Narrative spaces in the representation and understanding of evolution[1]

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“I'm not used to reading diagrams or whatever. I'm a Music major.”

“I'm sure the Biology department is shuddering right now at what I'm saying.”

–Undergraduate students reading a cladogram

1 A problematic representation

As scientists continue to learn the extent of life’s diversity, their representations, too, are changing (Pennisi, 1999, 2003). Far from 19th century metaphors of a tree of life (Archibald, 2008; Hoenigswald & Wiener, 1987), modern phylogenetic diagrams better capture the complex of patterns of speciation and common ancestry. Cladograms are one such kind of branching diagram used to represent phylogenetic relationships among species, and are essential to reasoning in evolutionary biology (O'Hara, 1988). Used both as vehicles and tools for the creation, development, and exchange of knowledge, cladograms have been instrumental in such feats as tracing the viral histories of emergent diseases (Crandall, 1999), prioritizing species conservation efforts (Hendry, et al., 2010; Mace, Gittleman, & Purvis, 2003), and in one case, even helping to solve a murder case (Metzker, et al., 2002). Although many state education standards do not require explicit training in phylogenetics, cladograms appear in both formal and informal environments across branches of biology (Baum & Offner, 2008; Catley & Novick, 2008; MacDonald, 2010). The importance of understanding these representations is becoming increasingly apparent. In response, a growing community of researchers is urging that

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cladograms should figure into the visual lexicons of any scientifically literate person (Baum, Smith, & Donovan, 2005).

However, students' well-documented errors with reading cladograms are problematic (Catley, Novick, & Shade, 2009; Gregory, 2008; Meir, Perry, Herron, & Kingsolver, 2007; Novick & Catley, 2006; Novick & Catley, 2007; Novick & Catley, 2009; Novick, Shade, & Catley, 2010). They demonstrate that similar to other expert representations, cladograms can present cognitive challenges to novices (Baum, et al., 2005; Lehrer, Schauble, Carpenter, & Penner, 2000). Among other skills, understanding scientific representations requires an ability to connect those representations to the relevant concepts of the discipline (Linn, Chiu, Zhang, & McElhaney, 2009), but the consistency of errors observed among novices – and even among some professionals (Baum, et al., 2005) – highlights the additional influence of visual design on students' interpretations. That the kind of representation can greatly impact how and what students learn (Ainsworth, 2006; Cromley, Snyder-Hogan, & Luciw-Dubas, 2010) means that both the interpretation and the design of visual representations have important implications for science education (Cheng, 1999). Just as educators must reconsider how they present the cladogram's underlying concepts, so must designers therefore reconsider how cladograms are designed for textbooks, websites, museums, and elsewhere. Undertaking this task requires that we first understand *why* and *how* cladograms are misinterpreted.

Prior research on students' interpretations of phylogenetic trees provides useful guidance for answering these questions. It also opens further issues to be addressed. For example, science educators have extensively catalogued common reading errors in undergraduate students' interpretations of phylogenetic trees (Gregory, 2008; Meir, et al., 2007); but what are the reasons for these errors? Qualitative researchers have documented rich descriptions of undergraduate students reasoning in a systematics course (Halverson, 2009; Halverson, Abell, Friedrichsen, & Pires, 2009; Halverson, Pires, & Abell, 2008); but what are the specific factors in interpretation, and how do these interact? Meanwhile, experimental researchers have carefully isolated and observed effects of different diagrammatic features, such as format and configuration, and of students' prior coursework experience on their correct responses to questionnaire items (Novick & Catley, 2007; Novick & Catley, 2009; Novick, et al., 2010; Sandvik, 2008; Shade, 2008). Importantly, this work shows the contribution of perceptual structure to students' errors reading cladograms. But what processes of meaning-making might their measures have concealed? Although each of these prior efforts helps identify processes involved, it is only with a more complete picture of interpretation that we may inform an effective redesign of this problematic representation. For this, we must better understand the role of the cladogram's particular visual structure in its interaction with students' prior knowledge of evolution.

In this chapter, we argue that students' reading errors with cladograms are rooted in popular folk theories of evolution, and that both can be traced to a cognitive bias toward narrative structure. Beginning with the notion of interpretation as an interaction between the representation and viewers' prior knowledge of its content (Kozma, 1991), we describe the cladogram as a syntactic structure that appeals to viewers' intuitive ways of framing their understandings in terms of narrative. Illustrated with excerpts from interviews conducted with undergraduate students, we will ultimately sketch a map of the cladogram's narrative space (Figure 5); that is, a model of how students related the abstract meanings of folk narratives of evolution onto the concrete spaces of the diagram, and so symbolized them as pieces of a story.

Thus explaining misinterpretations in terms of the cladogram's visual grammar, we build upon prior work to create a more complete picture of novice meaning-making. Also by this approach, we begin to derive criteria for the design of a more pedagogical representation: One that would scaffold students' perceptions and guide their developing reasoning skills with the conventional cladogram. We begin this task by outlining a framework of how scientific representations are interpreted.

2 Interpreting scientific representations

Scientific reasoning is based in representations. When mapped onto the concrete spaces of a visual display, abstract concepts such as velocity, mass, increase, and in our particular case, phylogenetic relatedness, become perceptually accessible, and, perhaps, cognitive tractable (DeLoache, 1995, 2004; Lynch, 1990; Uttal, 2005). Such representations allow us to manipulate ideas just as we might physical entities in actual space, and so come to better understand them and their relations to others. By some arguments, it is only through representations that we come to know the world (Wood & Fels, 1992). Unfortunately, conventional representations do not serve as ready-made schemata for expert thinking that students might then internalize as their own. Instead, numerous accounts of misunderstandings have shown that students often come to different interpretations of the same representation, and often in spite of the designer's intentions. As educators across disciplines face the challenge of helping students connect external representations with the concepts intended, one wonders whether expert representations hinder more than they help students learn.

