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Naturalness in the Making: Classifying, Operationalizing, and Naturalizing Naturalness in Plant Morphology

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Abstract

What role does the concept of naturalness play in the development of scientific knowledge and understanding? Whether naturalness is taken to be an ontological dimension of the world or a cognitive dimension of our human perspective within it, assumptions of naturalness seem to frame both concepts and practices that inform the partitioning of parts and the kinding of kinds. Within the natural sciences, knowledge of what something is as well as how it is studied rely on conceptual commitments. These conceptual commitments shape how entities and processes are categorized *as* natural depending on how naturalness has been understood within that discipline. In this paper, I explore how commitments to naturalness shape different conceptualizations of what were previously and what are now considered to be fundamental parts in plant morphology. Relying on an historically informed epistemological approach, I trace the origins and development of models of plant morphology from (1) Goethe's classical LEAF-ROOT-STEM archetype model; (2) Agnes Arber's revisions to Goethe's model reconceived in her partial-shoot theory of the leaf; and (3) Rolf Sattler's proposal for a processual model of plant morphology. These influential models posit ontologically and epistemologically inconsistent conceptualizations of the natural fundamental parts of plants and how they are related to each other. To explain what this inconsistency means for the concept of naturalness and the role it plays in plant morphology, I suggest naturalness might best be conceived of as a contextually bound classificatory concept that is made and remade through its operationalized use within a model, theory, set of practices, or discipline.

Keywords Natural · Naturalness · Conceptual commitments · Agnes Arber · LEAF-ROOT-STEM model · Rolf Sattler · Ontologizing practices · Historical epistemology · Philosophy of plant morphology · Kinding · Operationalism

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1 What is Naturalness?

Answering the question, What is naturalness?, seems to require us to define what it means to be "natural" or at least what is "nature". However, these terms may privilege certain notions of nature and natural in ways that may depend on what is intended as well as the investigator using these terms. Attempting to avoid these definitional challenges, we might instead start by distinguishing between different dimensions of naturalness. We might then ask a different question:

> 1A: How do we distinguish between ontological dimensions of naturalness and cognitive dimensions of naturalness?

This poses a seemingly easier question to answer than the original. Ontological accounts of naturalness take naturalness to exist in the world. That is, for some entity, process, or classification to be natural is a property of the way the world is structured. On this account, the existence of naturalness, natural kinds, and natural partitionings is mind independent. To be natural is to then correspond to the way the world is structured according to its actual partitionings – a world structure that excludes the influence of human scientific activity or the influence of their epistemic aims. Natural classifications are based on kinds that are real and not conventional, as Mill explains: "in so far as natural classification is grounded on real kinds, its groups are certainly not conventional; it is perfectly true that they do not depend upon an arbitrary choice of the naturalist" (Mill, 1843: 720).

The contrast class of this ontological naturalness is often taken to be cognitive naturalness. Cognitive accounts of naturalness take the naturalness of some entity, process, or classification to be determined by the mode of investigation or aims of the investigator. On the cognitive account of naturalness, the property of naturalness, the existence of natural kinds, and the identification of natural partitionings are framed by the aims and purposes to which their naturalness is attributed. To be natural is to correspond to the way the investigator takes the world to be structured according to their presumptions and partitionings of it. As such, knowledge of the world's structure is ineliminably shaped by human scientific activities and epistemic aims. Natural classifications and natural kinds are understood and treated as natural by knowers through their knowledge-making and "ontologizing" activities.

> "the naturalness of natural kinds is revealed in how they are used, discovered, or made. This shifts metaphysical inquiry of natural kinds from the contents of the world to the activities of partitioning, conceptualizing, comparing, and categorizing—that is to *ontologizing* practices" (Kendig, 2016a:3).

Following Kendig (2016a), naturalness can be understood in terms of how it has been ontologized where ontologies are taken to be made and revised by those studying and interacting with them rather than exemplifying a way of being that exists apart from knowers' investigative interactions. While Kendig (2016a) attempts to preserve a notion of naturalness that is metaphysically grounded in the activities of partitioning and categorizing, metaphysical grounding may not always be necessary. If the concept of naturalness can be operationalized—as Bridgman suggests all concepts can—it should be treated “as being synonymous with the corresponding set of operations” (Bridgman, 1927:5) that are used in its detection or discovery. This means that the concept of naturalness can be treated as the set of operations that are employed in the identification of naturalness in order to explain the practices of scientists using the concept. Chang (2007, 2022), a Bridgman inspired operationist, fleshes out how conceptualizations become operationalized within scientific practice. In *Realism for Realistic People*, he explains how conceptualizations are operationalized through aim-oriented coherent activity:

> “Operational coherence consists in aim-oriented coordination. A coherent activity is one that is well designed for the achievement of its aim, even though it cannot be expected to be successful in each and every instance…it consists in doing what makes sense to do in specific situations of purposive action” (Chang, 2022: 40).

