular biologist and the chair of the UK-based group Christians in Science, thinks part of the USA's problem is the enforced separation of church and state laid down in the country's Constitution. Because fundamentalists cannot get religion on scholastic curricula through orthodox teaching methods, he argues, they pursue backdoor attempts to squeeze in their views. Bill Newsome, a neurobiologist from Stanford University (Stanford, CA, USA), agrees that many things cannot be measured through scientific experimentation. Nevertheless, he believes the US Constitution sets an important precedent. "I do not want religious authorities of any kind dictating science," he said. "I think America got it right with having separation of church and state."

"Historically, science and religion are first cousins"

Still, religious views are more prevalent in the USA than in European countries that have a less strict separation of church and state. In 2009, the British research group CommunicateResearch (London, UK) and the British Broadcasting Company (London, UK) conducted a poll of the UK population's stance on evolution. In response to the question of whether 'young-Earth creationism'—or the idea that God created the world sometime in the past 10,000 years—is true, 11% of the 2,060 respondents said it's "definitely true" and a further 21% said it was

"probably true". The Gallup Organization (Washington, DC, USA) and USA Today (McLean, VA, USA) conducted a similar poll in the USA in 2007. Out of the 1,007 adults questioned, 39% said creationism—defined by the poll as "the idea that God created human beings pretty much in their present form at one time within the last 10,000 years"—is "definitely true" and 27% said it is "probably true".

Despite the perpetual battleground of the origins of life, molecular biologist Denis Alexander of the Faraday Institute for Science and Religion at Cambridge University, UK, said God and science work fine together—in the proper context. "Historically, science and religion are first cousins," said Alexander, who helped set up the first prenatal diagnostic clinic in the Arab world in 1981. "Science came out of a theological worldview. In the early years, with the worldviews of the Abrahamic faiths, the ideas of science were shaped by theological concerns such as laws. [...] God revealed moral laws and by the efforts of scientists, scientific laws were discovered."

The Catholic Church has also largely made its peace with science. "We cannot say: creation or evolution, inasmuch as these two things respond to two different realities," wrote Cardinal Joseph Ratzinger before he became Pope Benedict XVI. "The story of the dust of the earth and the breath of God [...] does not in fact explain how human persons come to be but rather what they are. It explains their inmost origin and casts light on the project that they are. And, vice versa, the theory of evolution seeks to understand and describe biological developments. But in so doing it cannot explain where the 'project' of human persons comes from, nor their inner origin, nor their particular nature. To that extent we are faced here with two complementary—rather than mutually exclusive—realities" (Ratzinger, 1995).

However, some scientists, such as Dawkins, have taken an antagonistic stance towards religion. For more than 30 years, Dawkins has argued that science disproves the existence of a supreme being. In 2006, he wrote *The God Delusion*, in which he argues that the idea of God is falsifiable. As such, his anti-religious arguments have fuelled movements that maintain religious fundamentalism is holding back progress in science, society and education.

This passionate denial of religion puzzles Newsome. "They call people like Dawkins

...dismissing religion as irrelevant to the human condition also risks dismissing its moral teachings, which have underpinned Eastern and Western societies for millennia

new atheists, but I think of them as evangelical atheists," he said. "[They are] out to make converts [...] The intensity of belief is the mirror image of the evangelical and fundamental religious counter part." Fox, who is also a professor of biochemistry at Southampton University in the UK, agreed: "We don't get the same kind of lobby groups against science [in the UK] as in the USA [...] We have more antagonism from the other extreme [...] who say science and religion are incompatible, claiming that not only is religion wrong, but that it is dangerous and does not deserve respect."

The debate about the relationship between science and religion surfaced again when an editorial in *Nature Immunology* (Anonymous, 2010) expressed concerns over the selection of Francis Collins as director of the US National Institutes of Health (NIH) because he has openly discussed his religious convictions (Collins, 2006). Collins, who was appointed to the Vatican's Pontifical Academy of Sciences in 2009, insists that his beliefs do not affect his role as the NIH director. "Yes, I'm interested in this area of the interface between science and faith and yes, as somebody who was once an atheist and became a believer, I do think it's important for us to have these conversations about the compatibility and even the harmony of the scientific and the spiritual worldviews. But as the NIH director, my decisions are completely based upon scientific reasoning and scientific arguments," Collins said. "I was very troubled by a recent editorial in *Nature Immunology* where the unsigned editorial writer stated otherwise and implied that somehow I was involved in an ongoing way in promoting my own personal beliefs."

