SCIENCE EDUCATION

The evolution of antievolution policies *after* Kitzmiller *v.* Dover

A phylogeny identifies ancestors of modern creationist legislation

By **Nicholas J. Matzke**[1,2]*

Political attempts to denigrate and dilute the teaching of evolution in science classrooms have been a feature of the U.S. educational scene for 90 years (*1*). These may be classified into three major waves (*2*). Bans on teaching evolution were enacted in the 1920s (and unsuccessfully challenged in the 1925 Scopes Monkey Trial) and persisted until ruled unconstitutional in 1968. When bans were rescinded, creationists (*3*) began to lobby for "balanced treatment" for creationism whenever evolution was taught, first trying biblical creationism, then "creation science," and finally "intelligent design" (ID). Each strategy was ruled unconstitutional (table S1), in part due to court attention to creationist origins. Creationists did not give up with the defeat of ID in *Kitzmiller* v. *Dover*, decided in U.S. District Court on 20 December 2005, but instead shifted political efforts to the third wave of antievolutionism, "stealth creationism" (*2*): legislation that avoids mentioning creationism in any of its varieties but advances creationist antievolutionism with an evolving collection of strategies (table S1). I use a phylogenetic tree to show how antievolution legislation has evolved, and at times succeeded, in the 10 years since *Kitzmiller*.

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After *Kitzmiller*, even the Discovery Institute (DI), the institutional home of ID, claimed it had never encouraged teaching ID in public schools [incorrectly: (*4*)] and heavily promoted "Academic Freedom Acts" (AFAs), aimed at encouraging teachers to promote antievolutionism. At least 71 bills have been proposed in 16 states (table S1). Stealth creationist bills have been signed into law in three states [Louisiana, Tennessee, and Mississippi (*5*)]. Legal challenges seem to have been dissuaded by strategic vagueness in avoiding mention of the bills' religious motivations and by only permitting, rather than requiring, disparagement of evolution. Previous court rulings against teaching creationism remain in effect and are not trumped by state legislation, but acts by individual teachers can only be challenged if students and parents complain, and complaints can be discouraged by local social pressures.

Phylomemetic analysis (*6*), using the tools of statistical phylogenetics to study cultural transmission, is useful for estimating the detailed evolutionary history of policies by considering which passages from which bills were copied and modified into other bills. Phylogenetic comparative methods can illuminate which key events produced the array of antievolution bills in circulation, assessing the influence of legislative success on the evolving antievolution tradition and the strategies likely to be used in the future.

EVOLUTION OF LEGISLATION. Texts of 65 bills archived by the National Center for Science Education (NCSE) (*7*) were studied, along with the DI model bill and an obscure but crucial policy from Ouachita Parish, Louisiana [full details of all analyses provided in supplementary material (SM)]. Maximum parsimony searches provide strong evidence of bill-to-bill copying and "descent with modification" (see the chart). In addition to this lineal (parent-to-offspring) transmission, it has been noted (*2*) that the 2008 Louisiana bill [originally an AFA but renamed a "science education act" (SEA)] and later antievolution bills have a composite history, combining text from the AFA tradition and from the Ouachita policy.

> ***"The creationist origins of modern antievolution strategies are clear...."***

Scientific targets of antievolution bills. Most strategies used in the AFA and SEA bills have precedents in pre–third-wave antievolutionism (table S1). However, mapping the strategies on the phylogeny (see the chart) shows a major innovation in the SEA tradition that originated from the Ouachita policy: targeting for "critical analysis" not only evolution and origin-of-life studies but also global warming and human cloning. The tactic appears to be an attempt to circumvent earlier legal decisions suggesting that targeting evolution alone is prima facie evidence of religious motivation and, thus, unconstitutional; an additional motivation may be dislike of climate change research by economic and religious conservatives (*2*). The addition of human cloning and global warming was copied in over a dozen subsequent bills, two of which passed (the 2008 Louisiana SEA and the 2011 Tennessee bill).