The coordinated aim-oriented design on which operational coherence rests does not provide, in itself, any judgement on whether the aims themselves are suitable or fit for purpose. While operational coherence provides a useful means by which to evaluate the quality of knowledge and concept use, it seems like more is needed to assess this coherence as conducive to knowledge-seeking. Chang cautiously points out in the above, that coherent activity “cannot be expected to be successful in each and every instance”. But we might reasonably want to know how it can be at least a sometimes reliable condition for success. Chang’s answer is of course, that it is “well-designed for the achievement of [intended] aims”. But this seems to require that we also attend to the scientist’s intentions and ontological commitments. Attending to these may be necessary if scientists’ intentions and ontological commitments play an important role in knowledge-seeking. That is, if they contribute to scientists’ viewing a set of activities as coherent, judging the aims to be well-justified, or deeming appropriate a certain form of coordination necessary for achieving these aims.

For Chang, operational coherence can be relied upon to adjudicate between different theoretical conceptions. Referents of whichever theoretical conception appear to lead to success should be those that are used. Success as operational coherence puts the usual success of science argument on its head by not assuming what we are setting out to prove. Chang criticizes this unjustified assumption employing an example from the history of chemistry; the now known non-existence of phlogiston. Standard success of science arguments argue that Priestley’s experiments, although coherent, provided no proof that phlogiston was real even though he thought he was experimenting with it. Chang challenges this assumption arguing that phlogiston is real within an appropriate domain (Chang, 2022: 152): “without presuming that our current most popular theories tell us the truth about ultimate reality, how do we *know* that phlogiston [is] *not* real?” (Chang, 2022: 153). The standard success of science arguments privilege the present state of knowledge over past stages in order to judge as unsuccessful the experimental results of past scientists. They only succeed in making their argument for the success of science because they rely on concepts we now know to fail to refer to phenomena or entities (like phlogiston). Success as operational coherence does not just require attending to scientist's intentions and commitments, it also demands that we remain without prejudice when considering the concepts used by all investigators (both current and historical):

> "…here is a thought for the standard scientific realists who put their trust in the argument from success: we should be open-minded and generous to all investigators, by granting reality, provisionally and defeasibly, to the referents of whichever theoretical conceptions seem to lead to success" (Chang, 2022:153).

The naturalness of natural kinds, understood as that which is revealed through scientists' ontologizing practices (Kendig, 2016a, 2020) and the notion of concepts, understood in terms of their operationalization through coherent activities (Chang, 2007, 2022) sets the groundwork from which we might begin to investigate the role of concepts, like naturalness, in scientific practices.

Investigating the role of concepts in scientific practice, I build on both Kendig (2016a, 2020) and Chang (2007, 2022) in explicitly adopting a practice-focused approach to our present investigation of naturalness. Doing so would mean that instead of seeking to define naturalness as a concept which is domain invariant and univocally definable, we instead explore how and in what ways concepts of naturalness have been used, criticized, and reimagined within scientific investigations relying on them. In pursuing this route of investigation, we replace the question "what is naturalness?", with another which is connected to it. The new form of the question originally posed in the heading of this section, now expressing the practice-focused approach, would be:

> 1B: What role does the concept of naturalness play in the development of actual scientific knowledge and understanding?

The replacement treats the question of the concept of naturalness as one that can be investigated in its role as a methodological criterion that has framed empirical constraints of experimental design and knowledge-seeking practices. In doing so, it directs our philosophical investigation of naturalness to the history of its use in science rather than to analytic metaphysical discussion of what is naturalness. Shifting the locus of investigation to the role naturalness plays in scientific practice requires knowing who is using the concept, what are they doing with it, how are they applying it, and within what context, domain, or discipline is it being employed. To attempt to answer the revised question (1B), an investigation of how naturalness has been relied upon in generating scientific knowledge is needed. In order to study the role played by naturalness in shaping knowledge-seeking practices, we begin by turning briefly to general biology to inquire into its use in partitioning parts from wholes. Following this, we explore the role played by naturalness within the discipline of botany and in particular plant morphology.

