A tribute to Carl Woese

IoT Mote
17 hr ago

Carl Woese's class Syllabus for Evolution in the Microbial World, Spring 2006

Write a one page essay defining one of the following (as used in Biology).

These essays will be the basis for discussion in the next several classes.

NEW

What are theories, hypotheses, conjectures, models (in science)?
In what ways are they similar
In what ways are they different

What is explanation?
What is understanding?

How is importance defined (in biology)?

What is reductionism?
What is holism?
What is emergence?

What is complexity?

What is analysis?

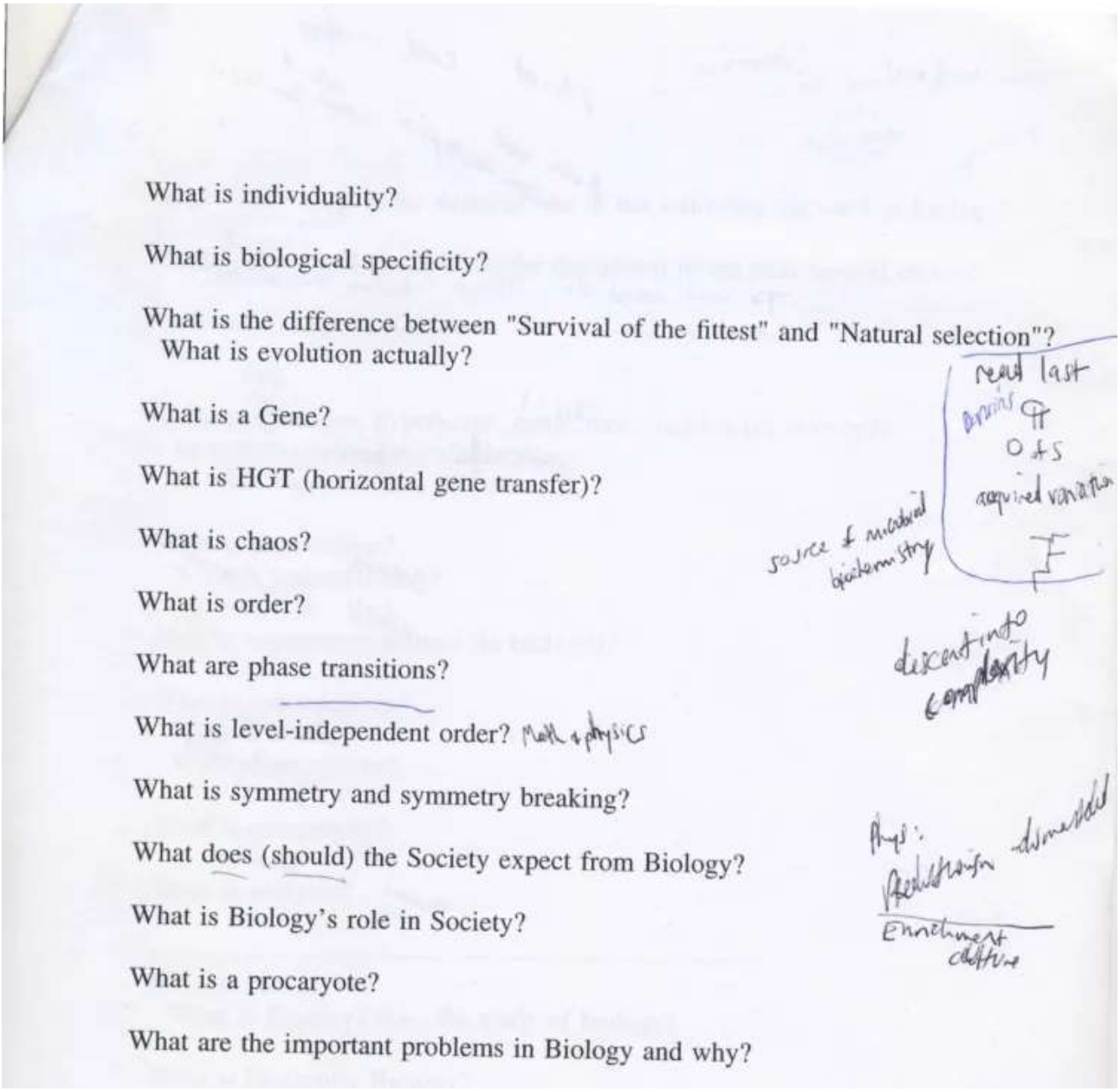
What is biology?
What is Biology? (i.e., the study of biology)

What is Molecular Biology?

