

## A PERSPECTIVE PIECE

# Evolution of the Violin: The Law of Effect in Action

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As is true for most other human inventions, the origin of the violin is unknown. What is known is that this popular and versatile instrument has notably changed over the course of several hundred years. At issue is whether those evolutionary changes in the construction of the violin are the result of premeditated, intelligent design or whether they arose through a trial-and-error process. Recent scientific evidence favors the latter account. Our perspective piece puts these recent empirical findings into a comprehensive selectionist framework. According to this view, the many things we do and make—like violins—arise from a process of variation and selection which accords with the *law of effect*. Contrary to popular opinion, there is neither mystique nor romance in this process; it is as fundamental and ubiquitous as the *law of natural selection*. As with the law of natural selection in the evolution of organisms, there is staunch resistance to the role of the law of effect in the evolution of human inventions. We conclude our piece by considering several objections to our perspective.

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The provenance of the violin is said to be mired in mystery. According to historian David Schoenbaum (2012), Jean Benjamin de La Borde, court composer to French King Louis XV, was among the first to try to discover the origin of the instrument. His effort proved fruitless, as he confessed in his 1780 *Essay on Ancient and Modern Music*: “Knowing so little about something is very close to knowing nothing at all” (quoted by Schoenbaum, 2012, p. xviii). A century later, the Reverend Hugh Reginald Howe (1898) had little more to offer from his own historical investigations than to opine that the violin is a sweet, sensitive, and sonorous musical instrument whose final form “slowly emerged as the *survival of the fittest*” (p. 12, italics added).

Fast forward to the present, where we now find physical science assiduously investigating the evolution of the violin. Two recent high-profile reports not only focus on changes in the construction of this popular and versatile instrument, but they each advance intriguing parallels between those structural changes and the Darwinian process of organic evolution.

### Evolution of the Sound Hole

According to Nia et al. (2015), major structural evolution of the violin arose through changes in the geometry of its two sound holes. These authors observed that the sound-hole geometry of the violin’s

many ancestors gradually and progressively changed over several centuries “from simple circular openings of tenth century medieval fitholes [fiddles] to complex f-holes that characterize classical seventeenth–eighteenth century Cremonese violins of the Baroque period” (p. 2). This structural evolution led to greater sound-hole efficiency, roughly doubling air-resonance power efficiency.

By theoretical proof, experimental measurement, and numerical computation, Nia et al. (2015) were able to document that the increasing *length* of the violin’s sound holes rather than their total *area* was the key variable affecting the acoustic power and evolution of the violin. “This perimeter dependence is found to be of critical importance in explaining the physics of airflow through f-holes and sound radiation from a violin at air resonance. It is also found to have significantly impacted violin evolution” (p. 3).

Specifically, by isolating acoustic power within their rigorous analysis of six different physical dimensions of violin construction, Nia et al. (2015) determined that gradual morphing of the f-hole enables “conductance to increase by roughly 50% through triplication of perimeter length for the same sound hole area” (p. 7). This increased power efficiency in turn played a prime role in violin evolution.

Findings from the archaeological record indicate the ratio of inefficient to total sound-hole area was gradually reduced over the centuries by increasing aspect ratio and geometric complexity [thereby yielding] greater conductance, greater air volume and mass flow rates over time, and higher radiated power for the same sound hole area at the air resonance frequency (Nia et al., 2015, p. 8).

This greater efficiency and power became paramount “as the violin’s prominence rose . . . because its greater radiated power enabled it to project sound more effectively as instrument ensembles and venue sizes historically increased” (Nia et al., 2015, p. 8) from intimate royal chambers to cavernous concert halls. The modern violin therefore owes much of its success to these changes in perfor-

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mance practices and venues, which promoted its preeminence while other instruments with sound holes of lower outer perimeter, such as the viol and the lute, “became effectively extinct, perhaps partly due to [their] relatively low radiated power” (p. 8).