2 What is a Natural Part of Something?

If we say of something that it is a natural part of something else, reference to its parthood is usually thought to be metaphysically grounded. Knowing that *x is a part of y* explains some relevant feature of the natural phenomena of which it is thought to be a part. Biologists Daniel McShea and Edward Venit define a natural part as something that:

> "is both integrated internally and isolated from its surround[ings] … [components that] may be spatially distributed [such as] a hormone-mediated control system or a local population of crickets chirping in synchrony" (McShea & Venit, 2001: 262).

The concepts PART and WHOLE play important and interdependent roles in biological understanding. Within scientific investigations, these concepts furnish specific abilities to cognitive agents, for instance, the ability to identify the compositional structure of a particular biological system or infer phylogenetic relationships among individuals. As such, the knowledge gained from the partitioning of natural parts often depends on what role the parts play in an explanation referring to them.

Within disciplines in the natural sciences, knowledge of what something is as well as how we should interact with it rely on conceptual commitments to what is conceived of as naturalness in that discipline. These conceptual commitments affect how certain entities and processes are categorized in terms of their possession of a quality or state of being natural.

Taking an historical approach, I examine how conceptions of naturalness have served as organizational concepts in shaping botanical knowledge in defining parthood relationships and morphological topology in (1) Goethe's LEAF-ROOT-STEM archetype-based model; (2) Agnes Arber's developmental model of the leaf as a partial-shoot; and (3) Rolf Sattler's processual model of plant morphology.

2.1 Compositional Metaphysics in Plant Morphology

Given the significant role naturalness plays in the partitioning of parts and wholes and in biological explanations relying on these parts and wholes, we might want to investigate how these conceptions come about, how they are revised over time, and how they guide other concept-based activities. Investigating these questions, I track the development and use of naturalness within partitioning practices. Investigating the role played by naturalness, the purpose of the present discussion is to trace how the concept of naturalness and natural partitionings came into being within plant morphology. Adopting an historically informed epistemological approach[1] provides a critical method to understand both past and current usage of naturalness as it reveals

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[1] Historically informed epistemology has been pursued in at least three different ways: (1) Employing historical case studies as test cases for general philosophical principles, (2) as an history of epistemology, (3) tracing the development and origin of certain epistemological concepts (Schickore, 2011: 326–327). In the present paper, following Schickore, I adopt the latter approach, what she has also referred to as an *historicized epistemology.*

how commitments to naturalness have shaped knowledge through the conceptual commitments held within specific biological domains.

2.1.1 Goethe's Classical LEAF-ROOT-STEM Model and the Archetype Concept

I begin by focusing on the origins of what is widely referred to as the *classical model* in plant morphology. The classical model presents a general topology of seed plant morphology. According to it, seed plants ('spermatophytes'), such as fruit trees, grains, vegetables, and flowers, are understood to possess a common structure composed of three distinct parts: LEAF, ROOT, and STEM. These organ categories fix the positional relationships of each of the organs within the plant's generalized structural body plan or *Bauplan*. The origins of the LEAF-ROOT-STEM model can be traced back to Johann Wolfgang von Goethe. Goethe describes his metaphysical finding that "everything is [a] leaf" (in a letter to Charlotte von Stein in 1787) following his studies of the shape and form of seeds and seedlings of flowering plants. In doing so, he initiated the conceptual basis on which the classical model was developed. Goethe expanded on his claim that "everything is a leaf", in *The Metamorphosis of Plants*, by explaining how the diversity of form in plants that he observed can be unified under a generalized model that captured the shared morphological features of all plants—the seed leaves, foliage leaves, bracts, sepals, petals, stamens and carpels—as all "essentially the same" (Goethe, 1790). For Goethe, LEAF was a natural conception grasped through empirical observation and characterized in terms of "the process by which one and the same organ presents itself to our eyes under protean forms, as a metamorphosis of plants" (Goethe, 1790: 4, translated by Arber, 1946: 91). Plant morphology was fundamentally conceived of in terms of a concept of the archetypical flowering plant that Goethe refers to as the *Urpflanze* (Goethe 1787). This archetype concept informed the fundamental topological structure of flowering plants as well as the relationships between leaf, root, and stem. For Goethe, these fundamental morphological parts, or organ categories, were distinct from one another. According to the LEAF-STEM-ROOT model, an organ must either be a root or a stem or a leaf. Organ categories were mutually exclusive (Goethe, 1790). For instance, considering Goethe's type appendage LEAF and STEM, this meant that a plant stem bears leaves of different types which are comparable to one another but nonetheless belong to a different organ category than the stem.