As others have argued, meanings of symbols are situated in their use (Dorfler, 2000; Sfard, 2000; van Oers, 2000). Finding ways to support students' meaning making therefore involves finding ways to engage them in disciplinary practices, by which they know that the senses they construct of expert representations are socially acceptable (Dorfler, 2000). Theorizing interpretation is in essence about finding entry points for students' participation in disciplinary discourse (Dorfler, 2000). It is moreover a task that we undertake in the following sections, that is, to better understand the processes involved in making meaning such that we might more effectively scaffold them.

Any act of interpretation involves a *representation* and a *viewer*. Within each of these, we distinguish two components (Figure 1). The *structure* of the representation includes perceivable features such as lines, shapes, and their spatial arrangement, while its *content* refers to the particular messages intended. The viewer meanwhile, brings a host of *prior knowledge* to the encounter, including conceptual knowledge of the *content*, as well as experience with reading the *representational system*. Mediating the interactions between these elements is *context.* Context establishes viewers' expectations of the representational system and so cues particular sources of prior knowledge. As a result, it directs attention toward certain visual structures over others, and guides construction of the most plausible meanings from among the multitude of possibilities (Guo, 2004; Sfard, 2000).

[Insert Figure 1]

How each of these processes occurs is complex. What is clear, at least, is that viewers dynamically build meaning rather than passively receive it intact from the representation (Fiske, 1990; Lakoff & Johnson, 1980; Sfard, 1993; Sfard & Linchevski, 1994; Sherin & Lee, 2005). Meaning, in other words, is not contained within the representation, ready to be transmitted directly; but neither is the representation a mere conglomeration of marks that only gain symbolic structure through interpretation. Any sense making situation will involve viewers comparing and coordinating the information encountered in the external representation with their prior internal representations of its content (Fiske, 1990; Hegarty, 2004; Schank, 1990). This implies that the meanings to emerge from this coordination will depend as much upon the structure of viewers' internal representations as they do upon the structure of the external one, and each influences the other in a dynamic interplay. In the next section, we apply this general analysis to the particular case of the cladogram.

2.1 Reading cladograms

The diagonal or "ladder" cladogram, the form most common in high school and college textbooks (Figure 2) (Catley & Novick, 2008); it is also the form that presents students with the most difficulties (Novick & Catley, 2007). For experts, the structure of the cladogram and its context as an evolutionary diagram will cue appropriate conceptual associations to their prior understanding of the content. These cues will direct an expert's attention to the symbolically meaningful units of representation, such that they will see time as running upward along a vertical axis; they will understand that all taxa at the branch tips share derived ancestral traits denoted by the nodes from which they extend. They will also recognize that lines can be lengthened or shortened, and branches rotated about their nodes without changing the topology of the relationships depicted (see Gregory, 2008 for a fuller explanation of how to read cladograms.)

Importantly, experts will have learned to see the cladogram as a nested hierarchy of clades: Evolutionary groups that includes a common ancestor denoted by a node, and all its descendants denoted by the branches that extend from the node. Their familiarity with the cladogram's representational system, as well as their grasp of the underlying concepts, allows experts to determine the relative relatedness among species based on membership within clades. By building and reconfiguring these nested hierarchies, experts may communicate theories, test hypotheses, and reason more deeply about those relationships (Kemp, 1999). Reasoning phylogenetically therefore calls upon a confluence of expert skills, including an awareness of the connections between symbols and their relevant disciplinary concepts, an understanding of the representational nature of models (Grosslight, 1991), and a spatial facility to mentally manipulate meaningful units in space (Linn, et al., 2009).

[Insert Figure 2]

As with other such standard notations, the structure of the cladogram is based upon semiotic strategies established through longstanding use and scientific discourse. The result is a recognized set of conventions, socially ratified ways of employing particular visual elements, and manners of combining and arranging them to suggest desired meanings (Guo, 2004). Arguably, the most effectively designed representations not only align visual structures with their intended concepts, but do so in ways that tap into viewers' intuitive manners of interpreting marks in space. For those initiated into the representational practices of phylogenetic reasoning, the cladogram is one such effective design, in which *structure* and *content* are linked toward facilitating expert interpretations. But for novices, who bring alternative sets of knowledge resources to their interpretations, these same representational structures may cue very different kinds of conceptual associations, and so lead to very different symbolizations.

Existing work has identified a litany of such conceptual misunderstandings. Generally, students' tend to believe evolution involves transformative change driven by an underlying purpose toward a determinate goal, and a physical struggle among individuals, in which the strong conquer the weak and along the way, acquire advantageous traits through will and cunning (Larreamendy-Joerns, 1996; Larreamendy-Joerns & Ohlsson, 1995; Ohlsson, 1991; Ohlsson & Bee, 1992). Whether these framings of evolution are attributable to a tendency toward essentialism (Gelman & Diesendruck, 1999), to the effect of teleological thinking (Kelemen, 1999), to the influence of intuitive Creationism (Evans, 2001), or to an innocent slip into a vocabulary of convenience (Zohar & Ginossar, 1998), we believe them to be rooted in the intuitive cognitive architecture of narrative.

Ferrari and Chi (Ferrari & Chi, 1998) allude to this narrative tendency in their explanation of novices' misunderstandings of complex systems. They argue that novices tend to mistakenly categorize certain scientific processes as event-based, and characterized by distinct, sequential, causally linked actions with determinate goals, and so fail to see they are actually equilibration-based processes, characterized by randomness, emergence, and simultaneous, continuous actions. Such equilibration processes are rare in our direct experiences, and so less likely to appear in novice explanations (Larreamendy-Joerns, 1996). Meanwhile, event-based processes appeal to the intuitive tendency to frame experience in terms of narrative, a mode of thought distinct from the academic, logico-scientific mode, which is based in general causes, universal explanations, and testable hypotheses (Bruner, 1990).