Direct ancestors. It may be useful in educational and legal contexts to identify the exact sources of now-prominent antievolution policies. Traditional phylogenetic analyses do not infer direct ancestry (i.e., bill Y copied directly from bill X, rather than X and Y from a common ancestor), but a new Bayesian method (*8*, *9*) can search phylogenies where some tip branches have 0 time length (and are thus direct ancestors rather than side branches). Here, the method identifies seven bills as having greater than 90% probability of being direct ancestors of the dominant subsequent tradition (see the chart). Direct ancestors of the AFAs include four Alabama bills from 2004 to 2005 (HB391c and SB336c are identical copies) and a 2006 Oklahoma bill. Two Tennessee bills (SB893 and HB368a) introduced before passage of a modified bill (HB368b) served as direct ancestors of the nine SEA bills proposed from 2012 to 2015. All post-2008 SEA bills are clearly members of a clade beginning in Louisiana, although no published Louisiana bill can be identified as the direct ancestor, perhaps because of extensive legislative modifications.

The phylomemetic tree exhibits strong asymmetry (SM), which indicates bias in which policies have been selected for new antievolution efforts. This suggests that antievolutionists tend to select particular bills and/or strategies for promotion. Heavy promotion in one state may spread to others, or perhaps, simply, "success sells."

The Discovery Institute model bill. The DI supported key changes to Alabama bills in 2004 (www.discovery.org/a/2037). Thus, there is some chance that the model bill was distributed before being posted online in Fall 2007 and might be ancestral to AFAs. Leaving the date free to vary and estimating it (fig. S10) along with the phylogeny indicates an earlier date, closest to the 2006 Alabama bills but suggests that the 2005 AL HB352 was directly ancestral to later legislative proposals. The DI's "brand" may have been suf-

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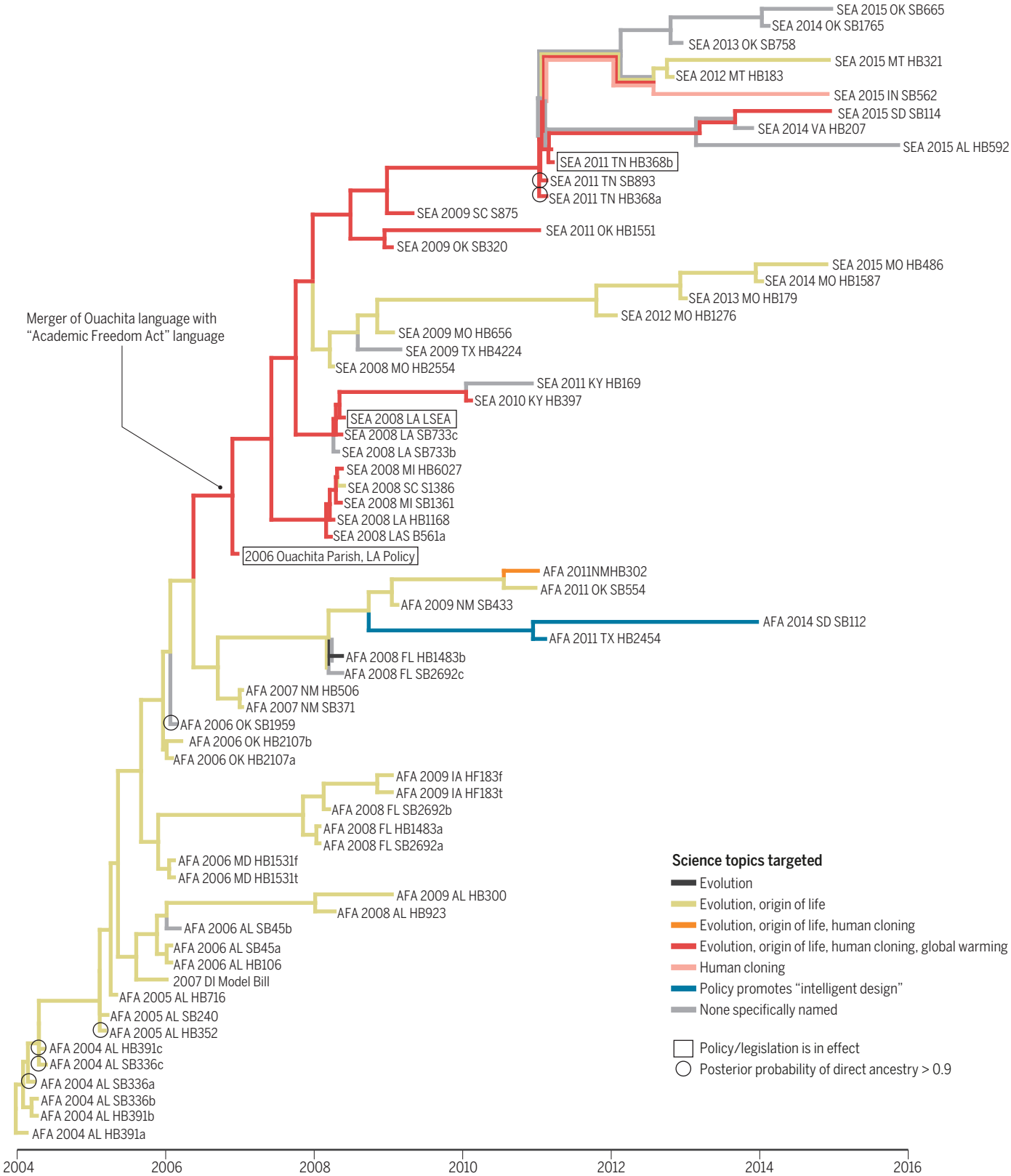

