NATURAL ARTIFICIALITY, NICHE CONSTRUCTION, AND THE CONTENT-OPEN MEDIATION OF HUMAN BEHAVIOR

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ABSTRACT
There are at least two senses in which human beings can be called “naturally artificial”: (1) being adapted for creation of and participation in niche constructed environments, and (2) being adapted for creation of and participation in such environments despite an exceptional indeterminacy in the details of the niche constructed environments themselves. The former puts human beings in a common category with many niche-constructing organisms while the latter is arguably distinctive of our species. I explain how this can be so by developing an account of supporting concepts of complexity, contingency, and content-openness, and show how to defend the position against a common style of objection by a single comparative case study: hermit crabs and their shells versus humans and their movable dwellings. Finally, I consider evidence that such a feature is indeed species-typical and evolved in human populations.

Keywords: human behavior; human evolution; artifacts; niche construction; complexity; plasticity; Marjorie Grene

1. Introduction
 A familiar trope of the anthropology, biology, and philosophy of the past 100 years is that humans are physiologically and behaviorally adapted for material culture (Alsberg 1970 [1922]; Washburn 1959; Dobzhansky 1962; Berger & Luckmann 1966; Grene 1974; Boyd & Richerson 1985; Tomasello 2000). Anyone schooled in the history of these disciplines can recognize instances of the basic idea, even if precise vocabulary and conceptualization vary. This paper is devoted to a description and defense of one version of this idea. Its purpose is to specify the details of the version I’d like to defend and begin to defend it by situating it within current theorizing in biology and philosophy of biology.
 My starting point for this effort is a usefully synoptic phrase for referring to the phenomenon itself, which I borrow from the late 20th-century philosopher of biology Marjorie Grene: “the *natural artificiality* of man” (Grene 1974, 358).[[1]](#footnote-1) Grene summarizes her understanding of this concept as follows:

 We become human, not just by being born *homo sapiens*, but by relying on a complex
 network of artifacts: language and other symbolic systems, social conventions, tools in
 the context of their use – artifacts which are in a way extensions of ourselves, but which
 in turn we actualize in our personal lives. It is our nature to need the artificial, art in the
 broadest sense of that term, or indeed, poetry in the broadest sense of that term: making
 and the made. We cannot become human beings without this. (Grene 1974, 358)

Grene’s idea can be classified as a version of the thesis just mentioned, a thesis that, at the time of her writing, had recently been proposed elsewhere, albeit sometimes with different emphases (e.g. Washburn 1959, Dobzhansky 1962, Berger & Luckmann 1966). Grene’s version emphasizes the naturalness of this phenomenon in two senses: First, naturalness in the sense of the *non-supernaturalness* of artifacts and of the organism-artifact interaction. (This is part of an effort to defend a broadly naturalistic view of culture *contra* idealistic renderings of culture like Karl Popper’s “third world,” an explicit target of Grene’s 1974 paper.) Second, Grene emphasizes the naturalness in the sense of the *species-typicality* for human beings of a robust interaction with artifacts, and the “unnaturalness” (atypicality) of any human life that didn’t involve this interaction.
 These two emphases of Grene’s account are captured in a well-known diagram from the essay (Image 1). The diagram shows both (a) the non-supernatural status of artifacts and human involvement with them (indeed, the belonging of both in the category of “natural world”), and (b) the dependence of human beings on this artifactual involvement for achievement of “normal” or “natural” human adulthood (in Grene’s language, “personhood” [in the diagram] or “becoming human” [in the quotation]).



Figure 1. From Grene (1974, 356). The relation between nature as a whole, material culture, developing human organisms, and “normal’ or “natural” human adults (here “persons”), according to Grene.

 Grene’s expression of the notion in this passage and diagram, however, leaves us with many unanswered questions, particularly from the vantage point of a biology and philosophy that is now 45 years in the future of Grene’s proposal. What, more precisely, should the phrase “natural artificiality” be taken to mean? How are the terms making up the phrase – “natural” and “artificial” – to be conceived? Given the traditional opposition between the “natural” and the “artificial,” the term “natural artificiality” even has an air of paradox: “How can anything be both natural and artificial at once?” we might wonder. Granting the bare coherence and plausibility of the notion, however, other questions remain. How general is the phenomenon of “natural artificiality” among humans? How far back in hominid evolutionary history and how commonly across the variety of the world’s cultures can it be found? Is it unique to humans? Can the phenomenon of natural artificiality be understood in a manner consistent with contemporary biological points of view? What arguments can be made that it is a real phenomenon in human populations and has been selected for or otherwise emerged in the course of humans’ evolutionary history?
 This paper attempts to clarify and make more precise (or, “explicate” [Carnap 1947]) the concept of natural artificiality in a way that makes it both (a) a plausible descriptor of human organisms’ species-typical life histories, and (b) useful from biological and philosophical standpoints. It thereby addresses one subset of the questions above. My focus is not on a full empirical defense of the idea but rather on an explication of the idea in terms of contemporary biological theory, including a defense of the idea’s coherence.[[2]](#footnote-2)

2. Two Paradoxes of Natural Artificiality
 In my view, Grene’s formulation suggests two paradoxes. A first, relatively superficial paradox arises from the tension between the terms “natural” and “artificial.” This paradox can be settled relatively quickly and easily. If by “natural” one means “not supernatural,” then of course artifacts are natural and can be given fully naturalistic descriptions and explanations. On the other hand, if by “natural” one means “species-typical,”[[3]](#footnote-3) then the prospect that some type of “artificiality” could be natural in the sense of species-typical is already well-imaginable. It is a relatively direct implication, for instance, in the literatures on niche construction theory (Odling-Smee et al. 2003), eco-system engineering (Pearce 2011), and extended phenotypes (Dawkins 1982; Sterelny 2005). On the second reading of “natural,” the seeming incompatibility between “natural” and “artificial” would be like a proposed incompatibility between marble and statues. Not everything made of marble is a statue, and not all statues are made of marble, but *some* statues are made of marble, and some marble things are statues. Likewise, not everything natural is artificial, and not everything artificial is natural (that is, species-typical), but *some* of what is artificial is natural, and some of what is natural is artificial.
 A deeper paradox, however, arises from awareness that the specific features and uses of artifacts (which I will call their *contents*) can be connected with physiology with more or less variability. This suggests that some artifacts are *both* species-typical (“natural”) in their presence and *non-species-typical* (“non-natural”) in their contents. Furthermore, part of what makes human natural artificiality so interesting is that it exhibits such a high variability of this kind, a feature I will refer to as the “content-openness” of natural artificiality.
 Though I don’t think Grene conceived or discussed the second paradox very explicitly, the term “natural artificiality” hints at it and thereby distinguishes her view from those of many similar discussions before and since (e.g. Washburn 1959, Alsberg 1922 [1970]). By clarifying the source of this paradox and offering a theoretical route to its resolution, consistent with contemporary research and theory in evolutionary biology, we thus stand to gain novel insights about human behavior and evolution.
 The procedure I follow here has the following steps: description of the phenomenon of content-open natural artificiality from a *prima facie* (i.e. pre-theoretical) perspective (section 3); explication of the concepts of *complexity*, *contingency*, and *content-openness* as these apply to artifacts and artifactually-mediated action, which is a crucial step in noticing differences between human and non-human “artifactuality” (section 4); consideration of a case study, intended to forestall a likely objection (section 5); and brief discussion of the reasons for thinking “content-open natural artificiality” is an evolutionarily entrenched feature of human populations (section 6).