Before examining students' reading errors of cladograms, we first consider how narrative structures the prior knowledge novices bring to their interpretations.

3 Narrative

3.1 Our penchant for stories

Telling stories is a distinctly human behavior. We think with and within narrative: As a mental representation, it frames how we interpret our experiences (Bartlett, 1995; Fivush, 1991; Just & Carpenter, 1987; Kintsch, 1977; McAdams, 1997; Nelson, 1980; Schank, 1995); as a design template, it structures the media we encounter in our learning experiences (Ryan, 2004); and as a cognitive heuristic, narrative provides intuitive explanations that are easier to think about than the complexity that exists in reality (Bruner, 1990). Our narrative instinct to seek causal patterns in our surroundings, reason in the events we experience, and purpose in the actions of living and nonliving things, is moreover one that begins early in development (Buresh & Woodward, 2007; Heider & Simmel, 1944; Király, Jovanovic, Prinz, Aschersleben, & Gergely, 2003; Michotte, 1963; Scholl & Tremoulet, 2000). So integral is narrative to cognition that even as we may place these experiences within broader interpretive structures such as frames (van Dijk, 1980), schemata (Bartlett, 1995), and plans (Schank & Abelson, 1977), when our experiences violate our expectations, we construct narratives to explain them (Lucariello, cited in Bruner, 1990). By so structuring the complexity of our experiences, narrative allows us to more easily understand and recall them (Just & Carpenter, 1987; Nemirovsky, 1996).

But although there may be heuristic value to such teleological thinking (Zohar & Ginossar, 1998), we must not disregard its potential cognitive consequences. Because how we frame our experiences determines the meanings we make of them, we must ask what implications this narrative rhetoric has on novices learning evolution. To understand how narrative conveys meaning, we must first examine how it structures it.

3.2 Sense in narrative structure

That language maintains a linear sequence of events in the relation between subject, verb, and object, may alone constrain us to narrative expression (Bruner, 1990; O'Hara, 1992). But scholars maintain there is more to narrative cognition than this. Although definitions vary across disciplines, they generally feature two basic components of narrative (Chatman, 1978). *Content* includes the descriptive structure of narrative (Frye, 1957) Also known as *histoire*, *fabula*, or simply *story* (Forster, 1976; Just & Carpenter, 1987; Wilson, 2003), the content of a narrative includes the events of the narrative, their timing and location, and the actors that participate in them, often toward achieving particular goals (Schank & Abelson, 1977; Wilensky, 1980). *Form*, meanwhile, is the literal structure of the narrative. Also called the *discours* or the *sjužet,* form describes the *way* a narrative is told; that is, how its basic elements are linked into a causal structure or *plot* (Just & Carpenter, 1987).

The plausibility of a narrative depends on the internal coherence of its structure (Fisher, 1985). Moreover, inferring causality and chronology is not only an essential part of general story comprehension (Just & Carpenter, 1987), but it is also the heart of historical and scientific thinking. In these disciplines, explanations are constructed by selecting and placing observed events into a logical sequence with a clear beginning, middle, and end. Interpretations of these sequences occurs through a kind of holistic perception, and how the story created from these pieces resonates with other familiar narratives allows us to easily grasp and to infer new meaning (Fisher, 1984; Landau, 1997).

Narrative structure serves as a useful communicative device across genres and media. Semantically, scientific and historical accounts of evolution are commonly riddled with tendencies toward intentional, goal-direct language of narrative (O'Hara, 1992). However, certain larger narrative themes and structures can also be identified, and which recur in the stories children tell (Bruner, 1990), in the myths that shape cultures and personal identities (McAdams, 1997). These include themes of struggle from lowly beginnings, transformation, and eventual victory against odds, which each figure in the universal narrative archetype of a hero’s journey (Campbell, 2008). From Darwin’s own words, Landau (Landau, 1997) observes one of the more impactful renderings of the human plight as a quest. “Man,” writes Darwin , “may be excused for feeling some pride at having risen, though not through his own exertions, to the very summit of the organic scale; and the fact of having thus risen, instead of having been aboriginally placed there, may give him hope for a still higher destiny in the distant future” (Darwin, 1871) p.405.

But even modern paleoanthropological accounts of evolution have been cast in these narrative terms (Landau, Pilbeam, & Richard, 1982). Although the anthropologists considered in her analysis debated the chronology of the events, Landau identifies a narrative structure common to each of their accounts; and in each of the events named, she recognizes particular narrative functions that correspond to those defined in Propp's analysis of the morphology of folk tales (Propp, 1968).

As Landau observes, these accounts first establish the initial situation (1), usually in an environment among the trees, and introduce the hero as our primitive primate ancestor (2). But a change in environment or within the hero himself, who might acquire an upright posture or a larger brain, for example (3), disrupts the situation and sends him on a journey away from home (4). Once away, the hero undergoes a test of survival in the form of adverse climate or a fierce new predator (5). But just as the heroes of the classic folk tales receive magical gifts from benevolent donors, our hero emerges with the gifts of intelligence and humanity (6). The tools, reason, and morals that these entail leave him transformed from his initial state of deficit (7). After a final test of survival, commonly in the form of the European Ice-Age, the hero triumphs (9). He has conquered the predators and the environment that threatened him, and now revels in the establishment of civilization and newfound moral value.

3.3 *The problem with narrative*

The difficulties with such narrative framings are not just in the details that are lost in translation, but also in the kinds of sense they convey. When told as a story, complex evolutionary processes are reduced to a series of crises. But by their placement relative to one another, these isolated events appear linked by transitions and come to convey meanings beyond those they had initially (O'Hara, Landau). Because it situates explanations upon causes for events and seeks to locate within them the actors and their goals (Norton, 2007), narrative is a language that fails to capture the emergent qualities we know evolution to have.