What is organism?
What is organization?

What is environment?

What is a species?
What is a bacterial species?


What is individuality?

What is biological specificity?

What is the difference between "Survival of the fittest" and "Natural selection"?

What is evolution actually?

What is a Gene?

What is HGT (horizontal gene transfer)?

What is chaos?

What is order?

What are phase transitions?

What is level-independent order?

What is symmetry and symmetry breaking?

What does (should) the Society expect from Biology?

What is Biology's role in Society?

What is a procaryote?

What are the important problems in Biology and why?

I first heard of Carl Woese in my introductory Molecular and Cellular Biology Course (MCB 150) in the Fall of 2003. It was my sophomore year, and I had just switched majors from English. The course instructor (not Dr. Woese) had a masters degree, and he had no research responsibilities at the time. He was fully invested in highly engaging lectures. He had a flair for putting on theatrical PowerPoint presentations, and the slide started, "A long time ago, in a galaxy far, far away..." 1977 was the year Star Wars A New Hope premiered in theaters. It was also the same year Carl Woese discovered the archaea domain of bacteria, and that it was more closely related to humans than the prokaryotes. A long time ago, in Burrill Hall. One article quotes Woese saying that his discovery of

the archaea was like discovering an alien species. So that's where Star Wars comes in. Two years later, in my senior year, Woese offered an undergraduate class for the spring semester, Evolution in the Microbial World, MCB 423. (He typically taught graduate classes, I heard) I was one of the first to sign up. The class size was around 12. Sometimes only 6 or 7 students attended.

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giovanni.lostumbo@gmail.com ✓

When Woese entered the class, I immediately knew that this was master Yoda. Average height, in his late-70s, he wore a red cardigan and carried a stack of papers- the syllabus (above) and reading material.

Many of the students had questions like journalists. "Do you have a cell phone?" "I just got one." We all smiled.

Some of the students there were pre-med. 1-2 were graduate students. It was open to any undergraduate. Some were there to learn or debate Evolution, either from a theological viewpoint, or an anthropocentric one. And others, like me, were content with just sometimes just observing the man and thinking about Biology. Ever since I declared Biology, when people would ask me my major, I would often get a follow up- "are you pre-med?" By senior year I had been asked this so many times I started to wonder whether most people think Biology is a medical school or pharmaceutical training program. It's not just that.

When I enrolled in this class, little did I know it would change my life forever. On the first day, he asked us to each talk about what our backgrounds are and what we hoped to research. I told him I was applying to biomedical research graduate programs. He said,

"well don't focus too much on that." I knew exactly what he meant, since I had read a lot about him by then, and I agreed with him too. I still do.

I remember him telling the class, "I'm going to teach you Biology." He said this with an emphasis on *Biology*. It was a resoluteness, which sounded like, "what others have taught you, isn't the full story". And it wasn't. This was a man who had a lot to say, and wasn't done teaching Biology, because much of society got it all wrong.

In the attached syllabus, I added some notes. Throughout the semester, a few recurring books were mentioned/suggested. One is Schrodinger's *What is Life?* Another is *The Eighth Day of Creation*, by Horace Freeland Judson, and, the last paragraph of Darwin's *Descent of Man*. The University of Illinois has the largest public library in the world. In the Spring of 2006, I visited the "stacks"-library shelves that are packed and moved on mechanical rails at the push of a button to read the last paragraph of Darwin's Origin of the Species, or was it the Descent of Man, as Woese instructed us to. Here is what I found from the Origin of Species:

"There is grandeur in this view of life…whilst this planet has gone cycling…from so simple a beginning endless forms most beautiful and most wonderful have been, and are being, evolved."

https://www.bbvaopenmind.com/en/science/bioscience/the-origin-of-species-darwins-corrections

On my syllabus, I write last paragraph of Origin of the Species, but I recall him mentioning both books. In the Origin of the species, apparently some revisions mention a creator- perhaps to appease religious critics. But when speaks of "simple beginnings," of course, it is conjecture, or metaphorical,- he could be speaking about shorter mammals, rather than insects or microbes, and there was no way to determine in 1860 how exactly Man could have originated from simple, organic, but invisible to the naked eye beginnings-microbial soup.