These historical changes in sound-hole geometry did not occur quickly, as one might have expected if they had suddenly sprung from an innovative, preconceived change in design. Instead, using concepts and equations akin to those developed in biology for generational changes in gene frequency, Nia et al. (2015) concluded that “the gradual nature of the sound hole changes from the tenth to sixteenth century . . . is consistent with incremental *mutation* from generation to generation of instruments” (p. 8, italics added), these structural changes arising by *chance* and being acted upon by “a *selection* process favoring instruments with higher power efficiency” (p. 8, italics added), and thus according “with evolution via accidental replication fluctuations from craftsmanship limitations and subsequent selection” (p. 11).

Prior to the 19th century, only random craftsmanship fluctuations appear to have produced such small, but measurable structural mutations. However, in the early 1800s, the more experimental “rationalized” violin built by physicist Félix Savart and the “guitar-strung” violin built by naval engineer François Chanut involved smooth, uncomplicated sound holes that dramatically exceeded the expected range of random craftsmanship fluctuations. These “relatively drastic and temporally impulsive changes to sound hole shape . . . and violin design . . . made by Savart and Chanut [proved to be] unsuccessful evolutionary offshoots” (Nia et al., 2015, p. 16).

The authors’ detailed physical measurements revealed that

The air resonance power efficiencies and conductances of the Savart and Chanut sound holes are significantly lower than those of the classic violin f-holes: Savart and Chanut sound holes have perimeter lengths that are lower by roughly 34% and 30%, and air resonance powers that are lower by roughly 23% and 17%, than those of classical Cremonese violin f-holes (Nia et al., 2015, p. 16).

Much like unsuccessful “pattern” coins and “concept” cars, these “experimental” violins are now stored in private collections and museums, but are not used.

The extraordinary success of the classical Cremonese violinmakers through their “conservative approach of letting inevitable *random* craftsmanship fluctuations [occur]” (Nia et al., 2015, p. 16, italics added) contrasts sharply with Savart’s and Chanut’s notably unsuccessful and “far riskier approach of gambling with the implementation of drastically different sound hole shapes based on *preconceptions*” (p. 16, italics added). Nia et al. conceded that “such gambling could produce much greater changes in efficiency in a short time” (p. 16), yet they failed to do so. The authors’ assiduous analysis of these historical failures in violin making lends further credence to the idea that our most successful inventions may not come from inspired or preconceived designs, but rather through the generation and selection of numerous accidental and random mutations over a protracted period of time.

### Evolution of Violin Shape

Chitwood (2014) concentrated on changes in the overall shape of the modern violin. These changes are generally believed to be less consequential to sound quality and volume than are changes in

other physical attributes such as sound-hole geometry, sound-box thickness and taper, and wood properties (Nia et al., 2015). Nevertheless, these overall shape variations might represent key stylistic features that could affect the salability of the instruments.

Chitwood (2014) found that, with respect to these predominately aesthetic modifications, “violin shape is modulated by time, in a manner affected by the known *imitation* of luthiers by one another, resulting in a limited number of archetypal, copied violin shapes” (p. 9, italics added). Indeed, advanced morphometric analysis suggested a possible parallel between the factors contributing to changes in the overall shape of the violin over hundreds of years of construction and the gradual changes of complex biological shapes, such as those exhibited by plant and animal life over millions of years of evolution. “That such a large number of violins from prominent luthiers cluster in only four groups suggests that violin shape space is not so much continuous as based on variations upon a limited number of copied instrument archetypes. One might easily imagine radically different, but acoustically equivalent, forms of the violin had the *whims* of the original . . . luthiers been different” (p. 9, italics added).

In considering the origin of these distinct shape variants, Chitwood (2014) conjectured that, “it is not hard to imagine that during long years of apprenticeship within a workshop (which often followed family lines) that peculiarities in the design and shape of instruments, transmitted luthier-to-apprentice, would arise, not unlike *genetic drift*. The process of creating the outline, whether adhering strictly to a preexisting mold or pioneering a new shape, is not unlike *inheritance* and *mutation*” (p. 9, italics added).