Folk theories are one instantiation of narrative intuition. These systems of shared popular beliefs, by which people organize new experiences and make sense of the natural world (Atran, 1998; Gopnik & Wellman, 1994; Keil & Lockhart, 1999; Murphy, 2000; Murphy & Medin, 1985; Rips & Conrad, 1989), are in fact those narratives that have persisted over time to pervade public memory. The canonical folk story of human evolution is a distilled version of the expert accounts described above. An idealized story of humans striving from a primitive toward a more "sophisticated" form, it continues to make numerous appearances in contemporary material culture (Clark, 2001; Gould, 1995). In magazines, on coffee mugs, and in advertisements, we see references to the metaphor of a tree of life, to a ladder of creation (Lovejoy, 1936), and to the familiar march from a slouching ape to an upright man.

Part of our argument in this chapter is that the narrative structure typical of *verbal* explanations of evolution is also to be found in the *imagery* of evolution (Gould, 1990, 1995; Gould & Lewontin, 1979; Landau, 1997; O'Hara, 1997). In fact, that students asked to recall images of evolution nearly always produce some variation of the iconic *March toward Man* (Figure 3) does not so much allude to the descriptive power of the image as it does to the appeal of its literal narrative structure. That is, it is not in *what* figures are lined up in a row – whether monkey to human or fish to four-legged mammal – but in *that* each subsequent figure suggests a progression of states and events; and it is not even that the topic is of biological change toward complexity and adaptiveness, but *that* the linear composition suggests a sequence to be read with a beginning and an ultimate goal. Put simply, the *March toward Man* persists as an icon because it tells a good story: One that is simple in its linearity, appealing – the heroes are, after all, us –

and consistent with our cognitive tendencies to seek cause, effect, and purpose in our experiences (Gould, 1990).

[Insert Figure 3]

As such an intuitive mental structure for naïve understandings of evolution, narrative will undoubtedly play a central role in novice interpretations of evolutionary representations. Of particular concern is how this simple linear narrative of a *March toward Man* will influence students learning the complex, nonlinear processes depicted in the cladogram. In the next sections, we consider students' reading errors in terms of their folk theories of evolution, and explain how the cladogram's syntactic structure that cues a narrative mode of interpretation.

Narrative interpretations of the cladogram

Among students' errors is a tendency to read a temporal progression of species across the branch tips and increasing qualities within those species from the bottom toward the top of the graphic space; to use spatial proximity of elements as a measure of their relatedness; to perceive a main evolutionary line that is somehow more important than the side branches that appear to extend from it; and to assume that evolutionary change is represented as strictly occurring at the nodes rather than also occurring along the branches. (Catley, et al., 2009; Gregory, 2008; Meir, et al., 2007; Novick & Catley, 2006; Novick & Catley, 2007; Novick & Catley, 2009; Novick, et al., 2010).

That the errors observed are so consistent across individuals suggests there may be a cognitively natural interpretation of the cladogram; one that depends upon its unique structure, and that interacts in particular ways with novices' understanding of evolution. Indeed, within each of these reading errors, we may identify the narrative themes of the naive folk theories of evolution. The view of evolution as anagenesis, in which new species arise from previous ones through a linear series of transformations, is read in the apparent sequence of states across the branch tips. The perception of a trend toward more complex, sophisticated forms is one that maps easily along the cladogram's vertical axis from the lowest root to the upper branches. Finally, there is the canonical hero's journey that Landau identified in paleoanthropological accounts of human evolution, in which a species rises above the challenges of the environment, and through wilful effort achieves a more sophisticated form. This last misconception neatly maps onto the cladogram's prominent diagonal line, from which branches diverge as side stories within this grander tale of survival (O'Hara, 1992).

That the recognizability of this narrative depends upon its form rather than upon its content means it is easily transposed across media. Thus we recognize it in a teacher's spoken explanation, in the copy of a panel in a museum exhibit, and as we shall show, mapped onto the structure of the cladogram. Exactly how these abstract narrative elements – a dramatic sequence of events, characters acting toward goals, and a plot with a clear beginning and determinate end – come to be symbolized from the concrete structures of such a minimalist diagram is less clear. To answer this question, we must examine how pictorial elements are composed to make visual statements, and how these grammatical structures convey meaning (Barbatsis, 2005; Guo, 2004; Kress & Van Leeuwen, 2006).

3.4 Visual narrative

Scholars of visual studies have traditionally focused on the depictive qualities, or on the visual *lexis* of images (e.g., Eco, 1976, Barthes, 1977; Panovsky, 1970; Goodman, 1969, Hermeren, 1969; Williamson, 1978). Far less studied has been their visual *syntax*. Yet, we find narratives in all kinds of images from film, to illustration, to the assembly instructions in electronics manuals; and the reason is attributable not only to our inclination toward it as a cognitive structure, but also to the nature of representation. As an act of selection, representation necessarily leaves gaps in what is represented; and because a symptom of our penchant for stories is to seek closure in our experiences, we find these gaps irresistible to fill (Abbott, 2008). Designers often capitalize upon these tendencies in order to elicit desired reactions from their audiences, whether it is to create feelings of suspense in films or novels, or to suggest richly complex stories from simple book illustrations. Interpretation thus largely involves constructing narratives to fill in these representational gaps. At the same time, our tendencies to do so lead us to even interpret narratives where none are intended.

The cladogram provides one such case. Students' reading errors of them point to a misalignment in the cladogram's structure between its intended content and the intuitive narrative mode of interpretation to which it appeals. They moreover highlight the importance of understanding the influence of visual syntax. Ultimately, such an understanding would inform a design that better aligns concepts with intuitive ways of interpretation; one that would therefore support students' developing reasoning skills.