3. The *Prima Facie* Phenomenon
 My “first pass” conjecture, defended in this section, is that a particular aspect of a great many human behaviors is, *prima facie*, distinctive of humans in comparison with non-human animals.[[4]](#footnote-4) This *prima facie* observable distinctiveness of human practices could be expressed as follows: human behaviors are more creative, more varied (from one group to another, and/or from one time period or generation to another), and more symbolically rich and complex (that is, they exhibit signs of a communicative, social value) than otherwise comparable behaviors of non-human animals. Skyscrapers, space travel, and mathematical physics would be examples of this, but so would jewelry, snowshoes, and mythical origin narratives. Something unusual is going on in human behavior that has something to do with artifacts. (There are also unusual things about how we relate to one another – our communication, symbolism, and sociality – and how we cognize and experience, including our minds and brains – but my focus here is just on artifacts.)
 This initial impression of distinctiveness can be refined with the help of a more specific concept: namely, that of a “*content-openness*” in behavior. We can approach the concept of content-openness by first noting that species of organisms can be compared in terms of the range of behaviors that their species-typical physiology accommodates.[[5]](#footnote-5) In other words, the range of behaviors supported and enabled by a species-typical physiology may be wider or narrower. Let’s call the width of this range its “content-openness.”
 Note further that the relation between this physiology and the behavioral possibilities it enables or supports can sometimes be affected by “artifactual” or “niche-constructed”[[6]](#footnote-6) entities, themselves more or less variable. Call such influence “artifactual mediation.” Some human physiology and behavior is related in precisely this “artifactually mediated” way.
 Finally, note that many of the human cases of artifactually-mediated behavior are exceptionally content-open. Consider, for instance, three relatively distinctive physiological features of human beings: the *hands*, the *brain*, and the *voice*. In each case, the organ’s capacities are extraordinarily wide-ranging. Each further has environmental complements that are “constructed” and open-ended (wide-ranging) in their possible manifestations: *tools*; *beliefs* and *skills*; and *language*.[[7]](#footnote-7) The (premise 1) parallel between these three couplings between physiologically-rooted capacity, constructed complements with wide-ranging contents, and wide-ranging behaviors shaped by or defined (in part) by interaction between this physiology and these environmental complements and their contents, as well as (premise 2) the relative species-distinctiveness of these couplings, suggests that (conclusion) these couplings may be manifestations of a more general, or more generally expressible, feature of the species-typical human condition.[[8]](#footnote-8)
 Similar couplings of physiological capacity and a varied range of contents is exhibited by many features, both in human and non-human species. The visual apparatus and the digestive system both are relatively stable, species-typical physiological features of organisms that have them, and their possible contents vary along some set of dimensions. An eye distinguishes more or less finely across a spectrum of light and with finer or coarser distinction across parts of the visual field. A stomach can digest some range of nutritional sources. Likewise, the adaptive immune system takes a wide range of possible “contents,” despite being a species-typical attribute of the species that exhibit it.[[9]](#footnote-9) These cases can be viewed as non-artifactual analogues of cases that involve artifactual mediation. And the non-artifactual cases are often simpler and less content-open than the artifactually mediated ones. The relation of a human *hand* to the range of artifactual supplements that it can take as “content” is analogous to that of the eye and its possible contents. But the relation of a *hand-artifact coupled system*, on the one hand, to the environmental contents that it affects, on the other, is also analogous to this relation. In the case of artifactually-mediated behaviors, the range of possible contents taken by the physiological-behavioral system may be increased by the presence of such mediating factors.[[10]](#footnote-10)
 Further, we might distinguish two kinds of physiological systems that can be “mediated” by artifacts in this way: physiological systems that are *evolutionarily adapted* for such mediation; and physiological systems that are not so adapted (even if they might nonetheless *become* mediated by artifacts). For instance: it is plausible that the human hand is adapted for the creation and use of tools; likewise, that the human brain is adapted for mastering and employing systems of conventional symbolic communication and a variable range of skills. It is unlikely, however, that human eyes are adapted for the use of eyeglasses or telescopes, or that the human immune system has been adapted for supplementation by vaccines, even though these artifactual mediations have by now become common.[[11]](#footnote-11) This allows us to describe some physiological systems as exhibiting a *natural* artificiality, while others do not.[[12]](#footnote-12) Many species exhibit a “natural artificiality” in this sense: for instance, the species-typical physiological and developmental adaptations that support bees in their production of and lives within and around beehives; or that support beavers in their production of and lives within and around dams; etc.
 Finally, cases of “natural artificiality” can be distinguished from one another in terms of *the range of contents that can be taken by* the physiology-supported behavioral system as a whole. This involves both the range of *artifacts* with which the physiology can be coupled, consistent with its “natural” operation, and the range of *relations to or interactions with the environment* that any such coupling can support. By this metric, I argue, human natural artificiality is exceptionally content-open in comparison with nearly any non-human organism’s natural artificiality. This description captures the sense of our initial *prima facie* description in more precise terms. The key distinctions considered in this section are summarized in Table 1.

|  |  |  |  |
| --- | --- | --- | --- |
| Artifactually-mediated? | (Relatively) content-open? | Naturally artifactually-mediated? | Examples of behavioral subsystems meeting this description |
| No | No | N/A | Reflexes |
| No | Yes | N/A | Vision; digestion; immune response  |
| Yes | No | Yes | Beavers’ construction of and behavior around dams; bees construction of and behavior around hives |
| Yes | Yes | Yes | Humans’ construction of and behavior around tools; humans’ construction of and behavior around conventional symbolic systems  |
| Yes | Yes | No | immune response mediated by vaccines; vision mediated by eyeglasses |

Table 1. Comparison of behavioral subsystems in terms of three variables: (a) artifactually mediated or unmediated; (b) relative width of the range of possible contents (i.e. “content-closedness” vs. “content-openness”); and (c) naturalness or non-naturalness of the artifactual mediation.