What about the different violinmakers’ selection among innumerable imaginable shape flourishes? Aside from the possible whim of the individual luthiers, why else might these craftsmen have chosen one shape variant over another? Chitwood (2014) argued thus: “Jean-Baptiste Vuillaume [a famous French luthier] purposefully studied and copied the Cremonese masters (especially Antonio Stradivari) to increase the desirability of his instruments and meet *consumer demand*, as did many others luthiers” (p. 11, italics added). So, analogous to the case of sexual selection, the fancy of the *customers* may have been as important to the evolving shape of the violin as the fancy of the *constructors*: *de gustibus non est disputandum!*

### Structural Changes in the Violin: A Case of Behavioral Evolution

What, then, are we to make of the intriguing observations and speculations concerning the evolution of the violin issuing from these two extremely careful and thoughtful investigations of instrument construction? Let’s begin by radically rephrasing the issue: Violins did not evolve; rather, the behavior of violinmakers evolved. Once the matter is properly rephrased, it must be appreciated that any real insights into the changing shape of violins will come only when we can explain how and why the violinmakers changed their methods of fabrication.

Nicholas Makris raised this point in a press release coinciding with publication of his team’s paper (Chu, 2015): “Mystery is good, and there’s magic in violinmaking,” Makris said. “I don’t know how [some luthiers] do it—it’s an art form. They have their techniques and methods.”

Less mysteriously, Chitwood (2014) hypothesized that the luthiers' behaviors may have been the result of natural evolutionary processes. "Perhaps not so surprising for an object crafted by *living organisms, themselves subject to natural laws*, the inheritance of violin morphology was influenced by mimicry, genetic lineages, and evolved over time" (p. 11, italics added). Yet, the key natural law that Chitwood suggested in connection with his interesting conjecture was natural selection. Just what bearing does natural selection have for humans' creation of novel behaviors and inventions? Might another natural law—unnamed by Chitwood—be in an even better position to explain what people do and make? We believe so, as we next describe.

### The Law of Natural Selection and the Law of Effect

In his autobiography, Charles Darwin (1887/1958) emphatically denied that an intelligent designer was responsible for the origin and diversity of life on earth; he instead proposed that a mindless, mechanical law of nature—the *law of natural selection*—underlies organic evolution. Of this law, Darwin wrote: "There seems to be no more design in the variability of organic beings and in the action of natural selection, than in the course which the wind blows. Everything in nature is the result of fixed laws" (p. 87). The exquisitely adaptive construction of *humans* and other life forms thus represents apparent design without a designer.

Yet, in this same work, Darwin seemed uncritically inclined to accept intelligent, premeditated design in the construction of exquisitely contrived devices *by humans*.

The old argument of design in nature . . . which formerly seemed to me so conclusive, fails, now that the law of natural selection has been discovered. We can no longer argue that, for instance, the beautiful hinge of a bivalve shell must have been made by an intelligent being, like the hinge of a door by man (1887/1958, p. 87).

But, what do we actually know about the inventors of hinges and violins? Must we believe that people fashioned these devices with full foresight of their final form and function as demanded by design? Or might there be another less magical way to explain their development?

Permit us to propose the following answers to these questions.

First, we do not know with any degree of certainty just how humans came to make such devices as hinges and violins; the historical record is woefully incomplete and inconclusive, although the recent studies of Chitwood (2014) and Nia et al. (2015) have provided new data and offered fresh insights into our understanding of violin evolution. What we do know about the provenance of human contrivances and adaptive actions—from the origin of tepees, light bulbs, and telescopes to the selective breeding methods of pigeon fanciers, the high-jumping styles of Olympic athletes, and the riding stances of thoroughbred jockeys—seriously questions the necessity of intelligent, premeditated design in the process (Hughes, 2011; Simonton, 2012, 2015; Wasserman, 2012; Wasserman & Blumberg, 2010). Trial-and-error learning and sheer chance often turn out to be the most important contributors to developing the things we make and do (Petroski, 2012).

Second, the notion of premeditated, intelligent design may be a largely romantic fiction which will turn out to be as unhelpful in explaining the origin of novel inventions and behaviors, as it has

proven to be in illuminating the origin of species. In the face of sound scientific evidence, should we not be just as willing to jettison intelligent design as an explanation of the origin of human inventions as Darwin was to jettison intelligent design as an explanation of the origin of human beings?