In the next sections, we expand the notion of narrative representation in order to consider the syntactical structure of the cladogram. To illustrate our discussion, we present excerpts from interviews with undergraduate psychology students conducted as part of a larger study on the interpretation of cladograms. In their interviews, students used a cladogram (Figure 4a) to solve common problems of relative species relatedness, and were asked to justify their reasoning based on how they interpreted its diagrammatic structure. We divide our discussion into three sections. First, we describe the narrative functions of the cladogram's graphic elements: How students related conceptual metaphors to compositional space; how the notion of *center* was graphically constituted; and how a Gestalt perceptual effect allowed students to string these diagrammatic elements into coherent narrative explanations – explanations that aligned with their prior folk theories of evolution. We then discuss the influence of context and prior knowledge on students' interpretations; and finally, we describe conditions that demonstrate the symbolic flexibility of these graphic structures.

4 The cladogram as a narrative

The notion of a visual grammar implies that elements in verbal narratives have graphic counterparts in visual ones (Kress & Van Leeuwen, 2006). In this section, we describe how the narrative elements of students' prior folk theories of evolution are metaphorically structured upon the cladogram in interpretation.

4.1 Actors

Actors in a narrative are those that experience events, and whose actions keep the plot moving forward. In verbal narratives, they are denoted by nouns. In visual ones, they correspond to any entities depicted in graphic space. That cladograms typically feature taxon names at their branch tips means these easily stand for actors, and for novices that bring prior narratives to their interpretations, these actors moreover assume very specific roles.

Amanda was a student we interviewed for whom the classic *March toward Man* was initially prominent in her mind. When asked at the beginning of her interview to recall any image of evolution, she sketched and described a row of figures that began with a monkey at the left, and ended with a human at the right. When we then showed her the standard cladogram and asked her if it agreed with the ideas she just expressed, Amanda immediately noticed correspondences. Pointing from her sketch to the cladogram, she identified the characters of her folk theory with the nonsense words depicted, and described how: "…L-O-F would be a monkey, and then J-I-V would be a gorilla, and then M-I-P would be an ape…." Similarly, Philip, described how “LOF, that branch, would be like some other type of fish. Then after that, you would progress onto land, and … there is like monkeys and humans…” Apparent from these interpretations is how the arrangement of simian figures in the *March toward Man* and of the words across the cladogram’s branch tips neatly mimics the linear sequence of words in a sentence. Notable is how items so arranged acquire causal relations they may not have had otherwise. So it was that by mapping their prior internal representations onto this diagrammatic one, students readily attributed the transitory states of the actors from the folk theory to the nonsense words of the cladogram.

4.2 Events

A narrative is essentially a chronology of events, and it is this temporal dimension that distinguishes it from a conceptual representation. In verbal narratives, verbs convey this temporal information. In diagrammatic ones, verbs are denoted by vectors, graphic structures that connect actors and describe the processes and events that take place between them. (Kress & Van Leeuwen, 2006). In the cladogram, these functions are easily assumed by the lines that connect taxon names.

However, lines are used for various purposes in diagrams across domains (Tversky, 2000). Those in the cladogram conventionally denote lines of species descent, and the nodes at which they converge indicate points of speciation. Importantly, evolutionary change is implied to occur along the lengths of the lines from the nodes toward the branch tips. Yet, a common reading error is to interpret change as restricted to the nodes, rather than as occurring along the lengths of the branches. Doris, another student we interviewed, read the diagonal line segment between nodes as an “ecological and environmental state of stability.” To her, the straightness of the line indicated that there was “no need for the animals to like change their current situation.

There’s probably some gradual change, an evolution forward, but it wasn’t like any sudden change that happened to the animals in order to survive.” Likewise, Philip read lines in the cladogram as “a progression… So it's just like something is changing slowly, like just like a feature or something.”

Meanwhile, the cladogram’s nodes appeared as abrupt shifts in direction, and as moments of more dramatic change. This was “because of the spaces in between” the nodes, as Doris explained. The diagonal line “goes along for a long time and then all of a sudden it branches off so quickly. It’s not like some gradual like, ‘Oh look they’re separating from each other," but it’s like, oh, sharp contrast to what the original species was… you have these very specific points where the animals change and like groups diverge off.” Meanwhile, “you have like these spaces in between that seem to connect the ones with like drastic change in the habitat, which leads me to believe that those lines there were stable.”

Philip described one node, for example, as the event in which “a fish turned into something that could go onto land.” For Doris, this same node meant that “at that point in time… some natural disaster happened and animals that were more equipped to like live in the new environment… were the ones that survived and like created these new group of animals… So kind of like the concept of like the ice age.” Of another node, Doris describes a similarly catastrophic event of how one portion of a population “runs off and gets separated by like a mountain range, or something happens like a lake forms all of a sudden, and then you get two animals that are separated geographically or otherwise. The two groups will, if they’re mating among themselves… will become different enough, two species…”

How students managed to conjure such vivid events from such a minimalist design appears to be by a coordination of various resources. Among these are the perceptually embodied intuitions that novices use as heuristics for reading unfamiliar representations. Combined with a prior knowledge of a folk theory already rich in conceptual metaphors, we see how easily students may metaphorically structure their abstract conceptions of the content onto the graphic elements of the cladogram. Mark, for example, interpreted events along the lines and nodes as though describing his own journey along a path. He describes how:

> “the big line coming from here [SOR] to here [VEK] would be kind of the standard path. And then when you get up to here [VEK], like, looking at mine [i.e., his sketch of a *March toward Man*], it's like you're almost stood up. But this [node] could be kind of… like a kink, I guess. And, like, so [the character in the story] comes up, you get to this point [i.e., a node], and, like, you either continue on that [diagonal] path, or you could kind of continue on that other [vertical] path.”