4. Complexity, Contingency, and Content-Openness
 According to the thesis under consideration here, human natural artificiality is especially *content-open*. To elucidate this claim, I’ll now provide a more rigorous definition of content-openness and relate that concept to the concepts of complexity and contingency.
 Simon (1962) defines the complexity of a system as deriving from two variables: (1) the number of components of the system and (2) the number of relations between those components:“by a complex system I mean one made up of a large number of parts that interact in a nonsimple way” (468). Thirty years later, McShea (1991) writes that “[t]here is some consensus now that the structural or morphological complexity of a system (biological or otherwise) is some function of the number of parts it has and the irregularity of their arrangement … Thus, heterogeneous, elaborate, or patternless systems are complex” (1991, 304). Wimsatt (2007, 179-192) presents a sort of “second-order” version of these metrics by suggesting that the compositional and relational complexity of a system should be identified with the number of causally-distinct decompositions of a system and its relations that one can conduct. Godfrey-Smith (1996, 24), on the other hand, presents a stripped-down version by simply defining complexity as heterogeneity.
 The “content-openness” of a system can be defined as the *range* of states that each part of a system can take. Such variability is plausibly an important contributor to the total complexity of a system.[[13]](#footnote-13) At the very least, this variability is a feature that, along with (other dimensions of) system complexity, makes an important difference to how a system operates and what we can expect from it. A similar variability is sometimes referred to in system-theoretic literature as the “degrees of freedom” of a system or a system component; or, in some biological literature, as the “plasticity” of a system.[[14]](#footnote-14) The analysis of content-openness that follows may thus have applications to the concepts of “degrees of freedom,” “plasticity,” and “variation.”
 A few consequences of this definition are worth noting here. First, content-openness is a modal trait insofar as it concerns possible rather than only actual variation. It is possible to define or to estimate content-openness on the basis only of actual variation; but such a definition or estimation is a restricted version of the more expansive modal definition I’ve given above. Second, in order for a system to be capable of being in different states, its continuing identity must not itself be incompatible with any of these states. Greater and lesser heat may be responded to by an organic system in various ways, but a sufficient quantity of heat will simply destroy the system. So attribution of greater or lesser “content-openness” to a system involves commitments about the identity conditions of systems of that type. Third, it can be wondered how a difference of states is to be defined and measured. Consider a visual system that registers a relatively continuous range of values between light and dark. How many different “content-states” can it be in? Are there just two states (light and dark), three (light, dark, and intermediate), or a larger set? Or is there an infinite set of continuously varying values between two extremes? If not an infinite set, what justifies distinguishing the possible states taken by the system into any one finite number?
 There is a familiar anxiety associated with this last set of questions, namely, how can we be sure that the distinctions we make between states, and the resulting “count” of the possible states that may be taken, is not arbitrary? If this arbitrariness cannot be ruled out, it may seem that a necessary condition of having a useful and evidentially responsive concept of “content-openness” is not met. This is an analogue, within modal space, of a problem long known to complexity theorists: How are systems to be parsed into “parts” and “relations” so that these parsings aren’t simply arbitrary, thereby supporting attribution of *any* arbitrarily desired degree of complexity to a system? And this problem, in turn, could be read as an instance of the even more general problem of non-arbitrarily identifying or ascribing kinds (for instance, “natural kinds”). Godfrey-Smith thus notes the parallel between the problem of how to count the elements and relations making up a system as a measure of system heterogeneity, on the one hand, and Nelson Goodman’s famous “grue” paradox about the individuation of kinds (Godfrey-Smith 1996, 153-157; Goodman 1955).
 The problem of how to non-arbitrarily individuate kinds pre-exists complexity theory as well as the proposed concept of “content-openness” and remains a generally controversial issue. It might therefore be considered fair to simply defer questions about individuation to that larger and longer-standing conversation. I think, however, that there are some especially promising strategies for addressing the concern in connection with content-openness. I will briefly discuss these later in this section.
 We can distinguish between two basic ways that one system can be said to be more “content-open” than another: (i) the range of values that be taken by some part or feature of the system (call this the “range degrees of freedom”); and (ii) the number of different parts or features that can vary (call this the “dimension degrees of freedom”).[[15]](#footnote-15) To use a mechanical metaphor, the *dimension degrees of freedom* (DDOF) of a behavior-affecting factor measures how many behavior-affecting “switches” are in the system, while the *range degrees of freedom* (RDOF) measures how many different states a switch can take. A sufficiently high DDOF factor can have the same variety and magnitude of effects as a RDOF factor and vice versa, but the structure of the interactions between the variable factors and the system’s behavior as a whole is different in each case. The distinction is thus helpful for analyzing and thinking about the difference-making powers of factors, even if these powers can – in principle – be achieved by either route.

|  |  |  |  |  |
| --- | --- | --- | --- | --- |
|  | **Parts** (for example) | **DDOF**(number of behavior-affecting switches) | **RDOF**(number of differently behavior-affecting states per switch) | **Examples** |
| **System Type A**(low DDOF, low RDOF)  | ab | 2 | 32 | Reflexes; tic-tac-toe (just at the level of the link between players’ moves in the game and their score at the end)  |
| **System Type B**(low DDOF, high RDOF) | ab | 2 | 4590 | Thermostat (just at the level of the link between “GUI” controls and machine states) |
| **System Type C**(high DDOF, low RDOF) | abcdef… | 110 | 322434… | Genetic code, binary code |
| **System Type D**(high DDOF, high RDOF) | abcdef… | 110 | 50351690482… | Electronic computer, car, organism, language |

Table 2. Examples of four broad types of systems distinguished in terms of *dimension degrees-of-freedom* (DDOF) and *range degrees of freedom* (RDOF) [*Note*: The middle three columns only give sample values (and not necessarily values that exactly match the examples in the fifth column).]

 Range degrees of freedom can be specified quantitatively or qualitatively: that is, the variability can be in a single measurable quantity or in a qualitative state. Quantitative ranges, in turn, can vary discretely or continuously.[[16]](#footnote-16) There are at least two ways that one range of quantitative states can be “larger” than another: (a) one can extend further than the other at its extremities; or (b) one can be more fine-grained than the other between two shared extremities. These concepts of greater and lesser (a) width and (b) fineness of grain might be applied by analogy to qualitatively varying sets of states.
 With these distinctions in hand, some other challenges for a non-arbitrary measure of content-openness can be anticipated. For instance, note that “continuously varying quantities” are infinitely content-open between their extremities. In general, we can say that a *continuously varying* dimension is more content-open than a *discretely varying* dimension of the same width (as, for instance, the set of rational numbers between any two numbers M and N is greater than the set of natural numbers between M and N), and that a continuously varying dimension *of greater width* is more content-open than a continuously varying dimension *of lesser width*. But how should we rank a *continuously varying* dimension of lesser width in comparison with a *discretely varying* dimension of greater width? And what of two dimensions with a set of discretely varying states: is the dimension with the greater *number* of states *always* more content-open than the other, or only when the states of the smaller set have a smaller total range than those in the larger set (for instance, because they overlap with a subset of the set of states in the larger set)? From a purely formal standpoint, these difficulties might be handled by adding “weights” to various of the states in the model, thereby treating some as greater indicators of content-openness than others. Likewise, if the values of the continuously varying variables, or the discrete states we’re not sure how to comparatively weigh, could be somehow (on the basis of some consistently applied “rule”) associated with others that are discrete and ranked, and the latter justifiably used as proxies for the former, then the ambiguities we’ve identified would be solved for those cases. But the question with both of these strategies is whether these theoretical or formal decisions can be made non-arbitrarily.
 In general, there are at least three broad strategies for addressing the worry about “arbitrariness of state distinctions” we’ve been concerned with in this section. One strategy is to construe content-openness as an *absolute* measure. According to this strategy, every system in the universe has a particular degree of “content-openness” – that is, all systems can be ranked in terms of the extent to which their states can vary without this compromising their identities. Simon’s proposal to use causal regularities and irregularities to justify a non-arbitrary decomposition of a system (so-called “near decomposability”; see also Wimsatt 2007) is an example of this strategy, though it’s not immediately clear how this proposed solution can be applied in modal space. Alternatively, building on Wimsatt’s (2007) definition of “descriptive complexity” as the number of alternative *K-decompositions* (basically, theoretically-motivated descriptions of the system) with non-congruent boundaries for system parts, one might construe the *absolute content-openness* of a system as the number of possible variant states of system parts, for all possible K-decompositions of the system.
 The primary strength of the absolute approach is its promise of objectivity and consistency across different analyses. However, the absolute approach has some strange consequences – such as that vaguely defined systems will, *ceteris paribus*, be more content-open than precisely defined ones (since vaguely defined system descriptions apply to a wider range of systems overall); and spatially or temporally larger systems that include smaller ones will nearly always be ranked more content-open than these smaller ones (since they include more “parts” that can themselves vary). And because the project of actually ranking all absolute systems by their content-openness is feasible only through approximation, in practice this strategy will involve simplifying assumptions that invite worries of arbitrariness.
 The second strategy is to construe content-openness as a *relative* measure between two systems that share many common features. The common features can thereby serve as an assumed stable background against which variability in other features can be compared. This allows one system to be ranked as more or less content-open than another regarding just one dimension or set of dimensions. This strategy is exemplified in Godfrey-Smith’s allowance that what kind of heterogeneity is of interest, and thus how two systems are ranked in terms of their complexity, may vary across different analyses (1996,25). The *relative content-openness* of a system can thus be defined as the number of variant states of system parts according to any admittedly non-absolute, but at least commonly applied, set of rules for system decomposition, applied to each of a set of systems under comparison. The *relative* strategy has the advantage, first, that its simplifications can make quantitative analyses feasible and fairly understandable; yet it suffers from the disadvantage that those simplifications are themselves subject to criticism (either general, as in the “grue paradox,” or particular to the analysis, as when a critic charges that an important dimension of variation hasn’t been considered).
 The third strategy is to rest the discrimination of a system’s states and dimensions on the likely *differences made* to further states of the system, or other systems, by thesestates or dimensions. The aim here is to rest the distinctions between states on “differences that make a difference” (Waters2007). The “effects” may be conceived and identified in a variety of ways – for instance, empirically, operationally, or functionally. This *effect-anchored* approach has the advantage of allowing the analyses to rest on independently well-supported or motivated understandings of the world as a structured system of causes and effects, including recognized causally-produced and causally-effective kinds and regular patterns (“laws”) that describe what happens. Its major disadvantage is that, insofar as the theoretical systems of specific laws and kinds on which any one “effect-anchored” account rests is itself questionable (again, in general [*a priori*] or in its particulars [empirically]), its models and results will also be questionable.
 In sum, we’ve found that *content-openness* – like the related concept of “complexity” – is both intuitive and promising as a theoretical tool, yet subject to concerns about its potential arbitrariness in application. It should be noted again, however, that this worry about arbitrariness is a general problem involved in all individuation of kinds, even if the modal feature of “content-openness” adds special complications.