While Goethe's classical LEAF-ROOT-STEM model was widely adopted, there has been continued discussion over what kinds of morphological parts, or organ categories, should be considered as the fundamental natural organ categories. For instance, plant morphologists have asked, why are flowers and shoots not included as fundamental natural parts as well as leaves, roots, and stems? In addition to questions concerning what should and should not be considered fundamental natural parts, debate over what is the nature of the relationship that exists between parts also continues. Is the relationship between fundamental morphological parts one of mutual exclusivity as Goethe maintained, or is the real relationship one of potential overlap with the other organ categories? If the LEAF-ROOT-STEM model is maintained, where do flowers and shoots fall? Are they intermediates between the fundamental parts? Tracing how the natural fundamental morphological parts and their relationship with each other was reconceived, subsequent sections of the paper trace the conceptual contributions of two successor theories to Goethe's LEAF-ROOT-STEM, model of plant morphology. Arber and Sattler provide alternative models to the classical model that rely on conceptualizations of the natural fundamental parts of plants that are both ontologically and epistemologically distinct from those relied upon by Goethe.

2.1.2 Arber's Partial-shoot Theory of the Leaf and the Dynamic and Fuzzily-bordered Nature of Plant Life

British botanist and natural philosopher, Agnes Arber, analyzes the role played by the type concept in Goethe's classical model operationally. She argues that for Goethe, type is used as a mental tool for the purpose of imposing order on the disorderly phenomena observed in nature, "the type concept is essentially mental—an intellectual instrument wherewith the mind brings order into the variegated manifold of phenomena" (Arber, 1950: 68). Critical of Goethe's commitment to the essential discontinuity of the leaf and stem, she writes:

> "the notion that leaf and stem are ultimate and discrete units of the plant body, is indeed of great antiquity; it was fostered, no doubt, by the observation of autumnal leaf-fall, which was taken, not unnaturally, to indicate an essential discontinuity between the leaf and the axis which bore it" (Arber, 1950:70).

Arber sought to revise the classical LEAF-ROOT-STEM model by replacing Goethe's conceptual commitment to the archetype and the mutual exclusivity of organ parts with conceptual commitment to the developmental nature of plant growth and of plant morphological forms. Arber's (1950) dynamic approach to morphological categories, outlined in *The Natural Philosophy of Plant Form*, focuses on the process of continuous morphogenetic change over a plant's development.

Rather than explaining plant morphology in terms of Goethe's LEAF-based model and the mutual exclusivity constraint characterizing the relationship between LEAF, ROOT, and STEM, Arber conceived of these structural categories as concepts with blurred boundaries which did not respect the clear-cut borders of organ categories of Goethe's LEAF-ROOT-STEM model. Challenging the rigidly defined morphological organ categories defined typologically, Arber offers empirical evidence for a more unified analysis of plant morphology. Employing her dynamic account of the nature and processes of continuous morphogenetic change, she reconceptualizes the underlying natural causes of the resultant morphological categories initially conceived of by Goethe as typologically derived. Whilst Goethe's LEAF-ROOT-STEM categories were derived from his archetype model, Arber's natural plant part categorizations arose as a result of plants' constant and processual "self-maintenance" exemplified in their repetitive patterns of growth over time (Arber, 1950: 77).

Arber effectively operationalizes Goethe's typified organ categories in a way that is informed by the nature of plant development. She argues that plant morphological parts are not archetypical but the result of the dynamic nature of plant life which she understood to be typified by repetitive branchings over the life of the plant: "the plant in endeavoring to preserve in its own being, repeats that being time after time, each daughter shoot or root becoming, in its turn, a parent shoot or root" (Arber, 1950:78). Seeking to explain the cause of this repeated branching, she suggests that it is the result of the plant's "urge towards whole-shoot characters" (Arber, 1950: 78).[2] In doing so, Arber also translates Goethe's discrete, mutually exclusive, types into continuous developmental stages of the plant's life cycle. Part-part and part-whole relationships of the plant express very different relationships of parthood than those characterized by Goethe's mutual exclusivity claim, owing to the developmentally liminal nature and identity over time of plant parts in the course of their development. For instance, in terms of the compound leaf, "the leaflet stands in the relation of part to whole, but it is also the equivalent of the compound leaf as a whole, in another generation" (Arber, 1950: 142). Parsing the different relationships of sameness that exist when comparing the anatomical parts of one organism at one time with different parts of the organism at a different time, Arber argues that assessing these sameness relationships does not require commitment to Goethe's archetype. The cause of the sameness of parts is due to the developmental nature of plant growth. Relationships of sameness depend both on how parts are partitioned at different developmental stages and how they are causally related to the wholes of which they are a part.