Mark’s interpretation is reminiscent of reading mathematical graphs, in which abstract concepts such as time, velocity, and quantity more intuitively align with intuitive and embodied manners of perception (Nemirovsky, Tierney, & Wright, 1998). Although it is a logical strategy for novices to draw upon their experiences with known representations to read unfamiliar ones, it makes them all the more prone to error when faced with the peculiarities of the cladogram, and the misleading themes of linear, anagenetic change in the folk theory of evolution (cf., Sfard, 2000).

4.3 Plot

Plot is narrative element that weaves actors and events into a coherent causal structure. In visual narratives, plot is often indicated by prominent oblique lines, or else by arrows, which denote process, motion, causality, and direction (Gombrich, 1990; MacKenzie & Tversky, 2004;

Winn, 1987). In their function as vectors, the cladogram's lines not only suggest a sequence of events with distinct turning points at the nodes, but they also imply narrative direction. In this manner, they assume the conceptual qualities of arrows and weave elements together in a plot.

One way this occurs is by the particular spatial arrangement of lines, which features both a strong diagonal slope, and also creates a clear triangular shape. Artists commonly employ such geometric shapes for their symbolic power (Jaffe, 1967), and triangles in particular have conventionally stood for action, process, and direction (Dondis, 1973; Thompson & Davenport, 1982). This may largely be explained by the embodied appeal of their diagonal lines, which graphically embody gestures such as pointing, or the trajectory of an object being propelled through space. In art, diagonals represent deviations from compositional stability and evoke a sense of motion and purpose, and as such, are often used to lend visual dynamic to an image (Arnheim, 1966, 1982).

By the shape they create, the lines of the cladogram thus take on the functions of arrows, and conceptually, suggest a plot. For Philip, who described how "farther along that line, whatever organism SOR was became more like VEK," the lines did not only suggest events experienced by the organisms, but they also indicated a clear direction of their occurrence. In a more elaborate interpretation, Mark identified one of the nodes as a human who was "kind of hunchback, like, almost standing." Then, at the node immediately to the right, the person was "getting kind of stood up a little bit more, but still not quite there," language that implies some ultimate goal toward which these characters strove. The fate that Mark then described for VEK as "the peak. Like the, like the stand, like the end line [Sketch_ST_651]," resonated with the conceptual metaphors of Darwin's own description of "man as having risen… to the very summit of the organic scale."

In addition to noting the correspondences between narrative and diagrammatic elements, we see in each of the interpretations above the multiple ways by which novices structured their naive understandings of evolution upon the cladogram. Perceptually, the change in the direction of a line at a node appealed both to the experience of changing directions along a path, and to the narrative theme of a state change in the folk theory of a *March toward Man*. Meanwhile, the slant of the lines in the cladogram's triangular composition aligned with the physical experience of propelling oneself forward, and highlighted a sense of causality, and movement toward an ultimate goal. It was in this act of translating between worlds of the perceived, the physically experienced, and the conceptual, that students created from the cladogram symbols of these abstract notions of narrative.

5 Metaphors of space and time

Metaphor plays an important role in these symbolizations. Relating abstract conceptual relations onto the concrete elements of graphic space, a process termed metaphoric structuring, is a useful heuristic for thinking about them (Boroditsky, 2000). The cultural and embodied bases for how we perform these mappings (Tversky, Kugelmass, & Winter, 1991) are often exploited to produce representations that are cognitively natural to interpret (Tversky, 2000, 2002). The Western custom of temporally ordering items from left to right, and the universal one of associating increasing quantities along an upward axis, are common spatial metaphors across the domains of science, art, and marketing, and appear in visual artifacts from the Byzantine to the modern era (Kress & Van Leeuwen, 2006; Tversky, et al., 1991). Below, we examine how similar conceptual metaphors are structured upon the dimensions of the cladogram.

5.1 *Bottom, Top, Left, Right*

Along the vertical dimensions of a graphic, Kress and van Leeuwen (Kress & Van Leeuwen, 2006) identify the *Top* space to represent the *Ideal* state that either the characters in the image or the viewers of the image strive to attain. In folk evolutionary terms, *Top* might be associated with the most adapted, sophisticated, or complex state in a species' evolutionary progression. Meanwhile, the *Bottom* space represents the *Real,* or actual state of affairs, which might correspond to the simple, most primitive form in an evolutionary series. The image's horizontal axis, on the other hand, evokes less movement and direction than the vertical one. In marketing strategies, that axis commonly depicts a spectrum from the *Given* to the *New,* where items placed on the right suggest an improvement from the current situation pictured on the left (Myers, 1994). In the cladogram, the horizontal axis serves a similar purpose, as one may place the ancestral taxa toward the left and their descendents to the right, and so plot a rightward progression of time.

Philip's interview vividly demonstrated how such spatial metaphors allowed him to relate his folk theory of a *March toward Man* to the cladogram's structure. In his interpretation, Philip described SOR as "a fish that lived in water," VEK as "humans, because that is like the end of the chain," and JIV as "an amphibian, the animal that can live on water and on land... just because it's in the middle and for me stuff at the beginning is in the water and the end is humans." For Philip and for many others, the arrangement of nonsense words along a horizontal axis appeared to tap into the cultural practice of reading from left to right, and each word's position marked a new event, specifically, a change the character's state that neatly corresponded to the chronological order of the arrangement of figures in the *March toward Man*. Prominent in Philip's mind was the story of how life began in the ocean, and how, as primitive creatures crawled up onto land, they also gained more sophisticated forms. For Philip, the meanings held by locations in graphic space extended not only to metaphors of quality and time, but also to physical locations in the events of the internally-held folk narrative.

5.2 Center

In addition to these boundary locations of top, bottom, left, and right, the center also holds powerful symbolic meaning. The center position in compositional space tends to convey a sense of weight, stability, and distinction (Arnheim, 1982). Often, it acts as a hub around which other objects are placed, such that images are interpreted in terms of their relation to the center. When objects deviate from that center, they tend to suggest movement and to create compositional imbalance. They demand that the viewer construct a narrative to explain the deviation, just as discrepant events and gaps in our experiences demand narratives to achieve a sense of closure and coherence (Abbott, 2008; Bruner, 1990).