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Tracing the evolution of antievolution legislation. Maximum clade credibility tree from Bayesian tip-dating analysis of 67 policies. The SEAs originated by combining text from the AFAs with Ouachita Parish, Louisiana, policy text from 2006. Seven bills have a high posterior probability of being direct ancestors of the rest of the tradition (circles). The tips of branches reflect the bills' publication dates [except for the DI model bill (see text)]. The nodes (splitting events) represent copying events. The distance between a tip and a node is an inference about how much change occurred and how much time this took. When the node-to-tip distance is effectively zero, this indicates a high probability of direct ancestry. Tip labels indicate AFA or SEA, year, state, bill number (SB, senate bill; HB, house bill), and versions (a, b, or c, for legislative revisions; t or f, teachers or faculty targeted). Branch colors indicate the sciences targeted; mixed colors on a branch indicate uncertainty in the reconstruction. See SM for full details of analyses.

ficiently damaged by the *Kitzmiller* case that politicians shied away from direct use of DI resources, and found inspiration elsewhere, such as previous legislation. This may help explain the strong signal of descent with modification in the AFA-SEA tradition.

The creationist antievolution movement has reinvented itself not once but twice in the decade since *Kitzmiller*. The first guise was "academic freedom," but after the success of the Louisiana SEA, AFA proposals were almost completely replaced with SEAs. The inclusion of global warming in the SEAs indicates that societal debate over evolution education has the potential to leak into other societal debates where high-quality science education is inconvenient to certain established interests. The passage of SEAs in Louisiana and Tennessee have spread language devised in Ouachita Parish, population ~150,000, to negatively affect science education in two states with ~11.2 million people. Additional policies on the books in other states (table S1) indicate that science educators have substantial work to do to ensure that science classes teach the best science available, rather than false critiques and controversies promoted by creationists. Advocates for science education should not be dissuaded by the strategic vagueness of SEAs: The creationist origins of modern antievolution strategies are clear (table S1), and at least 63 of 65 antievolution bills considered here can be tied directly to creationism through statements in the legislation or by sponsors (SM). ■