Rather than the natural basic categories being defined in terms of the classical LEAF-STEM-ROOT model, Arber argues that the stem-and-leaf complex or shoot is the natural basic category of plant morphology. This formed the basis of her partial-shoot theory of the leaf: "the leaf is a partial-shoot, revealing an inherent urge towards becoming a whole-shoot, but never actually attaining this goal, since radial symmetry, and the capacity for apical growth suffer inhibition" (Arber, 1950: 133). For Arber, because LEAF and STEM are only conceivable in light of the other and in relation to the SHOOT, the most natural account of leaves is to conceive of them as partial shoots. Leaves and stems are parts of the whole plant body only insofar as they are parts of the shoot: "the leaf is a partial-shoot, [with] an inherent urge towards becoming a whole-shoot…just as the naked stem is a part of the shoot in which leaf development is in abeyance" (Arber, 1950: 78–79).

On Arber's partial-shoot theory, plant morphological structures were not Goethean ideal forms grounded in conceptual commitments to the plant archetype and metamorphosis, but processes at different plant developmental stages that grounded in the principle of repetition in plant growth. In *The Mind and the Eye: A Study of the Biologist's Standpoint*, Arber (1954) reflects more directly on the role played by scientists' conceptual commitments and theoretical implications of these in directing their choice of what to study and what to describe in their research. Emphasizing the ineliminability of these commitments within scientific investigation, she argues the

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[2] Arber explains what this urge means later in Chapter VIII in terms of the continual developmental urge and frustration of that urge in growth: "a typical leaf is a shoot in which the apex is limited in its power of elongation and in its radiality. The failure in lengthening arouses a tripartite character in the leaf, because the frustrated growth of the tip seeks to compensate itself by diversion into a basal branch on either side; while the failure in radicalness, brought about by inactivity on the adaxial face of the tip, induces a dorsiventral character, though a residual urge towards the radiality of whole-shoot-hood also persists" (Arber, 1950: 125–126).

science of plant form is best conceived of as ultimately being the science of the phenomena of plant form as viewed through scientists' conceptualizations of it:

> "*what* is to be described is not fortuitous, but demands preliminary selection, involving theoretical implications; otherwise observers would be lost in a chaotic nightmare of phenomena clamouring on all sides for their attention…every description exists on a background of biological theory, to which it is intimately related" (Arber, 1954: 9).

Both the investigators' choice of research object and the model chosen for investigation rests on the initial conceptions that were relied upon in that particular field of study, and the reconceptualization of these by later investigators; the initial definitions of scientific terms, and the revision of these; as well as the intended referents of these reconceptualizations and redefinitions. Arber is quick to point out that this does not always mean that knowledge is increased in the history of reconceptualizations and redefinitions. Repurposing "leaf$_{\text{sci}}$" as a scientific term with new definitions as set out in the classical model results in the narrowing of the range of referents intended by the scientific term, e.g., strictly defined leaves with clear boundaries and in particular topological position are only those that qualify as leaf$_{\text{sci}}$ and not those structures that were in the wrong position, primordial leaves, leaf rudiments, young leaves at the shoot apex, leaf stalks:

> "such ancient folk-names as 'leaf', 'seed', or 'root', each covers a much wider field in the mother tongue than when used in a strictly botanical sense; scientifically a grain of wheat ceases to be a 'seed', and a rose leaf is not a 'leaf'. The meaning of a word which becomes a scientific term may be reduced in depth" (Arber, 1954: 54).

The problem Arber describes in the above passage—that the narrowed range of intended referents captured by the scientific definition of leaf$_{\text{sci}}$ excludes the range of referents intended by the colloquially defined "leaf$_{\text{col}}$"—is one she tries to resolve in her developmental redefinition of the "leaf$_{\text{dev}}$" as a partial-shoot in the process of growing. Rejecting both Goethe's narrow scientific definition of "leaf$_{\text{arc}}$" as well as the conceptual grounding on which it rests, Arber introduces a broader scientific definition of leaf$_{\text{dev}}$ grounded in a developmental reconceptualization of the basic morphological parts.