Collins headed the Human Genome Project in 1993 and, in November 2007, he founded the BioLogos Foundation (Washington, DC, USA) to create a safe haven for Christians disgruntled with the friction between science and faith. According to the premise of the organization, science and Christianity can coexist peacefully. The

group promotes theistic evolution, or the belief that the existence of evolution does not rule out the existence of God. "I'm troubled by certain atheist interpretations that say if evolution is true, then there's no room left for God," said Collins, who resigned from the foundation upon his NIH appointment. "As soon as you move away from a completely literal interpretation of the book of Genesis, the evolutionary explanation makes perfect sense."

"Just like science is infinitely better at answering factual questions, philosophy is the right place to go when we ask moral questions"

However, he did point out that some Christian morals seem to make little evolutionary sense. "At times we are called by our sense of morality to do things which are truly contrary to what evolution would expect because [doing so] limits our reproductive potential—that's all evolution cares about," Collins said. "So Mother Teresa, Oscar Schindler and the Good Samaritan [...] are doing exactly the wrong thing if evolution was the only reason to be around."

Of course, neither religion nor the evolutionary imperative is the only force that motivates humans—or indeed other animals—to acts of kindness or malevolence. Nevertheless, dismissing religion as irrelevant to the human condition also risks dismissing its moral teachings, which have underpinned Eastern and Western societies for millennia. "Every culture of the past that has left a historical record has had some system of religious views concerning the meaning and proper conduct of human life, and so does every known human-society of the present," Ayala said.

Yet, Pigliucci questions whether religion is the right place to look for morality, pointing to Plato's *Euthyphro* dialogue in which the Greek philosopher questioned religion's authority in moral matters. "In it, Socrates gets around to pose what is known in philosophy as Euthyphro's, the main character's, dilemma: Is something right

because the gods say it is, or do the gods declare something right because it is so?" he explained. "Notice this is not an argument against the existence of gods. It is an argument about the irrelevance of deities in terms of morality. Just like science is infinitely better at answering factual questions, philosophy is the right place to go when we ask moral questions."

Other religions have found a more conciliatory relationship with modern science. Satya Narayan, professor of anatomy and cell biology at the University of Florida (Gainesville, FL, USA) and a follower of the ancient Indian Vedic scripture, believes that science and religion are synonymous. "Religion does not simply mean faith, as it is understood most of the time," he said. "Religion is the science of sciences because it provides us with proper understanding of the original cause of all causes."

...there remain fundamental questions of meaning, value and purpose that science might never be able to answer

Nityananda Pran Das, who has a background in engineering and is president of the International Society of Krishna Consciousness in Chicago (IL, USA), also believes there is definitely a relationship between science and God, although he said that religious sentiment without a sound philosophical basis itself is not a science. As a priest at the Hare Krishna Temple in Chicago, Pran Das leads several religious discussion groups, such as the Vedic Vision Society, which is comprised of students from the Illinois Institute of Technology (Chicago, IL, USA). Pran Das recalls one particular student who, while conducting research, started to believe that everything occurs because of random combinations, as opposed to the Vedic belief in cosmic order. She began leaning towards atheism and sought Pran Das' advice. "My response to her was [...] if you see a pregnant woman walking all by herself, would you not conclude

there is or was a man in her life? Although the man may not be with her and we may not see him, the fact that she's pregnant is an indicator of his existence," Pran Das said. "Although you don't perceive the presence of God, the fact that Mother Nature is working in a particular way, there has to be a Supreme Father."

Pran Das might or might not be correct about the nature of God and the cause of the world. What matters is that science and religion can coexist peacefully. Part of the human condition is to seek answers about our world in an attempt to understand our nature. Scientific discoveries that have enriched our understanding of the Universe and of ourselves now provide many of those answers. Nevertheless, there remain fundamental questions of meaning, value and purpose that science might never be able to answer. The truth remains that for billions of people, religion and faith provide comfort and meaning where science offers only fact or no answer at all. As such, although extremists on both sides of the divide are likely to continue to pound their fists and demand surrender, everyone else might find that science and religion—so long as they stick to what they are good at—can both enrich our lives.

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