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SUPPLEMENTARY MATERIALS

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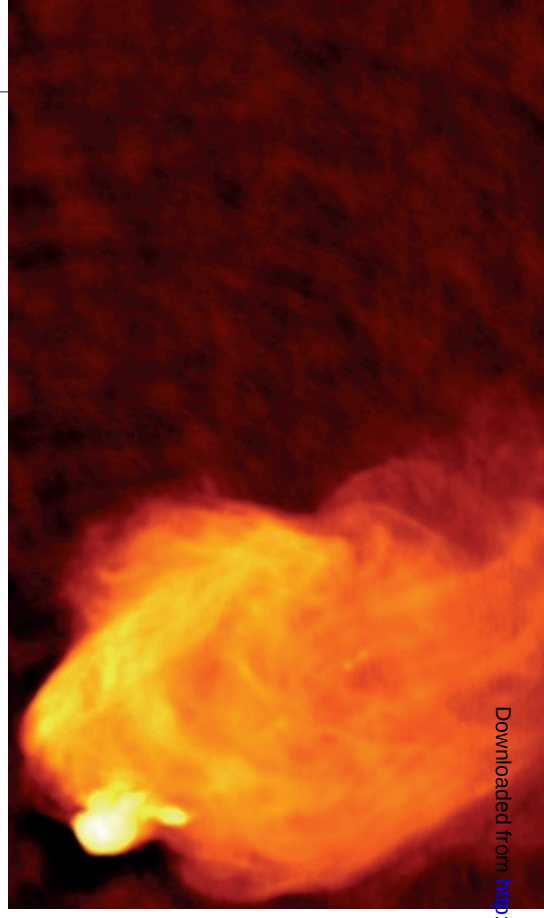
ASTROPHYSICS

The screams of a star being ripped apart

A star being devoured by a black hole provides a route to study accretion and jet formation

By **Geoffrey C. Bower**



Closely coupled, ubiquitous, and complex, accretion and outflow are the yin and yang of astrophysics (*1*). The processes occur on all length and time scales, from the formation of the first galaxies in the early universe to the formation of stars in our Milky Way. Compact objects such as white dwarfs, neutron stars, and black holes provide some of the most spectacular examples of these entangled phenomena. Quasars, for instance, are supermassive black holes with masses as large as 10 billion times that of the Sun that lurk in the centers of galaxies and are extraordinarily efficient accretors as revealed through luminous x-ray emission as well as producers of narrowly collimated relativistic jets that can extend millions of light years away from the black hole (see the figure). On page 62 of this issue, van Velzen *et al.* (*2*) report the discovery of a transient relativistic jet flowing from a supermassive black hole system that captured and destroyed a passing star. The discovery further confirms the coupled nature of accretion and outflow. Most important, the discovery shows that these events short-circuit the extraordinarily long evolutionary time scale of quasars, creating a laboratory for the study of accretion and outflow physics.

Since their discovery more than 50 years ago, quasars have provided deep insights into accretion and outflow processes. Accretion appears to occur in a wide variety of states, from highly efficient near the theoretical maximum accretion rate to very inefficient at low accretion rates (*3*, *4*). Outflows appear as both wide-angle winds and narrowly collimated jets. A central phenomenological fact has been the discovery that ~10% of all quasars produce so-called radio-loud jets, in which the radio emission from the relativistic outflow is a substantial fraction of the total accretion energy budget. The spin of the black hole may be a hidden parameter that determines whether accreting systems will launch a relativistic jet. Other evidence points to jets in some systems switching on and off, presumably as the result of changes in the accretion flow.

Unfortunately, much of what is known about accretion and outflow in quasars is circumstantial and derives from studies of the entire population. Evolutionary time scales are typically much, much longer than human lifetimes. For instance, one can't simply study the evolution of a quasar from radio-loud to radio-quiet. Einstein's theory of general relativity shows that all black holes have a minimum time scale determined by the size of a black hole, that is, the Schwarzschild radius, which is linearly proportional to the black hole mass. The minimum time scale is the period of the last stable circular orbit for accreting gas, which is 30 min for the 4×10^6 solar mass black hole in the center of the Milky Way (*5*) and tens of days for the most massive quasars. Quasars, however, have structures that can be millions of times larger than the Schwarzschild radius. Evolutionary time scales are primarily set by the size and dynamics of the gas reservoir supplying the black hole, which can extend to millions of years, as evidenced by the sizes of radio jets (*6*).

Stellar mass black holes have time scales that are millions of times faster than those

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