Third, we already have a good and ever growing understanding of how most human behaviors and inventions are created. They are likely to emerge via another fixed law of nature, one which generally parallels Darwinian selection—the *law of effect* (Dennett, 1975; Skinner, 1966, 1969, 1974).

According to the law of effect, which was discovered and aptly named by psychologist Edward L. Thorndike, out of a repertoire of unconditioned behaviors, those that are followed by reinforcers tend to be repeated, thereby promoting increasingly adaptive organismic action. This mechanical, trial-and-error process is capable of supporting novel behaviors and inventions much as the lawful process of natural selection produces novel organisms. The noted behaviorist B. F. Skinner (1966) dubbed this process *selection by consequences* to stress the analogy (but not homology) between behavioral selection (operating within the lifetime of an individual organism) and natural selection (operating across the lifetimes of many organisms).

### Violin Evolution From a Selectionist Perspective

From this selectionist perspective, we can summarize and synthesize the specific insights gleaned from current research into violin construction. Because we have no contemporaneous written records, the origin of the violin will probably never be fully known. Nevertheless, the studies by Chitwood (2014) and Nia et al. (2015) strongly suggest: (a) that key elements in the evolution of the violin are likely to have involved a trial-and-error process spanning several centuries, and (b) that the violin's early makers probably had no preconception of its now revered form and construction.

From this trial-and-error process, successful violins with greater f-hole length and acoustic power came to dominate as concert ensembles and venues grew in size. The costs associated with fabricating more extreme violin variants—in time, effort, and materials—may have tempered the luthiers' enthusiasm for creating more extreme experimental models, leaving only scientists such as Savart and Chanot to take such risks. Those acoustically inferior experimental violins fell into obscurity. So too did violins whose overall shape failed to conform with those styles that were deemed to be fashionable. The clear conclusion from this evidence and argument is that variation and selection produced the violin, not intelligent design.

This selectionist view of violin evolution may strike some readers as missing the mystique of creativity and minimizing the genius of such famous luthiers as Andrea Amati, Antonio Stradivari, and Bartolomeo Guarneri. Of course, there is no doubting these masters' supreme craftsmanship. But, the matter at hand is far more important than preserving the renown of violinmakers. What must be understood is how these premier luthiers came to ply their trade. Of critical importance to ask is, were their efforts truly guided by intelligent, premeditated design? Here, the general parallel between the law of natural selection and the law of effect demands further discussion.

## The Law of Effect: Asserting Its Role in the Evolution of Behavior

Skinner (1974) viewed Darwin as replacing an all-intelligent *deity* by a natural selective process to produce organic change. Skinner suggested a different interpretive substitution in which an intelligent human *mind* was replaced with a second selective process—the shaping of adaptive behavior by contingencies of reinforcement.

Skinner (1974) contended that the contingencies of survival and the contingencies of reinforcement can each produce novel and adaptive outcomes. “Natural selection explained the origination of millions of different species . . . without appealing to a creative mind” (p. 224). In the case of behavior, “contingencies of reinforcement may explain a work of art or a solution to a problem in mathematics . . . without appealing to a different kind of creative mind or to a trait of creativity” (p. 224). The general parallel: “As accidental traits, arising from mutations, are selected by their contribution to survival, so accidental variations in behavior are selected by their reinforcing consequences” (p. 114).

This parallel is indeed profound and it underscores how selectionist principles can explain both the origin of species and the origin of acquired adaptive behaviors. However, readers should be cautioned that quite different mechanisms may lie at the root of natural selection and selection by consequences (Moore, 2008; Wasserman, Brooks, & McMurray, 2015); we are pointing out parallel, but not necessarily equivalent processes.

Richard Dawkins (1984) has linked many people’s resolute resistance to Darwinian evolution to our own species’ notable success in crafting amazingly useful inventions; what else other than intelligent design could explain the development of the automobile, the computer, and the air conditioner?