One class session, a student posted a flyer on the chalk blackboard behind Woese's desk before class started, for a creationism vs. Evolutionism lecture being held somewhere on

campus. When Woese entered the room, he immediately tore the flyer off the wall, and said along the lines, "I will not allow this propaganda in this class."

In the Descent of Man (1871)- Darwin reaches further into the dark, yet grasps a little closer to the modern understanding of genetic evolution:

"We must, however, acknowledge, as it seems to me, that man with all his noble qualities, with sympathy which feels for the most debased, with benevolence which extends not only to other men but to the humblest living creature, with his god-like intellect which has penetrated into the movements and constitution of the solar system — with all these exalted powers — Man still bears in his bodily frame the indelible stamp of his lowly origin.

From Ch. XXI : General Summary And Conclusion"

There are two important phrases in that last sentence. Before they are mentioned, Charles Darwin was a greater poet than his grandfather, Erasmus. The first phrase is "nature's indelible stamp". This would be identified and confirmed to be DNA by the Hershey-Chase experiment in 1952. Microscopes existed in 1860, but Darwin could only observe the phenotypic changes of species at the time in the Galapagos. The second, and much deeper statement, would be discovered by Carl Woese in 1977: "his lowly origin." Using the phylogenetic tree to compare 16S Ribosomal RNA from bacteria, Woese could stand on the shoulders of Darwin and see much further into our past- to the point when microbial life developed the modern genetic code.

You see, Watson and Crick (with the help of Rosalind Franklin, who probably did as much of the work), discovered the structure of DNA in 1953. This provided much clarity to an understanding of the structure of hereditary material. But the 1950s and early 1960s were still a period of intense research into many other fundamental aspects of the cellular replication machinery, namely the ribosomes and the amino acids, and how they are encoded by triplets of nucleotides. Each of these discoveries were huge leaps in the understanding of molecular biology, hence the recurring mention of *The 8th Day of Creation* in his class. It's as if gold was discovered, and the first to arrive would find the biggest nuggets.

That was the era of 1946-1966. But by 1970, many of the biggest questions pertinent to the genetic material and replication machinery were largely answered (including the Okazaki fragments). There were still tons more questions to answer. Molecular Biology had already begun turning into a field of research mainly for human-related genetics and therapies. The biggest remaining question that few to no one else was looking for was Darwin's 100 year old conjecture of "lowly origin" as described above. That is, how the newly discovered DNA material is related to all the other species.

In 1962, Woese spent a few months at the Pasteur Institute in Paris*, according to Wikipedia, where there was a "locus of intense research on the molecular biology of gene expression." There, he met Sol Spiegelman, who invited him to visit the University of Illinois. He was offered immediate tenure. Woese told our class that one of the things the University said in their recruitment of him was that Urbana-Champaign was a "cosmopolitan" city. Woese and all of us laughed because we knew Urbana was in the middle of cornfields.

In 1964, Fred Sanger (2x Chemistry Nobel Laureate) developed RNA sequencing. By 1967, the 5S Ribosomal RNA sequence was determined. Woese would spend the next 10 years using Sanger RNA Sequencing to compare the most ancestral protein in the genome, the 16S Ribosomal RNA across microbial and eukaryotic species. This would ultimately lead to the 1977 discovery of the third domain of life, the archaea, one that continues shift our worldview from one that viewed Darwin as the only evolutionary authority, to one that viewed Darwin as just the middle phase of Evolution. It was like when Newton's classical mechanics no longer applied to special relativity. An exception to the rule finds staunch resistance amongst the most dogmatic.

"Limitations to Newton's laws have also been discovered: new theories are necessary when objects are very fast (special relativity), very massive (general relativity), or very small (quantum mechanics)."

Woese would go on to be rejected by Ernst Mayr and Salvador Luria. This entire link is worth a read:

"The third domain was not rejected because of the data, but because it violated a central dogma, the eukaryote-prokaryote dichotomy. So rather than question the dogma, most

biologists were content to condemn the finding. Their failure to question the dogma is one of the black marks in microbiology's history. 86,110. Evolutionary biologist Ernst Mayr (1904-2005), an icon of evolutionary biology, was one of a number of scientists who vigorously opposed Woese's (and Norman Pace's) suggestion that the catch-all term 'prokaryote' be banned from biology. Ernst Mayr joined the attacks in 1990 when Woese began *naming* archaea species as formal taxonomic units in the scientific literature. Until his death Mayr refused to accept that archaea represent a new domain of life (6). 87."