 One final note about contingency. I use the term *contingency* to refer to the variation of a feature of a system where the variation is independent of some specified set of causal factors with influences elsewhere in the system. Thus system features are only contingent relative to other features. For instance: genetic changes due to drift are contingent relative to natural selection. According to the well-known “evolutionary contingency thesis” (Beatty 1995; Gould1989), the course of evolution itself is contingent in some respects, relative to the laws of evolution. (The analogue of drift in this example is the “initial conditions” of evolution and random mutational events along the way. Due to these “contingent” events, evolutionary history has followed a certain course. If the entire history were “begun again” from the top, and the initial conditions were allowed to vary randomly while the “laws of evolution” were held constant, then the course of evolution would be different from what it has been.)
 Increases in complexity and in contingency tend to contribute to the content-openness of the systems they characterize. *Complexity* is an important contributor to content-openness because a system with more parts, the different states of which make a difference to the operation of the whole, is generally (though not necessarily) a system that can take a greater number of distinct states, and thus a system that is more content-open. *Contingency* is an important contributor to content-openness because a system with features that vary independently of other features is, almost by definition, a system that is “content-open” in regard to the contingent features. As I see it, the species-typical way that artifacts mediate human interactions with environments is, compared to non-human animals, highly complex and contingent in its contents (contingent, that is, relative to the genetic and other biological determinants of species-typical human nature), and this complexity and contingency supports and tends to expand its content-openness.