[Contemplating the remarkable adaptedness of such biological creations as the hand, the eye, and the brain] took a very large leap of the imagination for Darwin . . . to see . . . a far more plausible way [than premeditated, intelligent design] for complex ‘design’ to arise out of primeval simplicity. A leap of imagination so large that, to this day, many people seem still unwilling to make it (p. xii).

We now ask, is it not time for us to take another large leap of imagination? The creative and seemingly well-designed things that we make and do may also arise out of primeval simplicity—the shaping of behavior by the mechanical process of trial and error.

Like Skinner, we suggest that the law of effect should at long last be placed directly alongside the law of natural selection. Together, these two basic selectionist principles can produce organisms that are exquisitely adapted to their surroundings, and do so according to laws that are entirely natural, mechanical, and operant without premeditation. To all those who would instead insist that the development of the violin must have emerged *by design*, we might instead reply: “*Bye design!*”

## Criticisms and Rejoinders

Of course, we fully appreciate that many readers will not readily embrace our thesis. So, in the following sections, we do our best to address what are likely to be among the most obvious concerns of critics.

## Random or Directed Variation?

Unlike the case of Darwinian evolution, it might be contended that variations in the construction of the violin were not entirely blind, accidental, or random (for further discussion of blind variation and selection in behavioral adaptation, see Campbell, 1960; Simonton, 2011); instead, these variations might have been directed toward more effective acoustic performance. On this particular point, Kronfeldner (2010) has proposed that, for behavioral variation to be entirely blind, as in biological variation or mutation (Sober, 1992), the processes of variation and selection must be entirely *decoupled* (for more on this decoupling and other related points of discussion, see Dietrich & Haider, 2015; Epstein, 1991; Simonton, 2013). In her words, “the occurrence of new ideas is *not* influenced by factors that determine the selection of these new ideas (p. 198).”

In the case of violin evolution, such complete decoupling presents a real analytical challenge; by the time of their violin making, the Cremonese luthiers might have acquired sufficient knowledge about violin construction to anticipate which future variations would be more likely to yield better acoustic results than others. Specifically, those highly accomplished violinmakers may have appreciated with some degree of awareness the correlation between increases in f-hole length and acoustic power; they may therefore have been more likely to construct violins with slightly longer sound holes than with slightly shorter sound holes.

However, available evidence does not support this notion; theoretical and mathematical analyses have strongly suggested that the measured sound-hole variations among violins were more likely to have arisen from *random* craftsmanship errors than from *directed* variations (Nia et al., 2015). Thus, any structural variations among violins may have been random, but selection among them may have been directional, as expected from the operation of the law of effect.

## Does a Bottom-Up Explanation Suffice?

Another point of contention is whether trial-and-error learning alone can account for the evolution of the violin. By its very nature, the law of effect operates within the lifetime of an individual organism. Here, variation and selection can function to provide the opportunity for *innovation*. Yet, as Chitwood (2014) noted, Cremonese luthiers commonly learned their craft in the context of master-apprentice relationships, often following family ties and ultimately producing only four distinct clusters of violin shapes across many generations of violinmakers. Here, instruction and imitation would seem to be conservative forces more likely encouraging *replication* than innovation. These considerations suggest an extremely complex evolution of the violin, one which both incorporates and transcends the work of any individual luthier. Critics might thus claim that this complexity transcends the explanatory orbit of the law of effect.

We find it interesting that Skinner’s own writings can help us understand such complex evolutionary processes. Skinner (1984) identified and emphasized *two* different kinds of operant behaviors and controlling relations: *contingency-shaped* behaviors in which responses are directly controlled by the prevailing contingencies of reinforcement (a “bottom-up” process) and *rule-governed* behaviors in which responses are controlled by derived rules specifying

or codifying stimulus–response–reinforcer relations (a “top-down” process).

So, from direct experience you might learn to loosen screws by twisting your wrist counterclockwise and to tighten screws by twisting your wrist clockwise—contingency-shaped behaviors. On the other hand, you might also learn the simple verbal rule for turning screws in the correct direction—“lefty loosey, righty tighty”—rule-governed behaviors.