The center is not dependent upon spatial location, but rather finds its place through salience. Salience is moreover created by pattern and rhythm, as through repetition in a visual temporal display, or through visual weight, as suggested by the symbolic and embodied meanings associated with graphic space (Arnheim, 1982). The weight of *Bottom*, for example, is easily perceived for its common associations with everyday experiences of gravity, heaviness, and even with such conceptual metaphors as depression. In the cladogram, the funnel-shaped emanation of lines from the bottom-left toward the upper-right furthermore created the impression of a stable center. In one student, Stephanie's justification, "there's one like open end at the bottom and there's many at the top… visually, it gives the impression that everything flows from like the bottom out, and up into the right."

Positioned as it was in the lower left-hand corner, Stephanie guessed that SOR represented "the original species… that's kind of the great grandfather of all the other creatures… some very simple few cell creature or just kind of like origin of like all the creatures that developed after that. Or, you know, kind of like a prehistoric lizard that maybe all the reptiles developed out of. Or maybe, it could be some sort of batch of cells that, you know, all these bacteria developed out of afterwards.” Meanwhile, “VEK would probably be like the farthest, like… whatever would probably be the most evolved animal… because SOR is at the bottom, just because of the way the diagram is oriented.” With the gravity of its central location students thus readily associated SOR as an ancestral beginning with primitive, simple qualities.

5.3 Gestalt

How viewers created cohesion from these isolated pictorial elements of lines, nodes, and spatial locations, underlies the act of interpreting visual narratives. Scholars of visual communication describe the holistic nature of processing visual information as a kind of visual logic (Barry, 1997). Viewers act as bricoleurs to negotiate the arrangements of seemingly incongruent parts (Turkle & Papert, 1992), and abduct, as though by insight, a plausible narrative of the image (Moriarty, 2005). This holistic logic is similar to how historians find meanings in the totality of events, rather than in isolated ones (Landau, 1997). It is also related to concept of Gestalt, whereby meaning is conveyed by the impression of the whole diagram rather than the specifics of its individual parts (Wertheimer, 1938).

Novick and Catley (2007) consider one such Gestalt principle, Good Continuation, by which students tend to interpret a continuous diagonal line that extends from the bottom left toward the upper right of the cladogram’s graphic space. As they argue, the persuasiveness of this line as a single entity with a single meaning interferes with students’ noticing as experts do the nested hierarchies of clades. Accordingly, we observed Vanessa’s perception of a continuous line to greatly influence her choice of reasoning strategy. Rather than judge species’ relatedness based on clade membership, she viewed each of LOF, JIV, MIP, and VEK to be equally related because "they all break off from the main, this SOR main line." The connections of each of their vertical branches to that line, symbolized for Vanessa a direct relationship to SOR. Meanwhile, RIL was viewed as the least related because "it doesn't directly come off the line."

Generally, students viewed this line as a main evolutionary path from which all other lines were mere offshoots or side stories in the principle narrative. "Obviously," said Victoria, "because the line is slanting upwards [the species along that line] have made like some evolutionary progress… I guess this is the development from here [SOR] to here [VEK]… [the diagonal line is] just like the more straight evolutionary path from like one to the top of the diagram." As milestones along this path, in which LOF "would be like the first one and JIV would be like the second one," these other taxa progressed toward complexity, and JIV, for example, was "the second more complex out of the creatures that have developed… from this original SOR."

Thus the combination of these parts, the line with a clear beginning and definite end, the upward slope and periodic vertical offshoots, together resonated with students' narrative understanding of one taxon transforming into the next, and striving continually toward a pinnacle of creation (Figure 5).

[Insert Figure 5]

6.1 Contextual cues

That interpretations of the cladogram should so consistently feature this folk narrative might suggest universality to its symbolic meanings, but it also underscores the role of context. Context cues particular sources of prior knowledge; it directs attention to certain graphic elements, and guides viewers to construct the most likely interpretations. When not made explicit, viewers must draw upon other resources to create an ad-hoc context and system of rules for interpretation. A common convention across domains to which our students turned was spatial proximity as a measure of relations among graphic elements (Tversky, 2000, 2002).

Abigail, for instance, erroneously relied judged the relative relatedness among taxa by how closely they appeared together. As she explained, the diagonal line segment between LOF and JIV represented:

> “...the change between LOF and JIV, that there's a difference. One is more towards SOR and one is more towards VEK... There are more similarities between SOR and LOF than there are between, um, SOR and JIV... [because] I guess in my mind I was thinking of, like, in math class when you have, like, point A and B, and then like, how far C and D are from it... So, in my mind it's, like… SOR and LOF are closer [in graphic space], so they're more similar.”

Such borrowed heuristics from other domains also led to other students’ reasoning errors. For example, Samantha guessed RIL and VEK to be more closely related than JIV and MIP because their lines were "going [in] the same direction. Like, RIL is going the same direction as V-E-K.” Although RIL and VEK are indeed more closely related, it is only because they share a more recent common ancestor, denoted by their more recent shared node. Meanwhile, Hilary regarded LOF as one of the oldest species because it is at the tip of the longest branch, and "if it's longer, it probably meant, like, it was, it existed for a longer time." Although LOF does share the oldest common ancestor with the other taxa, it is the relative position of its node that indicates this, rather than the length and orientation of its line. With a different configuration of the same cladogram, each of these students’ heuristics would have led to different responses. Thus, when the rules of a representational system are not apparent, viewers will draw upon those from known domains; and while this strategy can support interpretations of unfamiliar representations, it can also lead to incorrect assumptions of the representational system (Sfard, 2000).