- "There must be no barriers for freedom of inquiry. There is no place for dogma in science. The scientist is free, and must be free to ask any question, to doubt any assertion, to seek for any evidence, to correct any errors."
- "What makes the treatment of evolution by biologists of the last century insufferable scientifically is not the modern synthesis per se. Rather, it is the fact that molecular biology accepted the synthesis as a complete theory unquestioningly–thereby giving the impression that evolution was essentially a solved scientific problem with its roots lying only within the molecular paradigm."

In a future blog post, I will take Woese's suggestion to ask any question, and focus it on the state of the linux software. One of Woese's questions in his syllabus is, What is Biology's role in Society?" To that, I would ask a similar question. What is linux's role in society? The mainstream Linux kernel has become an institution. And that becomes the equivalent to dogma in computer science. Andy Tanenbaum's "Linux is obsolete" email from 1992 stands out because it was ahead of its time. His words are becoming more and more prescient today. Like Darwin, he was making a conjecture, that perhaps 30, or 100 years later, someone might finally understand.

On Dogma: "Dogma: the eukaryote-prokaryote dichotomy was the central dogma of biology. Woese was making a claim of extraordinary scope. He was saying that we had missed one-third of all living things. People did not like that (5). "I hadn't been trained as a microbiologist, so I didn't have this bias" [about impossibility of bacterial classification]. (Woese)"

As a biologist, I do not have the same bias towards or against the monolithic kernel or computer scientist. To me, I see it like a genome, while portable code being like a

transposable element of DNA. Free software can be portable- but like viruses, it needs a host- a platform. If the linux kernel benefits everyone, then it is mutualism or cooperation. If it only serves a sect, then it may be commensalism, or worse, parasitism. Prosocial behavior, or intent to benefit others,[1] is a social behavior that "benefit[s] other people or society as a whole",[2] "such as helping, sharing, donating, co-operating, and volunteering".[3] Obeying the rules and conforming to socially accepted behaviors (such as stopping at a "Stop" sign or paying for groceries) are also regarded as prosocial behaviors.[4] These actions may be motivated by empathy and by concern about the welfare and rights of others,[5] as well as for egoistic or practical concerns, such as one's social status or reputation, hope for direct or indirect reciprocity, or adherence to one's perceived system of fairness.[1] It may also be motivated by altruism, though the existence of pure altruism is somewhat disputed, and some have argued that this falls into philosophical rather than psychological realm of debate.[6] Evidence suggests that pro sociality is central to the well-being of social groups across a range of scales, including schools.

Free software could practice more of the pre-Darwinian phase of cooperation (which wasn't *exclusively* collaboration-e.g. it had elements of Game of Thrones, but does not prohibit fundamental changes to the genetic pool)- the Bazaar in the Cathedral and the Bazaar. But we do see that in the linux community, to this day:

On From: torvalds@klaava.Helsinki.FI (Linus Benedict Torvalds) Subject: Re: Unhappy campers Date: 6 Feb 92 10:33:31 GMT

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>>Where is the sizeable group of people that want to evolve gcc in a
way that
>>rms/FSF does not approve of?
>A compiler is not something people have much emotional attachment to.
If
>the language to be compiled is a given (e.g., an ANSI standard), there
isn't
>much room for people to invent new features.  An operating system has
unlimited
>opportunity for people to implement their own favorite features.

Well, there's GNU emacs... Don't tell us people haven't got emotional
attachment to editors :)
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The linux community was aware of emotional attachments back then. That wasn't the only issue. The short answer is that free software needed a *kernel* back then. And Linus' kernel was fortunately ready. As time went on, it became more and more capable- one could write an entirely new operating system using linux. In a way, linux accomplished its goal of providing an operating system. It can continue for as long as it wants. But the issue of its monolithic status is becoming less and less of a necessity, because there are enough inexpensive platforms for software developers to work on the kernel to make it even more kinetic and nimble-more like a bike, or an X-wing compared to a Millennium Falcon. And not just one, but a *fleet* of tailored X-wings- one size fits all should no longer be the case. The other issue back then was hardware. Obviously Linux needed a host in 1992, and Torvalds chose the more advanced 386. Tanenbaum wanted to make Minux an educational tool, and felt using an older architecture, the 8088, would allow more students to access the software for educational purposes.