2.1.3 Sattler's Continuum Model of Plant Topography and the Processual Metaphysics of Plant Morphology

Despite sustained criticism of it, the classical model continued to shape thinking within plant morphology in the decades following Arber's proposed partial-shoot theory of the leaf. Leaves, roots, and stems continued to be treated as the natural and fundamental morphological parts of plants. Textbooks maintained the LEAF-ROOT-STEM conceptualization of plant morphology: "Roots, stems and leaves are the only vegetative organs of vascular plants. All other plant structures are modifications of one or another of these" (Greulach, 1973: 488). Research papers approvingly described the classical model as an "organizational ground plan" for vascular plants and continue to uphold the rigid tripartite model of plant structure: "the shoot bears leaves as lateral appendages and the root bears no leaves, just endogenously initiated lateral root branches" (Kaplan & Hagemann, 1991: 695). Recent textbooks reaffirm commitment to the classical model. They argue that the discontinuous organ categories facilitate identification of new structures by defining their positions with respect to the three discrete organ categories: "organs in plants are defined principally by their topographic-positional relationships", (Kaplan, 2022: 265).

The classical LEAF-ROOT-STEM model has remained in use despite having several well-known disadvantages. As Arber maintained, many of these disadvantages have to do with how shoots are characterized according to the classical model, e.g., shoots *qua* shoots do not exist because the model does not permit intermediate structures. Any organ that appears to be intermediate must be reinterpreted and recategorized as being either a stem, leaf, or root, e.g., shoots and flowers, must be interpreted as being structures composed of the stem (the floral axis) and the leaf (floral appendages) (Arber, 1950, cf. Weberling, 1981).

Drawing substantially on the history and philosophy of plant morphology and from the conceptualizations of it offered by Goethe and Arber, botanist Rolf Sattler investigates the role played by the metaphysical commitments relied upon to justify the partitioning of natural parts in the classical model. In his monograph *Biophilosophy*, Sattler writes, "although it is possible that a less general proposition, such as the statement that all trees have leaves, might be formed inductively, the invention of a generalization with the scope of [Goethe's] classical model required intuition and imagination" (Sattler 1986: 103). Goethe's classical model connected seed leaves, foliage leaves, bracts, sepals, petals, stamens, and carpels as all "essentially the same" (Sattler 1986: 103). The classical model was not the result of empirical study but was grounded in essentialism and commitments to an idealized model of natural plant parts, organ categories, and plant topology. This essentialism continues in plant morphology: "the phrase 'the true nature of an organ' and other essentialist expressions are still used by the majority of modern plant morphologists" (Sattler 1974: 369).

Resisting reliance on both essentialist expressions and the assumption of organ discontinuity underpinning the LEAF-ROOT-STEM model, Sattler suggests a revision to the classical model intended to accommodate the possibility of intermediate structures as well as provide a solution to its prohibition on positional changes in organs. Relying instead on Arber's dynamic and conceptually fuzzily-bordered structural categories, Sattler contends plant morphological topology is not best understood by assuming organ categories are essentially discontinuous in nature. Empirical analysis of the morphology of flowering plants of the riverweed family, Podostemaceae, the asparagus family, Asparagaceae, and many others, he argues that organ categories are more accurately described as being continuous in nature. Sattler replaces the classical model with his own continuum model, a processual model of plant morphology based on Arber's partial-shoot theory of the leaf and her developmental approach to plant organ categories, which allowed for both intermediate organs and changes in position:

> "the shoot may consist of the following parts: shoot, caulome, phyllome, root, emergence, and structures intermediate between any of the preceding…and are no longer mutually exclusive; they may merge into each other…Besides intermediate forms, all changes in position are accepted as such" (Sattler 1974: 367).

As the earlier discussion of her partial-shoot theory showed, Arber was keenly aware of the liminality of organ boundaries in plants. In her own work on the genus *Utricularia*, she warns,

> "the attempt to fit so elusive a genus into the Procrustean bed of rigid morphology, is doomed to failure. It is probably best, as a purely provisional hypothesis, to accept the view that the vegetative body of the *Utricularias* partakes of both stem nature and leaf nature" (Arber, 1920: 107).

For Sattler and others, observations of the primordium in riverweeds, such as bladderworts (*Utricularia spp.*) reveal that "developmental and positional constraints in *Utricularia* deviate considerably from the rules used in classical morphology…and may be better understood within the conceptual framework of Arberian morphology" (Rutishauser & Isler, 2001: 1194).