Skinner nevertheless underscored the primacy of reinforcement contingencies over derived rules in the control of behavior, because “it is the contingencies, not the rules, which exist *before* the rules are formulated” (Skinner, 1984, p. 589, italics added; also see Campbell, 1960). Yet, despite their possibly secondary status, those derived rules do not themselves fall outside the realm of a behavioral analysis; Skinner explicitly posited that, when it does control behavior, “a rule is effective as part of a set of contingencies of reinforcement” (1984, p. 587). So, violin evolution can be quite comfortably embraced by a behavioral theory that appreciates the intricate interplay between the prevailing contingencies of reinforcement and any behavioral rules that may have been socially acquired, as is very likely to have been the case in luthier–apprentice relationships.

Played out in the evolution of the violin, we can propose the following: With regard to sound-hole geometry, progressive increases in f-hole length were likely to have been the result of an increase in acoustic power (Nia et al., 2015)—a direct reinforcement effect. This increase in acoustic power became even more important with the rise in more capacious concert venues which demanded greater audible volume (Nia et al., 2015). Changes in the overall shape of the violin—although not contributing to gains in acoustic power—may also have been directly reinforced through the demand of customers preferring *au currant* styles (Chitwood, 2014), imitation being the fondest form of flattery. The perpetuation and possible exaggeration of each of these trends might also have been encouraged by derived rules of fabrication passed from master to apprentice. Hence, both bottom-up and top-down control may have participated in the evolution of the violin once established rules of construction had been established.

### Overt or Covert Processes in Violin Evolution?

Yet another concern centers on the familiar claim that a behavioral account based on the law of effect misses the possibly pivotal role played by covert cognitive processes in the creation of novel behaviors or contrivances, like the violin. Considering the substantial time, effort, and expense involved in violin construction, is it not highly likely that master luthiers behaved more rationally and economically—generating novel models and selectively retaining only those that could be envisioned to be acoustically superior—entirely in the theater of their consciousness?

The possible adaptive significance of such premeditated or intelligent design was famously proposed by Karl Popper, reasoning that ideas are more expendable than ourselves: “Let our conjectures, our theories, die in our stead!” (Popper, 1978, p. 354) Popper’s proposal was so compelling that Daniel Dennett (1996) dubbed those organisms capable of such fanciful trial-and-error, *Popperian creatures*; in contrast, he dubbed those organisms whose behaviors were modifiable solely by directly experienced contingencies of reinforcement, *Skinnerian creatures*.

We see at least two ways to respond to this alleged incompleteness of a behavioral account. First, at the *empirical* level, given the detailed observations of violin construction made by Nia et al. (2015), it appears that rather small sound-hole variations actually distinguished violins made over many years of fabrication; indeed, across approximately 200 years (1560–1750), sound-hole length increased by only 15 mm. Such small intergenerational variations are not at all what would have been expected if innovative models envisioned in the mind’s eye of master luthiers had inspired longer sound holes; considerably greater and more abrupt changes in f-hole length would have been far faster and less costly to produce. Those small sound-hole changes also occurred in the midst of many other changes in violin construction, any of which might also have promoted acoustic power, thereby making the cognitive chore of pinpointing the effective physical ingredient of enhanced violin performance extremely difficult to discern, even with the keenest vision of one’s mind’s eye.

Second, at the *theoretical* level, Dennett’s distinction between Skinnerian and Popperian creatures may be more apparent than real. No less an authority on the matter than Skinner himself famously argued that

An adequate science of behavior must consider events taking place within the skin of the organism, not as physiological mediators of behavior, but as part of behavior itself. It can deal with these events without assuming that they have any special nature or must be known in any special way. *The skin is not that important as a boundary.* Private and public events have the same kinds of physical dimensions (1969, p. 228, italics added).

The claim that the skin does not represent a critical boundary to behavioral analysis has proven to be highly controversial (Baum, 2011; Catania, 2011). What cannot be disputed, however, is that—whether inside or outside the skin—the basic elements of behavior analysis (stimulus, response, reinforcer) control the behavior of organisms without the participation of foresight. Skinner’s dismissal of the skin as a boundary—a purely theoretical claim for which decisive empirical evidence is lacking—should not be considered to represent an invitation to premeditation in the creation of novel actions or devices.