5. Hermits and Nomads
 My proposed resolution of Grene’s second paradox involves the claim that it is part of humans’ species-typical nature that their behavior is mediated by artifacts in a highly content-open way. According to my proposal, the extent of this *content-openness* (which, again, is claimed to be part of humans’ species-typical nature) distinguishes *human* “natural artificiality” from other species’ natural artificiality – beavers, bees, bower birds, and so on. Yet a critic of this proposal could claim that my assertion of greater “content-openness” in human artifact-mediated behavior is questionable. In particular, they may worry that it is an arbitrary judgment because the supporting individuation of states of the compared systems (namely, human and non-human animals’ artifactually-mediated behavior) is also arbitrary. To answer such criticism, I will briefly present a single comparison between human and non-human animal artificiality and employ concepts developed in previous sections to argue that the content-openness of artifactual mediation is greater for humans than non-humans in this case. I don’t intend for the discussion of this case alone to demonstrate or prove my claim about human natural artificiality being exceptionally content-open, but rather to provide guidance in how a fuller argument could be carried out. However, I *do* think that reflection on this single case, and its implications for others like it, ought to be enough to convince a reasonable evaluator that human natural artificiality is exceptionally content-open overall: that is, to confirm the *prima facie* observations with which we began.
 The case is a comparison between a similar behavioral repertoire – acquisition, construction, and use of movable dwellings – in two species: *Homo sapiens* and *Coenobita compressus*, a species of hermit crab. The crab case is an interesting and useful one because the crabs show some surprisingly elaborate behaviors involving their shells, and these behaviors have been well-documented and analyzed in a series of recent papers that also make use of niche construction concepts.[[17]](#footnote-17)
 On the human side, I further restrict my analysis to discussion of the movable dwelling known as the “tipi,” commonly employed by people of the great plains of the North American continent from 1600 onwards and likely from much earlier. However, it should be remembered that this dwelling-type is merely one instance among many movable dwellings employed by *Homo sapiens*. These structures bear structural and functional similarities and differences to one another, as well as possible connections of historical influence, none of which I will discuss here explicitly. I focus on the tipi as an example within this general class.
 First, the crabs. Members of the terrestrial hermit crab species *Coenobita compressus* spend most of their lives in shells that they do not directly manufacture but rather adopt from gastropods that have abandoned or been removed from them. Once in possession of a shell, a crab often conducts modifications in the form of carving out pieces of the shell’s interior, thereby increasing the volume of space in the shell’s interior and reducing the shell’s weight. The main benefits to the crab accruing from these changes are thought to be that they (a) increase where and how much water may be stored inside the shell, (b) increase how many eggs may be stored inside the shell, (c) increase the room for the crab’s bodily growth inside the shell, (d) increase the crab’s ability to hide from predators inside the shell, and (e) decrease the shell’s weight, making it easier to carry more quickly and for longer distances.[[18]](#footnote-18) At the same time, since the remodeling decreases the total thickness of a shell, the remodeling comes with certain costs – most significantly, the greater risk of the shell cracking when taken into the teeth or claws of a predator.[[19]](#footnote-19) Due to (a)-(e) being the likely functions of shell-remodeling, one might think of this bit of artifactual production, on the part of the crab, as having basically five *dimension degrees of freedom*, one dimension corresponding to each functionally significant dimension of variation. Of course, these dimensions do not vary entirely independently of one another.
 Evidence suggests that *Coenibita compressus* prefer shells that have already been modified by other crabsof the same species.[[20]](#footnote-20) As the crabs age and grow, they outgrow their current houses and need larger ones. Typically, the new houses are acquired at exchanges that bring, on average, 6-8 crabs together and involve regular patterns of shell-dropping, shell-testing, and shell-adoption.[[21]](#footnote-21) These “markets” begin when a suitable abandoned shell is discovered, or when a crab is forced from its home by another (typically the older and weaker forced out by the younger and stronger). A crab that deems the shell a possibly desirable acquisition will examine it and, if this trial is satisfactory, enter the new shell, leaving the old one behind. The next crab in line carries out the same process with the smaller shell that the first left behind. At these “markets,” the crabs line up by size. Thus the larger crabs drop shells for the smaller to try, and, if they find satisfactory, adopt, leaving their own shells for the next in line.
 The acquisition and modification of movable dwellings by members of *Coenobita compressus* is thus remarkably complex. The acquisition involves several different “dimension degrees of freedom,” including: (i) the material of the shell itself (for instance, the gastropod species from which it hails), (ii) whether the shell is found in a market or a pre-market condition; (iii) if in a market, one’s “place in line” (generally a function of relative size); (iv) whether the shell is previously owned or not[[22]](#footnote-22); (v)-(ix) if the shell was previously modified, how (here the five dimension degrees of freedom previously mentioned – modifications that facilitate *water storage*, *egg storage*, *growth*, *hiding* or *weight-reduction*– should be included); and (x) whether a shell is merely tried but not adopted, or is tried and then adopted.
 I propose that dimensions (ii), (iii), (iv), and (x) can be modeled as discrete state dimensions, with (ii), (iii), and (x) comprising two states each, and (iv) comprising between 2 and 8 (or, in rare cases, more) states, depending on the number of crabs that come to the market.[[23]](#footnote-23) (v)-(ix) can be modeled as continuous state dimensions, yet ones that cover a fairly narrow range of possibilities.[[24]](#footnote-24) At a first approximation, (i) could be modeled as a discrete state dimension ranging across the gastropod species whose shells may be utilized, though the dimension degrees of freedom according to which the material of these shells “makes a difference” to crab behavior and life-history is plausibly better expressed as a set of dimensions expressing weight, strength, and susceptibility to modification (for instance, brittleness) of the material itself.
 Regarding construction, we’ve already noted the relevant degrees of freedom ((a)-(e) above).
 What about “use” – that is, the ways that the presence and involvement with shells affects the behavior of the crabs? How features of their dwellings make a difference to the behavior of the crabs is only partially known. How much and in what variety of ways does increased water-storage capacity, or increased hiding space, affect the behavior of a crab in different types of ecological situations? For instance, do crabs register the weight or thickness of their own shells and alter their behavior to avoid contact with predators that would put them at greater risk of failing to escape (due to heavy shells) or of being crushed (due to thin shells)? For now, let us treat this part of the analysis as a “black box” with an unknown and merely roughly estimated quantity of added degrees of freedom.
 Now the humans. Movable conical dwellings have been a part of many human cultures, but were a particularly continuous feature of the practices of Lakota and other groups in the great plains of the North American continent since at least the 1600s and possibly for much longer.[[25]](#footnote-25) Regarding all three broad categories of behavioral mediation we will consider – acquisition, modification, and use – there were significant variations among these groups and even within subgroups, not all of which I will be able to discuss here. My primary reference will be Laubin & Laubin’s *The Indian Tipi*, 2nd ed. (1977), which is outdated in some ways but a reliable enough guide to the features of concern for this analysis. Laubin & Laubin focus on the Lakota (“Sioux”) style of tipi and its role in Lakota practices c. 1850-1950, with occasional comparisons to designs and practices of other groups. I adopt Laubin & Laubin’s account on these matters in this summary, without making any claim to its ultimate defensibility.[[26]](#footnote-26)
 The basic elements of a traditional Lakota tipi include poles (composed of tall thin tree trunks prepared for the purpose; usually 12-20, depending on size of the tipi), cover (usually composed of buffalo hide or, in later years, canvas), and inner lining (usually composed of furs). Other elements also play a role in the set-up of a tipi, such as hide straps, rope, pegs, or stones to hold down the corners.