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   MINIX was designed to be reasonably portable, and has been ported
from the
   Intel line to the 680x0 (Atari, Amiga, Macintosh), SPARC, and
NS32016.
   LINUX is tied fairly closely to the 80x86.  Not the way to go.
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The decision for Tanenbaum to charge users for his software, in retrospect, almost appears to have stalled the development of microkernels for decades:

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Subject: Unhappy campers
Date: 3 Feb 92 22:46:40 GMT
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"MINIX costs $169, but the license allows making two backup copies, so the effective price can be under $60. Furthermore, professors may make UNLIMITED copies for their students. Coherent is $99. FSF charges >$100 for the tape its "free" software comes on if you don't have Internet access, and I have never heard anyone complain. 4.4 BSD is $800.'

I don't blame Tanenbaum. Others were doing the same. But just because his kernel wasn't immediately successful and omnipotent, much of the world turned away from microkernels. Critics (from my own personal correspondence with a kernel developer) call microkernels an idea from the ivory tower.

While Torvalds quickly clarified, "Torvalds wants it understood that he holds no animosity towards Tanenbaum, and Tanenbaum underlines that disagreements about ideas or technical issues should not be interpreted as personal feuds.[2]," it seems the Linux Foundation sees the monolithic kernel a closed case. In the evolutionary time scale of 3.7 billion microbial years, when life was first observed, 30 years is a jiffy. Ada Lovelace's first algorithm designed for a machine was written in 1843. It would take another 100 years before algorithms saw modern usage.

One of the articles Woese handed us in 2006 is a NYT article, "The God Genome" a book review of Daniel Dennett's Breaking the Spell, Religion as a Natural Phenomenon, by by Leon Wieseltier. "The question of the place of science in human life is not a scientific question. It is a philosophical question. Scientism, the view that science can explain all human conditions and expressions, mental as well as physical, is a superstition, one of the dominant supersitions of our day; and it is not an insult to science to say so."

Woese studied basic science, not applied science as in biotechnology. He was a generalist, capable of proving new understandings of evolutionary biology that took decades to determine and additional decades to gain acceptance. He said in class, "Evolution is a *law*." Since the term "The theory of evolution" has been used so much, it was striking to hear him say it- no one else ever called it that. His PhD is in Physics, therefore the established field of physics, compared to molecular biology, was much more understanding of a time when a new physicist on the block challenged that their Newtonian laws were no longer universal.

In 1905, Einstein presented his *On the Electrodynamics of Moving Bodies:*

"Special relativity was originally proposed by Albert Einstein in a paper published on 26 September 1905 titled "On the Electrodynamics of Moving Bodies".[p 1] The incompatibility of Newtonian mechanics with Maxwell's equations of electromagnetism

and, experimentally, the Michelson–Morley null result (and subsequent similar experiments) demonstrated that the historically hypothesized luminiferous aether did not exist. This led to Einstein's development of special relativity, which corrects mechanics to handle situations involving all motions and especially those at a speed close to that of light (known as *relativistic velocities*). Today, special relativity is proven to be the most accurate model of motion at any speed when gravitational and quantum effects are negligible.[3][4] Even so, the Newtonian model is still valid as a simple and accurate approximation at low velocities (relative to the speed of light), for example, everyday motions on Earth.

Special relativity has a wide range of consequences that have been experimentally verified.[5]

We now know there is a pre-Darwinian, pre-"speciation" phase where genes are predominantly or exclusively exchanged without speciation being a requirement. This is the phase before what Richard Dawkins calls, "The Selfish Gene." DNA exchanges via transposable elements and many other ways outside of full genome replication. There is also a post-Darwininan phase, which can be both genotypic and phenotypic (microscopic and sentient- the macroscopic kind is a much more philosophical discussion-I will discuss more about Woese's implications of a post-Darwinian world in another blog post, where I will apply his lens to other fields, but first, I want to detail some of the reading material he gave us that semester.