### Does It Matter How the Violin Evolved?

A final point of contention is that the very issue of violin evolution may be of little importance to psychological science. Indeed, it may seem self evident to most readers that master fabricators designed the violin in the same way as so many other beautiful and functional objects were created (Weber, 1996). Of course, the design of the violin evolved across generations of luthiers. So what?

To properly answer this question requires that we clearly define just what we mean by the word *design*. Remarkably, by most standard definitions of the word, we are forced to conclude that the violin was *not* designed. Of course, generations of luthiers crafted violins over hundreds of years. But, their doing so did not abide by today’s hallmarks of design.

Consider these definitions of design as a verb. (1) To create, fashion, or construct something according to a sketch, outline, pattern, or plan. But, the world’s most treasured violins of the 17th and 18th centuries (or their less revered ancestors) were not

constructed according to detailed blueprints or computer renderings, as might now be the case. Furthermore, the evolution of the violin would have required the planning of *future* variants that differed from the *prevailing* versions; how could those future designs have been envisioned or passed on to unborn luthiers without mechanical drawings? (2) To form or conceive of something in the mind. We certainly have no convincing scientific evidence to support such mental processes in the evolution of the violin.

People do of course build many things: violins, hinges, bridges, computers, and airplanes. How we as a species have come to do so is both a matter of process and history. Dawkins (1984) has noted that we have become quite familiar with a world that is dominated by amazing feats of engineering. That very familiarity unfortunately leads to a lamentable brand of intellectual complacency when we do try to understand how those feats came to pass.

Consider the case of people now building an airplane.

However incompletely we understand how an airliner works, we all understand by what general process it came into existence. It was designed by humans on drawing boards. Then other humans made the bits from the drawings, then lots more humans (with the aid of other machines designed by humans) screwed, rivetted, welded or glued the bits together, each in its right place. The process by which an airliner came into existence is not fundamentally mysterious to us because humans built it. The systematic putting together of parts to a purposeful design is something we know and understand (Dawkins, 1984, p. 3).

Here, we must critically remark that anyone even remotely familiar with the history of heavier-than-air flight will appreciate that this is an entirely unsatisfactory account of the evolution of the airplane; it begins with how airplanes are *currently* constructed rather than with their *origin*. Nor will such a jejune, ahistorical account suffice to explain the evolution of the violin. The true origin of these inventions requires a full understanding of the behavior of aeronautical engineers and luthiers. That is precisely why the evolution of the violin is a matter that demands the expertise of psychological scientists; we alone can weave the kinds of physical evidence that were so meticulously collected and reported by Chitwood (2014) and Nia et al. (2015) into a coherent theoretical narrative that can properly explain the evolution of the violin and the many other remarkable things that we humans make and do.

### Coda

We began our essay by noting Reverend Haeussel's early proposal that the violin "slowly emerged as the survival of the fittest" (1898, p. 12). This Darwinian thesis was more recently advanced and empirically substantiated by Chitwood (2014) and Nia et al. (2015).

Our essay has concurred with their general conclusions concerning the role of variation and selection in the evolution of the violin. However, it has also suggested that the law of effect rather than the law of natural selection is the effective selectionist mechanism of structural change. As such, the evolution of the violin is best seen to have been produced by a blind, mechanical process—the law of effect—operating both within and across the lifetimes of individual luthiers in a way that parallels how the luthiers themselves were produced by another blind, mechanical process—the law of

natural selection—operating across generations of organismal variation and selection.

We hardly expect ours to be the last word on the origin of adaptive inventions given the rapid pace of progress in this remarkable realm of human endeavor. The creation of each new device—from the slingshot to the snorkel to the smartphone—represents a unique saga, rife with intriguing plot twists and turns. What we hope to have accomplished in our essay is to prompt readers to thoughtfully entertain the possibility that natural science may succeed in divulging basic laws that explain the provenance of these and other fabrications—and especially the behavior of their creators—without appealing to the intervention of an intelligent designer.

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