 Regarding the acquisition of tipis: this could occur in at least three ways: (i) by *gifting*, (ii) by *trading*, or (iii) by *manufacture* from its basic elements: The manufacture of a new tipi was generally the job of women of a tribe, particularly older women, and the entire process could take three women four or more days of continuous labor.[[27]](#footnote-27) A bride’s family would sometimes donate a new tipi to a couple upon the event of their marriage, which the wife’s family had itself built.[[28]](#footnote-28)
 Two senses of “construction” of a tipi should be distinguished: the initial manufacture – which, as noted, could take a small team of people several days to complete – and the “set up” and “take down” of a tipi, which could be carried out by 1-2 experienced people in 20 minutes or less.[[29]](#footnote-29) Some dimensions of the manufacture constrain the degrees of freedom of the “set up” and “take down,” but they leave many other degrees of freedom open: for instance, precisely where the intermediate poles are set into the ground, and whether the lining is attached to the bottom of the inside cover or left to hang, creating a larger and airier, or smaller and warmer, inside living space better suited to summer or winter.[[30]](#footnote-30)
 The dimension degrees of freedom characterizing the *manufacture* of a tipi primarily include those describing each of the basic components, that is, poles, cover, and lining. Some of these dimensions, once settled, constrain the degrees of freedom of the others, at least as long as we assume the resulting structure will match the basic prototype or standard of a decently “good” tipi.
 Regarding poles[[31]](#footnote-31), some degrees of freedom that characterize each pole include: (a) length; (b) thickness; (c) shape overall (which can be affected by taking an axe to inconvenient outgrowths – an ideal pole is smooth and straight, except for being tapered towards the top end); (d) the wood from which they are made (cedar, fir, and pine are some favorites); (e) whether this wood is acquired from a living tree trunk that is felled and then dried; or from an already dead and dried tree; (f) the *weight* of the wood (this is a functionally important consideration for transportation of the resulting tipi); (g) the *strength* of the wood in the face of wind-storms (this is a functionally important consideration for the *tipi’s stability* as a shelter and for the *longevity of the poles*).*[[32]](#footnote-32)* There are also degrees of freedom that apply to the total collection of poles making up the poles for one tipi: (L) the number of poles that are adopted for the tipi; (M) how many poles will be foundation poles (this has traditionally varied by group – for instance, Sioux, Cheyenne, Arapahoe, and Plains Cree traditionally used three foundation poles while Crow and Blackfoot traditionally used four foundation poles)[[33]](#footnote-33); (N) how the main poles will be placed *vis-à-vis* the ground and one another during set-up (this tends to be consistent from one set-up and take-down to another).
 Sometimes poles were purchased in bulk during travels to a place that was abundant in good wood from tribes that specialized in production of poles, rather than built by a tipi manufacturer for each new tipi.[[34]](#footnote-34)
 Regarding the cover, it was almost universally made of sewn buffalo hides, between 12 and 30 depending on the size of the tipi, though covers may sometimes have been made of buckskin hides, and in later years (late 1800s on) were usually made of canvas.[[35]](#footnote-35) The cover in some tipi designs is short enough to not reach the ground when wrapped around the poles; in others, it is long enough to lay on the ground for several feet. In some tipi designs the cover is held away from the poles at the bottom and attached to the ground with pegs; in others it is held to the ground with a ring of heavy stones.[[36]](#footnote-36) Covers can also have larger or smaller adjustable openings for smoke at the top of the tipi, as well as flaps that can be wrapped closed to prevent water from entering during storms. Finally, tipis have larger or smaller entrance ways, to which is attached a foldable or pinable door, usually made of the same material as the cover. Covers and doors may be modestly decorated in a variety of ways, and may in special cases be painted (though it’s thought that only 1/10 or fewer of traditional tipi covers were painted).[[37]](#footnote-37) A chief’s tipi would be sometimes marked by a buffalo tail switch or other “flag” hung from the tips of the protruding poles.
 The inside lining, as noted, could be fixed to the inside cover in at least two ways, and other details of the fixing of the lining could also vary. For instance, an inner rain covering, or *ozan*, can be strung above the center of the inside of the tipi, or over individual beds.[[38]](#footnote-38)
 To conserve space, I pass over variations in inner furnishings of tipis (including the composing materials, design, and layout of flooring, beds, backrests, and boxes); but note that inclusion of these furnishings would almost certainly increase the degrees of freedom of the tipi system as a whole in comparison with those of hermit crab dwellings.[[39]](#footnote-39)
 Regarding *use*, the important degrees of freedom include (i) whether the tipi is (a) folded up and prepared for transportation, or is (b) erect and habitable, or is (c) in process of set-up or of take-down; (ii) whether the tipi is (a) a standard home tipi for a nuclear family, (b) a chief’s tipi, (c) a tipi for a special society such as a hunting society, (d) a medicine tipi, (e) a burial tipi, or (f) a festive tipi for a special occasion[[40]](#footnote-40); and (iii) the wide variety of activities performed by humans in and around their tipis such as cooking, crafting, entertaining, gift-giving, sleeping, mating, tending to children, being protected from elements of different kinds (heat, cold, wind and dust, rain, sleet, and snow), being protected from rivals, and (plausibly) reinforcing “proprietary” boundaries of property, kinship, and status.
 This brief sketch of the degrees of freedom associated with tipis’ mediation of human behavioral repertoires surely leaves out many additional dimensions, and it should be remembered that the tipi is only one among many movable dwellings known to be employed by the same species, which in turn are a subset of the much larger category of human dwellings *tout court*.[[41]](#footnote-41) However, even restricting our comparison just to that between crab shells and human tipis, the greater overall content-openness of the latter artifacts’ mediations of human behavior, in comparison with that of the former’s mediation of crab behavior, should be undeniable.
 Human tipis are made of three different kinds of materials (poles, cover, and lining) in combination with one another, whereas crab shells are made of a single material. Both poles and linings exhibit one kind of variation exhibited by crab shells – namely, that of which species of organism supplied the raw material. Crabs shape the interiors of their shells, but so do humans by a combination of selecting and setting up poles, cutting and sewing the cover, and hanging the lining, as well as the other artificial modifications that humans introduce inside their tipis (such as furnishings and a fire pit). Furthermore, the human variations to the inside of a tipi – such as the hanging of lining closer or further from the inside of the cover in summer or winter – make the precise shape of the interior itself a reversibly variable factor, which the crab shells are not. Regarding *use*, tipis facilitate protection and hiding from the elements and from predators, as do crab shells, but also a range of social and ceremonial purposes. Crab shells and crabs’ interactions with them *do* mediate their social dynamics through time (Bates & Laidre 2018), and this introduces multiple dimensions of complexity, contingency, and content-openness, but parallel dimensions are present and show greater variation in the human case. Like the crab shells, tipis can store water (and progeny) as needed but much more as well – in fact, they usually store a great variety of things including fire, wood, clothing, tools, and ceremonial objects.
 Some concessions to the crabs must also be made. Crabs transport their shells on their backs, and therefore it might be thought that they exhibit more degrees of freedom in their movement of the shells than do humans in the movement of their tipis. But tipis can be transported as well (albeit not far except in a “taken-down” state); and even when erected can be turned along their horizontal axis (for instance, to position their doorways away from the wind). Nonetheless, it does seem that regarding just the dimension of “direction of movement while occupying,” crabs in shells exhibit greater content-openness than humans in tipis.
 In sum, the role played by human dwellings in mediating human behavior exhibits a much greater overall *content-openness*, in the sense defined here, than the role played by crab dwellings in mediating crab behavior. This difference derives in part from the greater *complexity* of the artifacts themselves and their mediation of behavior in the human case, and in part from the greater *contingency* of any one feature of that artifact and that mediation (relative to whatever is “species-typical” for human beings).[[42]](#footnote-42) We might further point to a species-typical human *physiology* and *pattern of development* that facilitates this content-openness precisely by accommodating such a complexly and contingently niche constructed environment.[[43]](#footnote-43)