Despite the suggestion for a more continuous model of plant organ morphology and positional topology, Sattler goes on to concede that his version is still just a revision on the old metaphysics assumed in the classical model, arguing that even his new account is really nothing more than a modification of, or further extension to the classical model in that it retains the general tripartite structure but simply removes the provision that organ structures be mutually exclusive (Sattler 1974: 378).[3] Like Arber's partial-shoot theory, Sattler's continuum model also proposed accounts of organ structures as intermediates by explicitly relying on Goethe's classical LEAF, ROOT, STEM typology. In doing so, both attempted to reconceptualize a better model reflecting the real nature of plant morphology that was, like Goethe's, not arbitrary (1986:118). Later critical amendments to the classical model are also framed as those that better represent "the developmental and positional constraints [of] plant bodies" (Rutishauser & Isler, 2001: 1194). Revisions are intended to improve the classical model insofar as they better characterize natural partitionings and the topological structure observed through empirical investigation. Revisions to the classical model have focused on: (1) revisions to how the topology is grounded, (2) revisions to which *a priori* commitments are conceived of as natural and necessary for a generalized model, (3) revisions to the number and type of conceptual categories of organ structures that should be included in the taxonomy, (4) revisions to what is considered the nature of the natural topology that should be used, and (5) revisions to which sorts of empirical observation can be considered as those that adequately serve as evidence for retaining the generalized account.

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[3] While Sattler humbly suggests his view is just a loosened-up version of the classical model. That is, one that allows for both non-mutual exclusive relationships between organ categories and variable organ positions. He claims that this looser model should be adopted as these changes have important epistemic and metaphysical consequences for our understanding of the nature of plant morphological categories and are of "profound importance for morphological research" (Sattler 1974: 378).

Sattler's suggested revision to the number and type of conceptual categories of organ structures that should be included in the taxonomy for his continuum model include the SHOOT, CAULOME, PHYLLOME, and TRICHOME as the basic morphological parts categories.[4] These effectively map out the conceptual topology in such a way that intermediate parts concepts are then filled in:

> "Each of the four concepts [SHOOT, CAULOME, PHYLLOME, and TRICHOME] functions as an injunction so that any individual structure that occupies the space between the four points can be a partial member of two, three, or four [of them]. For example, structures occurring on the leaves of *Begonia hispida var. cucullifera* may belong 100–0% to the leaf class and 0–100% to the trichome class. In other words: some are leaves, others are hairs (trichomes), and still others are intermediate between leaves and hairs (trichomes)" (Sattler 1986: 123).

If Sattler's and Arber's revisions are intended to offer us a better understanding of the real nature of plant morphology and organ positional topology, what role does the concept of naturalness play in these revisions? Put another way, what role does naturalness play in constraining the number and type of organ categories or whether they admit of intermediates or follow a strict tripartite pattern? I suggest, whether one relies on Goethe's original classical model, Arber's developmental model, or Sattler's continuum model, all models rely on a partitioning of parts that is, by virtue of the model being applied, constrained by natural phenomena. The difference in how these constraints are felt, understood, and interpreted by investigators varies with the model they use. In each model, the partitioning of the morphological parts relies on the natural partitioning of nature. However, each offers a different set of conceptual commitments by which to understand features of the empirical world as natural. Depending on the model, naturalness may be identified in terms of discrete morphological categories that are mutually exclusive and nonoverlapping, or continuous.

Sattler notes, "quite often the 'nature' of an organ is determined first, and then evolutionary inferences are drawn from this interpretation" (Sattler 1974: 370). Whether the entity identified as a leaf is accurately identified as a leaf is constrained by the concept of LEAF in the model used, its relationship to the object in question and the metaphysical commitments underpinning the concept LEAF. Partitioning of a part of the plant as a leaf relies on both ontological and cognitive notions of naturalness. What is considered a separate part of a union of two parts depends on what the morphologist considers to be separate and the concepts they rely on to "mentally dissect" wholes: "How is it determined that a whole consists of parts growing together? This is done by mental dissection. How does the morphologist decide in which way to mentally dissect a whole? This is done at least to some extent, on the basis of the classical model (if the morphologist is a classical morphologist)" (Sattler 1974: 370).

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[4] Sattler argues that by relying on this lowest level of classification, all other concepts, e.g., SYMMETRY, GROWTH PATTERN are possible (Sattler 1986: 122–123).

3 Naturalness in the Making

The conception of natural fundamental parts has played a central role in the science of plant form. Commitments to there being natural fundamental parts shaped all three models of plant morphology discussed above. Scientific research relies on these models to partition whole plant bodies into their natural parts and identify the real relationships that exist between them. This means that the accuracy of research conclusions employing these partitionings depends on the imputed naturalness of their parts conceptualizations as well as on how these have been employed in scientific investigations.