Woese's Microbial Evolution course was structured much like an English literature course. I never took a philosophy class in college, but this was the closest thing to what I felt was one. He assigned us weekly readings. One was a Financial Times article, titled "Mobility Special: Plugged into it all" by Richard Walters, published November 11, 2005. Covering online social networks cell phone use among students, and anxiety among some who felt like they were receiving too few text messages from peers. At the next class meeting, he asked us what or why we thought he assigned us that article for. I raised my hand, he called on me, and I applied my previous English major skills. "All this social media and sharing of posts and information online, is a metaphor for Horizontal Gene Transfer." Woese paused for a few seconds, and smiled with a "Yep!" I was seeking validation admittedly, not just in wanting to impress Woese, but also the classroom. I felt this was one strength I had in understanding the Humanities (Arts &

Literature) and the Sciences, even if I later would feel unsatisfied (at times) at being a jack of all trades, master of none. Woese also described another student he had in a previous year of the same course. Woese described the student as an "artsy type" and that he/she told Woese that "this was the one class that I could actually think." Woese was a well-rounded type, and didn't seem to be an elitist when it came to science vs humanities.

Woese was an extraordinarily gifted teacher, and I believed almost everything he said. He said that many Biologists were not as critical as the Physicists that he identified with. That said, I felt that the faculty at U of I possessed that kind of critical thinking, and not just because they were more aware of his efforts. I recall him describing Biologists as "patting each other on the back" (I do not recall if it was referring to Molecular Biology central dogma-like concepts or Biology in general) routinely concurring, whereas Physicists were more cautious about their conjectures.

He also showed us a Charlie Rose interview (on VHS with a cathode ray TV and VCR carted in from another room in Burrill Hall) with E.O. Wilson and James Watson. After Charlie Rose asked each scientist whether Darwin was the most important Biologist or Evolutionist, Woese pointed out that Watson's immediate "Yes" contrasted with E.O. Wilson's more delayed response. Woese said in class, "E.O. Wilson thought about it for a moment before responding." Woese was extraordinarily focused on determining if Biologists were thinking critically enough about their field, and I can assure you that he believed E.O. Wilson provided a more weighed response. To Woese, their answers were irrelevant or at the very least, less relevant than their pause, namely, the probability that they adequately thought about their response, in this context. Woese's class was not about measuring the "quickest" and supporting the most popular. My grade in his course was A-. There was very little to no objective grading or exams, just a final project and class participation expected.

I also recall a story he said when he was talking with some scientists- I don't remember who or where, but he said, "we were all drunk and bickering, and a scientist said, "UV (ultraviolet rays) doesn't cause cancer." So he was just explaining that not all scientists readily accept (or ever) accept new discoveries about the hazards of mishandling a new technology (or from the sun).

One of my favorite things that he said in his class was regarding a quip about the early fame of Watson and Crick. He told our class, from his desk, as a handful of students sat in attendance, something like this (I do not remember if he was retelling a saying made about him in the third person, or whether he used the first person), "Watson and Crick came marching along, and I was the only one to take a step [forward]. You may have to think about that for a moment." He smirked as he said this and I did too, because I imagined military parades where a row of soldiers are standing still, and raise one leg perpendicular to the other leg in repeated fashion but do not march forward with any displacement. This was Biology's "One Small step for Man, One Giant Leap for Mankind" moment and man, and Woese had a sense of humor in that way.

Woese also told our class us the story of when he gave a speech to fellow biologists- I don't know whether it was at a conference or an award ceremony. He says that when he mentioned that his work was made possible by the sequencing techniques of Fred Sanger, the room was/went silent, as if they did not know who he was. Apparently not many biologists knew who he was or thought of him as a very popular person- Sanger in fact, did go on to live a quiet life in retirement in 1983 at the age 65. Wikipedia states:

"In 2007 the British Biochemical Society was given a grant by the Wellcome Trust to catalogue and preserve the 35 laboratory notebooks in which Sanger recorded his research from 1944 to 1983. In reporting this matter, Science noted that Sanger, "the most self-effacing person you could hope to meet", was spending his time gardening at his Cambridgeshire home.[46]

Sanger died in his sleep at Addenbrooke's Hospital in Cambridge on 19 November 2013.[42][47] As noted in his obituary, he had described himself as "just a chap who messed about in a lab",[48] and "academically not brilliant".[49]"

Perhaps this explains why he received little to no applause in Woese's speech. It took approximately 10 more years for Woese's work to be accepted, therefore if Woese was giving a speech, Sanger had 2 Nobels but had already left the field for at least a decade.

*Out of curiosity, what are the chances Woese brushed paths with a Parisian anarchist named Jean-Paul Sartre in 1962?

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giovanni.lostumbo@gmail.com ✓

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