6. Content-Open Natural Artificiality and Human Evolution
 Those who remain skeptical about whether content-open artificiality *is* a natural (in the sense of “species-typical” and “evolutionarily entrenched”) part of human behavioral repertoires would probably like to see some historical argument that it *has* become entrenched in human populations, ideally by some theoretically accepted and empirically supportable evolutionary pathway. While I don’t expect to be able to demonstratively answer the “how-actually” evolutionary question here, it seems appropriate to briefly note some arguments in favor of the view that content-open natural artificiality is a natural and evolved feature of human populations, and regarding how that evolution may in fact have taken place.
 I will present these arguments in two sets: (1) physiological and behavioral evidence that content-open natural artificiality is indeed a species-typical and evolved feature of contemporary human populations; and (2) a consideration of evolutionary models and of the paleoanthropological record that speaks to how content-open natural artificiality could have evolved.
 In comparison with our nearest surviving sibling species – chimpanzees and other great apes – humans exhibit a number of relatively distinctive physiological features including brain size, brain structure, larynx, and opposable thumbs. In combination with the developmental evidence mentioned below, these features are plausibly explained as adaptations to support content-open natural artificiality: the hands by being especially adept at refined manipulation or production of features of artifactual environments, and the larynx and brain by supporting learning from others and from environmental cues how to effectively engage with a highly variable range of circumstances. These circumstances may be especially variable (that is, “non-species-typical”) both because (i) the behavioral plasticity enabled by content-open natural artificiality makes a wider range of “natural” environments survivable ones for human individuals and populations (a feature that is adaptive in the way that all broadenings of ranges tend to be adaptive) and because (ii) the environments of a species exhibiting content-open natural artificiality are themselves more likely to be niche constructed in a contingent and complex way.
Sophisticated mechanisms of “social learning,” such as Tomasello’s joint attentional processes (2000, 2014) and Sterelny’s “apprentice learning” (2012), are widely recognized to characterize human development and to be distinctive or near distinctive of our species. Such mechanisms facilitate development of highly refined skills that send learners down one or another developmental pathway depending on the differing developmental environments to which each is subject. Considered across the range of members of the human species as a whole, these skills and the connections they establish between humans and their environments may be described as complex, contingent, and content-open in the senses defined above. When coupled with artifacts that are also complex, contingent, and content-open, the resulting developmental and behavioral pattern exhibits a sort of “second-order content-openness” (or “second-order plasticity”): that is, one especially content-open system provides inputs to another especially content-open system, leading to feedback effects that increase the content-openness of the coupled systems as a whole.
 Under the plausible assumption that such variability has adaptive advantages (discussed further below), the mechanisms of social learning supporting this developmental and behavioral variability could have been selected for. The fitness advantages promised by content-open artifactual modifications of environments, and the suitability of social learning mechanisms to support acquisition of the needed skills for such content-open artifactual modifications of environments, are further arguments that content-open natural artificiality may be an evolutionarily entrenched feature of human populations.
 But how *could* such a feature as content-open natural artificiality have evolved? The question can be put more pointedly in parallel to a question posed by Boyd & Richerson (1985, 2006) for cumulative cultural transmission: “if [content-open natural artificiality] is so evolutionarily advantageous, then why is it so rare?” It has long been known that generalism is favored in heterogeneous environments (e.g. Mayr 1964, 21-22), and content-open natural artificiality could be construed as a kind of generalism. However, this particular generalizing mechanism does appear to be especially rare.
 From a reflective theoretical perspective, we can distinguish three routes by which an individual or a population can acquire its phenotypes: genetic evolution, individual learning, and social learning.[[44]](#footnote-44) Since content-open natural artificiality is plausibly facilitated by (or possibly even dependent on) social learning, a good first step towards answering the “how possibly” question is to ask under what circumstances a capacity for and tendency towards social learning will be selected for. In very stable environments, genetic evolution is expected to be favored over individual learning for at least two reasons. First, in a stable environment, innate responses generally leave less room for a mismatch between behavior and environment than learned responses (learned responses can always fail to be learned, whereas innate responses are part of an organism’s species-typical development in a less variable way). Second, genetically entrenched, innate responses are generally less developmentally costly than learned responses, which require an additional apparatus, beside the one enabling the adaptive behavior, for learning the adaptive behavior.
 In highly variable environments, however, *individual learning* can be selected for over genetic entrenchment of instincts because individual learning allows an organism to more finely adapt, in the course of its development, to environmental variables that can make a big difference to its fitness. Organisms that were plastically related to their environments in this way have an advantage, so long as (i) the environment varies regarding features that make a difference to fitness, (ii) the learner can differentially learn those features, and (iii) the individual learning is less costly (energetically and ultimately in terms of fitness) than any improvement in fitness gained by finer adaptation.
 In a population already adapted for individual learning yet subject to a moderately-paced rate of significant environmental change (say, changing every 5-50 generations rather than not changing for hundreds of generations, or changing multiple times in an individual life history or across each generation), however, it is conceivable to find selection pressure for a mixture of social learning and individual learning.[[45]](#footnote-45) A factor that can increase the fitness value of social learning in such scenarios is the difficulty of acquiring the most successful behaviors through individual learning (Boyd & Richerson 2006, 131-147). Such difficulty can be expected to characterize environments either (a) especially outside of the range for which a species was genetically adapted, (b) already subjected to significant niche-construction, or (c) where the fitness of some conspecifics is already fitness-enhanced by artifactual mediation (since this raises the standard for fitness maximization in a way that, plausibly, only social learning can allow an individual to meet). And features (a)-(c) do appear to increasingly characterize the environment of hominid populations in the 2-3 million years leading to the speciation of *Homo sapiens*.
Increases in social learning can be expected to facilitate a “content-openness” in the organisms’ involvements with such environments when considered across the species as a whole; and content-openness (those “degrees of freedom” in developmental plasticity) would be selected for by this circumstance.
 Overall, the paleoanthropological data is consistent with the hypothesis that content-open natural artificiality is a selected-for and entrenched feature of human populations, and arguably positively supports it. The paleoanthropological record shows an increase in tool use relatively early in the lineage leading to modern humans (Oldowan 3.5 mya; Acheulian 2.1 mya). The trend towards bipedal locomotion starts earlier (about 7.5 mya) but doesn’t achieve the extent shared by modern humans until 1.9 mya, about the same time that the trend towards increased brain size clearly begins. The full size of modern brains, as well as evidence of artifactual complexity beyond the Acheulian paradigm, comes much later (about 0.5 mya).
 Though of course the record admits of multiple interpretations, it is possible to read this sequence as supportive of the favored hypothesis. The initial increase in tool use 3.5 mya could have been a “lucky” discovery of a group of organisms well-adapted for individual learning (like modern-day chimpanzees who use tools and develop tribally specific lineages of such practices, or contingent “cultures”), which became entrenched by cultural transmission and then Baldwin-effect-type process (thus explaining the longevity of Oldowan technology). The increased reliance on bipedal locomotion to the point of its culmination in *Homo erectus* 1.9 mya could have been driven by the adaptive value of a capacity to explore a wider and wider foraging range and avoid competition with rival hominid groups. This increased range likewise would increase selection pressure for plasticity in behavior, including plasticity of artifactual production and perhaps also social interaction and organization (for instance, to facilitate foraging and cooperative foraging [see Sterelny 2012] in different environments).
 The fossil record indicates that the first major migrations out of Africa occurred shortly after the full development of bipedality, suggesting that migration was limited until that development (Tattersall 2008). And increasingly sophisticated tool use develops precisely in the period following upon these migrations, along with the trends towards further increases in brain size. There is also a fair bit of speciation in this period among hominid groups both in and outside of Africa, which itself can be read as evidence of strong selection pressures at work. The scattered record of artifactual innovations during this period – including evidence of control of fire 750,000 ya, of constructed dwellings 400,000 ya, and of bows and arrows 100,000 ya – coupled with long periods of *lack* of evidence of such advanced technologies even in places we know hominids to have lived and occupied (Sterelny 2017), further suggests the gradual selection for and eventual entrenchment, during this period, of a *capacity* for such content-open artifactual mediation, which *Homo sapiens* instantiates in the clearest and least ambiguous way of all its predecessors.[[46]](#footnote-46)
 There is, however, an alternative explanation of the paleoanthropological data with which this hypothesis must compete: namely, that the apparent content-open artificiality exhibited by human populations is not “natural” in the sense of evolved or species-typical, but is rather itself a contingent development of a shorter span of history than is sufficient to entrench a “natural” capacity (as considered, in different ways, by Mithin 1999, Malafouris 2013, and Sterelny 2011). According to this competing hypothesis, the contingency, complexity, and content-openness of human culture is directly a result of *cultural* processes, rather than (as the “content-open natural artificiality” thesis holds) a result of a combination of (a) rudimentary artifactual development and individual-learning-type developmental and behavioral plasticity early in hominid evolution, (b) selection pressure on responsiveness to more variable, complex, and niche-constructed environments leading to a Baldwin-effect entrenchment of culture-responsive physiological and behavioral plasticity, and (c) a continuing contingent and at times increasingly complex cultural development that, in combination with the entrenched species-typical developmental and behavioral plasticity, generates the diversity of cultural practices and traditions we see today.
 Of course, the facts may also be explained by a mixture of elements from the two hypotheses. At a minimum, the content-open natural artificiality hypothesis holds that the mechanism that goes by this name is *one* factor, and a somewhat important factor, in understanding human behavior and its evolution. Estimating the significance of this factor, in comparison with others, as well as precisely estimating the period and lineages in which it emerges and is selected for, are tasks for future research.