So, one might ask, what does the historically informed epistemology of past and current commitments to naturalness that informed Goethe's classical model and Arber and Sattler's revisions to it really reveal about the role played by naturalness? Firstly, the investigation into these models revealed that what was considered a natural part is determined by what model one employs which in turn grounds the partitioning practices one uses. Secondly, the investigation also revealed how what had been conceived of as natural in each model depended on an underlying ontological commitment. In the LEAF-ROOT-STEM model, this ontological commitment was to the archetype as a generalized model of plant form; in the partial-shoot theory of the leaf it was to the dynamic and developmental nature of plant life; and in the continuum model, it was to a fuzzy metaphysics of plant morphology.

What do we gain by shifting our attention from the natural part to the making and remaking of its naturalness? In the remaining, I show how focusing on how morphological models make, remake, or reimagine natural parts reveals a new set of questions open for investigation: How are natural parts identified according to this morphological model?, How are natural parts identified, tracked, and counted differently using different models?

Answering these questions requires that we pay attention to the conceptual commitments and models relied upon in the work of practicing scientists. These conceptual commitments provide information about parts and wholes in relation to the investigator and what the investigator already understands about the system being investigated. Within a particular investigative scenario, the investigator directs their attention to the plant parts and wholes (as they conceived them to be, *qua* plant parts). The perception of the naturalness of parts and their relationship to the whole plant is also a relationship that includes the investigator, the morphological model directing the partitioning, and the object of investigation. Pushing this even further, I would argue that both ontological and cognitive dimensions of naturalness frame access to how the world becomes known to the investigator at least in the case of plant morphology. What this means in scientific practice is that whether an investigator takes some thing, process, or pattern to be natural is often partially determined by the model they use. To make the connection between the ontological and cognitive dimensions of naturalness in plant morphology even more explicit, I would restate this as:

> 2 A: Investigators' assessments of the ontological naturalness of part *x* rely on their cognitive notions of naturalness of that part expressed by the model *y* they employ for its partitioning.

The position stated in 2A might be appropriately described as a model-mediated perspectival approach to naturalness. On this approach, naturalness is something that is not so much made through the model the investigator adopts but is made and remade in its repeated use and revision within plant morphology. This repeated use and revision is informed by the purpose for which the investigator is seeking to partition parts as natural. Being made and remade in its use within plant morphology, naturalness could be said to be *naturalized* when its meaning is defined in terms of its use within an investigative project.

What does describing naturalness as a property that can be naturalized tell us about scientific knowledge-making activities like partitioning or kinding? Naturalizing naturalness would describe a process by which a concept of naturalness becomes associated with or treated as, natural. This association includes appropriate empirical indicators of naturalness as it is conceived of within a particular scientific discipline. It is a process that includes the activities investigators need to use to find, represent, or measure naturalness using the empirical evidence identified as indicative of it. Critical reflection on the historically informed epistemology of the role naturalness played in successive revisions to models of plant morphology provides the basis of my analysis and the approach I suggest. If what we are interested in is the nature of naturalness, understanding of it would seem to necessitate that we attend to the activities involved in the making and remaking of naturalness in the field in which it is used. This short discussion of naturalizing activities was intended to capture how the ontologizing principles botanists rely upon to partition parts in current and past investigations are embedded in the models they rely upon to do so. Goethe's archetype-based LEAF-ROOT-STEM model, Arber's developmental partial-shoot theory of the leaf, and Sattler's processual continuum model each conceive of putative natural relationships of plant morphological parts in ontologically and epistemologically inconsistent ways. Whether natural parts are conceived of as those essentially bearing a relationship of mutual exclusivity or a processual continuum that admitted of intermediates, commitments to naturalness played different conceptual roles and informed different operationalizations of it within the history of plant morphology as well as within current practice. We are now in a position to return to attempt to answer the question posed at the beginning of this paper—what is naturalness? Critical reflection on the use made of the concept in the various models of plant morphology allows us to respond. Naturalness can perhaps best be described as a contextually-bound classificatory concept that is made and remade in its operationalized use within a model, theory, set of practices, or discipline.[5]

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[5] My conclusion about the role of naturalness might also serve as a necessary condition for other classificatory concepts that are made and remade. For instance, *mass* may also be best conceived of as a contextually bound classificatory concept that is made and remade through its operationalized use within a model, theory, or set of practices. Many thanks to an anonymous reviewer for this suggestion.

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Declarations

Competing Interests The author declares that they have no conflict of interest.

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