7. Conclusion
 It should be clearer now how Grene’s concept of the “natural artificiality” of human beings can be understood and defended in a manner consistent with contemporary science. A better understanding of this structure, its behavioral implications, and its possible evolutionary origins, has thereby been gained.[[47]](#footnote-47)

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1. Grene borrowed the term and concept of “natural artificiality” from the 20th-century philosopher Helmuth Plessner (2019 [1928]), who employed it in a more phenomenological register (having to do with the experience of life as a human being). I rely solely on Grene’s version of the concept here. [↑](#footnote-ref-1)
2. I do briefly and in passing discuss the empirical reasons for believing that natural artificiality is a species-typical and evolved feature of *Homo sapiens*, and some of the possible evolutionary routes by which it could become entrenched in human populations, but I leave a fuller treatment of both of these issues for another paper. [↑](#footnote-ref-2)
3. The notion of what is “natural” for a species – that is, what is “natural” in the sense of species-typical – has been the source of much controversy (e.g. Mayr 1959 [1976], Hull 1986, Grene 1990), including some influential recent defenses (Machary 2008; Kronfeldner 2018). In accordance with the recent defenses, I assume here that a notion of “natural” as species-typical and evolved by natural selection is defensible and analytically feasible. In the interest of full-precision, however, one would need to distinguish between concepts such as *species-typicality* (which itself carries some vagueness and ambiguity), *(biological) evolvedness*, and *evolvedness by natural selection*. Not everything that is species-typical is necessarily a product of biological evolution; and not everything that is a product of biological evolution is a product of natural selection. See Lewontin & Gould 1978 for the classic objections to assuming an overlap here. [↑](#footnote-ref-3)
4. By a *prima facie* feature I mean one that shows up for a reasonable but relatively pre-theoretical inquiry – that is, for an inquiry that seeks merely to capture how things appear when one attempts to observe and think about them in a reasonable and unbiased way, a way not guided by one or another “strong theory” that would pull one’s conclusions on the basis of observation in a highly contestable or controversial direction. The reliability of such a method is, of course, limited. That’s why I describe it as a “first pass” step in the argument: not an established or argued-for result, but a *prima facie* plausible view, to be refined and more carefully defended thereafter. [↑](#footnote-ref-4)
5. One might also consider “species-typical development,” but I leave that aside for now. I discuss developmental dimensions of the same phenomenon to some extent in Section 6. [↑](#footnote-ref-5)
6. By an “artifact” I mean “a relatively stable modification of an environment by a conspecific.” This definition equates “artifact” with any “niche constructed” (in the sense of Odling-Smee et al. 2003) part or feature of an environment, with the additional requirement that only those modifications produced by an organism or its conspecifics can be artifacts for that organism. [↑](#footnote-ref-6)
7. My aim here is just to note three couplings that exhibit the emphasized pattern. The association I draw between these physiological features and these constructed environmental components is not intended to be exclusive of other possible couplings. For instance: By mentioning the “voice” I do not mean to distinctly associate human linguistic ability with vocalization, just as I don’t mean to suggest that the only possible mediation of human behavior by tools occurs in conjunction with use of the hands. (I thank an anonymous reviewer for raising a question about these issues.) [↑](#footnote-ref-7)
8. This notion of a coupling between human physiology and especially variable niche-constructed environments is implied in some previous accounts, for instance, Sterelny 2003. Historically informed readers may note a similarity to the classic trope of humans as *Mangelwesen* (“deficient beings”), traceable to the 18th-century anthropologist-philosopher J.G. Herder if not earlier; and the sometimes-made suggestion that a variable set of tools “supplements” this human physiological indeterminateness (e.g. Alsberg 1922 [1970]). For discussion of the *Mangelwesen* thesis in a contemporary biological context, see Moss (2016, 2020). [↑](#footnote-ref-8)
9. Odling-Smee et al. (2003, 255) make a similar point about the structural parallels between constructed niches and the adaptive immune system. [↑](#footnote-ref-9)
10. The extent of this increase will vary across cases. In some cases artifactual factors may produce decreases in content-openness (for instance, if an artifact restricts the range of possible interactions with an environment – e.g., a jail cell). [↑](#footnote-ref-10)
11. I thank an anonymous reviewer for suggesting these cases as ones to be treated here. [↑](#footnote-ref-11)
12. These others might be called cases of “non-natural artificiality.” Note, however, that the use of eyeglasses can still be read as exemplifying a “natural artificiality” characteristic of human beings as a whole because eyeglasses are produced and used through the operation of these other, “natural artificiality”-supporting physiological systems (i.e. the hands and brain). The case study of human natural artificiality considered later in the paper (section 5) should be read in this way. [↑](#footnote-ref-12)
13. Godfrey-Smith’s “heterogeneity” definition of complexity seems to include this dimension of variability (1996, 24-25), but doesn’t analyze its structure and relation to other aspects of complexity as thoroughly as I do here. [↑](#footnote-ref-13)
14. For “degrees of freedom” in biological contexts, see Moss2013; for plasticity, see West-Eberhard 2003. [↑](#footnote-ref-14)
15. Note that a greater dimension degree of freedom could, in principle, be treated as itself a variation in the range degree of freedom of one variable describing the system, namely, the presence or absence of various subsystems (themselves also varying), though this would involve allowing some ranges to take other ranges as values – that is, the system would be given a “multi-order” description. [↑](#footnote-ref-15)
16. One might think that, as far as behavior is concerned, the set of distinct states along any one dimension ought in principle to be finite and discrete since there’s a minimum difference in environmental cues reacted to, or actions carried out. However, loose coupling between organism and environmental conditions makes it so that even these minimum differences may vary across different times and conditions, and due to variation in a population, this minimum difference can vary also between organisms of the same species. The size of this “quantum of difference” for any given organism’s behavior will for these reasons and others be difficult to determine with certainty. I think it’s better to allow some dimensions to be treated as varying continuously. [↑](#footnote-ref-16)
17. Laidre 2012, 2019; Laidre et al. 2012; Laidre & Trinh 2014; Bates & Laidre 2018. [↑](#footnote-ref-17)
18. Laidre 2012, 38-39; Laidre et al. 2012, 3575. [↑](#footnote-ref-18)
19. Laidre et al. 2012. [↑](#footnote-ref-19)
20. Laidre 2019; Laidre & Trinh 2014. [↑](#footnote-ref-20)
21. Bates & Laidre 2019, Laidre 2019. [↑](#footnote-ref-21)
22. The crabs greatly prefer previously modified over previously unmodified shells (Laidre 2019, Laidre & Trinh 2014). [↑](#footnote-ref-22)
23. On the range and average number of crabs in these gatherings, see Laidre 2019. [↑](#footnote-ref-23)
24. Some quantitative measures of these dimensions are given in Laidre 2012. [↑](#footnote-ref-24)
25. Laubin & Laubin 1977, 3-13; Holley 2007, 1-30; Hungrywolf 2006. [↑](#footnote-ref-25)
26. The strengths of Laubin & Laubin’s treatment include its origins in training from native practitioners (particularly Chief One Bull and Scarlet Whirlwind), its technical detail, and its apparent consistency with more recent accounts such as Holley 2007 and Hungrywolf 2006. [↑](#footnote-ref-26)
27. Laubin & Laubin 1977, 206. [↑](#footnote-ref-27)
28. Laubin & Laubin 1977, 104. [↑](#footnote-ref-28)
29. Laubin & Laubin 1977, 51. [↑](#footnote-ref-29)
30. Laubin & Laubin 1977, 182. [↑](#footnote-ref-30)
31. Laubin & Laubin 1977, 19-23. [↑](#footnote-ref-31)
32. As with the question of the species of gastropod from which crabs take their shells, we might drop (d) and focus instead on the “differences that make a difference” (that is, the other dimensions listed). [↑](#footnote-ref-32)
33. Laubin & Laubin 1977, 16-17, 279-231. I follow Laubin & Laubin’s names for these groups without being confident these are the most appropriate choices from a contemporary standpoint. Because I cannot guarantee that alternative names would designate all and only the groups that Laubin & Laubin intended to designate with their terms, I have elected to leave them as they are, with apologies for any confusions or offense that may arise. [↑](#footnote-ref-33)
34. Laubin & Laubin 1977, 8-9. [↑](#footnote-ref-34)
35. Laubin & Laubin 1977; Holley 2007. [↑](#footnote-ref-35)
36. Laubin & Laubin 1977, 45-50. [↑](#footnote-ref-36)
37. Laubin & Laubin 1977, 241-255. [↑](#footnote-ref-37)
38. Laubin & Laubin 1977, 61. [↑](#footnote-ref-38)
39. Laubin & Laubin 1977, 63-88, and the rest of Ch. 5. [↑](#footnote-ref-39)
40. Laubin & Laubin 1977, Ch. 7. [↑](#footnote-ref-40)
41. Including this dimension of variation – and the associated high degree of *contingency* – in our comparison would raise the estimate of the content-openness in the human case far beyond that of the crabs almost so obviously as to make the rest of the comparative analysis superfluous. [↑](#footnote-ref-41)
42. As noted, the estimate of this contingency is increased further when we consider that tipis are just one type of human dwelling among many. [↑](#footnote-ref-42)
43. For instances of this supportive human physiology and pattern of development, consider the hands, the plasticity of the neo-cortex, and adaptations for social learning such as joint attention (Tomasello 2000, 2014) or “apprentice learning” (Sterelny 2012). [↑](#footnote-ref-43)
44. The argument of the remainder of this section owes much to Boyd & Richerson (1985, 81-131; 2006, 99-147), Odling-Smee et al. (2003, 354-359), and Sterelny 2012, though my account does not necessarily match any of theirs in all details. See also Snell-Rood 2013 on evolutionary trade-offs in connection with behavioral plasticity. [↑](#footnote-ref-44)
45. Boyd & Richerson 2006, 131-147 conjecture that such a moderately-paced change of environment could have resulted from rapid climatic cycling during this time. Moderate rates of environmental change could also have been introduced simply by the increased migration enabled by achievement of full bipedality roughly 1.9 mya, as emphasized by Tattersall 2008. Niche construction itself can also speed up or slow down the rate of change of environments (as analyzed by Odling-Smee et al. 2003), a phenomenon that, once it had emerged, could have allowed the speed of change of environments to happen to be often enough at the right point to select for further capacity for social learning. [↑](#footnote-ref-45)
46. The delay of post-Acheulian technical sophistication until roughly 0.5 mya, however, and no clear and consistent evidence of symbolic cognition until 80,000 ya at the earliest, are admittedly hard to explain on the favored hypothesis. See Sterelny 2011, 2012, 2017 on this puzzle about “behavioral modernity.” [↑](#footnote-ref-46)
47. I thank the following institutions for opportunities to present drafts of this paper or parts of this paper: the Philosophy of Biology Circle, hosted by Sahotra Sarkar at the University of Texas, Austin; the Philosophy Colloquium of the University of Nevada, Las Vegas; and the undergraduate chapter of Phi Sigma Tau and philosophy club at the University of Nevada, Las Vegas. I also thank the following individuals for helpful comments or conversations: Ian Dove, Celene Fuller, Todd Jones, Kaeley Loskutoff, Lenny Moss, William Ramsey, James Spady, Stefen Starner, and two anonymous readers for the journal. My apologies for any omissions from this list. All errors are my own. This paper is dedicated to the memory of Joseph Margolis (1927-2021), who first introduced me to the phrase “natural artificiality” and the work of Marjorie Grene. [↑](#footnote-ref-47)