6.2 Symbolic flexibility

Many of the cladogram's graphic features appeared to function as symbols of progression, causality, and determinism, and to metaphorically correspond to the canonical folk narrative of progressive transformation. Indeed, prior research found the attribution of increasing quality and quantity to an upward vertical axis to be a universal spatial metaphor, and associations of temporal qualities to a leftward or rightward axis to be linguistically-dependent one (Tversky, et al., 1991). But are these necessarily rules? To the extent that such symbols can be flexibly interpreted holds promise to guiding students away from their naïve interpretations of the cladogram.

To investigate the symbolic flexibility of spatial metaphors, we presented some students with different animations of the cladogram (Figure 4B, C). With animation to control the order in which parts were viewed, we could impose external narratives upon the diagram to counter the narrative interpretations students tended to give. So imposing external narratives upon the cladogram through animation appeared to reverse the spatial metaphors associated with students' internal narrative interpretations, and suggested that both the horizontal, and the vertical axes have a more flexible symbolic meaning than previous research suggests.

Where students tended to associate the bottom-left position of SOR with a primitive, ancestral species that gives rise to the other taxa, when we animated the cladogram to be revealed from the top toward the bottom (Figure 4B), we observed a clear shift in the metaphoric attributions of quality and time to space. Now, viewers produced a downward interpretation. Especially to those who had never before seen a cladogram, the lines represented the paths of different species through time, and the nodes represented points of mating and reproduction. It was a story of "the combining of separate things into one," where SOR, positioned at the bottom leftmost space of the graphic, "represents the final result of the development of the five on top of it." Whereas students that viewed the static cladogram (Figure 4A) as well as those that viewed the Bottom-Top animation (Figure 4C) typically saw VEK as the endpoint in an evolutionary succession, students in the Top-bottom condition (Figure 4B) interpreted SOR as "the most modern, adapted" taxon.

Although animation could alter the metaphors attributed to spatial locations, it could not change the internal folk narrative that students mapped onto the cladogram. That is, although it was possible for students to variably associate either the top right or the bottom left of the graphic space with a pinnacle of evolution, this conflict in spatial and linguistic metaphors did not sway their appeal to the folk narrative of evolution to explain what they saw. Even when students viewed the cladogram unfold in a direction that opposed this intuitive narrative, they continued to map a story of how species "get more specialized, and they grow, and eventually they create a human."

Although intuitive perceptuomotor heuristics had an important influence on interpretations, it was students' conceptual assumptions that guided the conceptual metaphors they associated to graphic space. Our observations suggest that whereas certain perceptual heuristics can be flexibly applied, the internal narrative understandings, such as the folk theory of evolution, remain powerful organizers of perception.

6.3 The influence of "evolution"

Students' rich conceptual interpretations are notable, especially in spite of the artificiality of the interview situation, and of our efforts to avoid portraying specific taxa with the use of nonsense words. But how much of these meanings are attributable to the graphic features alone, and how much to their context as representations of evolution? To find out, we conducted interviews with some students in which we made no mention of the word “evolution,” and as a result, observed strikingly contrasting interpretations. For those students that had never before seen a cladogram, no longer were the folk themes of progress, transformation, and linearity the rule. Where graphic elements such as lines and nodes tended to be interpreted as paths of change and points of creation, now, they stood as symbols of relatedness, as in a food web, where one species was either the consumer or the consumed; or as in a family tree, where they are ancestor, descendant, cousin, or sibling. In Richard’s interpretation:

> "[SOR] um down here [in the bottom left] is the top of it [i.e., of the food web], kind of, so it would have to be something that would consume all of these things... then all of these [other nonsense words at the top] would just have to be something small... because [they're on] the bottom [of the food web]...."

Notable in Richard’s interpretation is that symbolic meaning no longer hinged upon space. Rather, it was the pattern of lines between taxa – the notion of relatedness that constitutes the cladogram's core underlying concept – that guided his symbolizations. Richard readily associated the conceptual "top" of the food web with the physical "bottom" location of the diagram, whereas students told the diagram pertained to evolution tended to avoid this conflict between spatial and linguistic metaphors. That students’ symbolizations of the same graphic elements can be so flexible suggests there may be instructional strategies by which the folk story-laden cladogram might be successfully introduced to novices.

7 Design implications

Although cladograms can be powerful reasoning tools, they are not without their caveats. Experts familiar with both its content and its system of representation find them useful tools for reasoning about phylogenetic relationships; but for novices, they are a cue to their intuitive folk theories of evolution. If introduced too early, the standard cladogram may thus hinder rather than help students develop proper phylogenetic reasoning skills (cf., Dufour-Janvier, Bednarz, & Belanger, 1987; Lehrer, et al., 2000). Moreover, directly providing students with a ready set of heuristics for reading cladograms may result in rote interaction with empty symbols (Dufour-Janvier, et al., 1987), for which the rules are quickly forgotten, and connections to concepts never made.

Yet, as problematic as it is for novices, the esoteric cladogram persists, situated as it is within an established system of scientific practices, and maintained through discourse within the biological community. But importantly, it is also through engaging in these discourses that learners become acculturated to these representational practices (Sfard, 2000). The task for designers and educators is thus to support making connections between concepts and their standard representations, such that they learners may meaningfully engage in the discipline.

Toward this goal, we underscore three observations of how students interpret cladograms. First, novices will metaphorically structure abstract relational structures of their narrative understandings onto the concrete structures of space (Boroditsky, 2000; Tversky, 2002). Second, prior knowledge of the content and of similar representational systems create contexts for interpretation. Third, under certain conditions students' apparently intuitive symbolizations are flexible. This last observation is encouraging, for an intervention designed to guide students' perceptions will only be successful to the extent that their perceptions are malleable.

Effective representations should capitalize upon our intuitive manners of conceiving of space and the marks made in it (Tversky, 2000); but they must also do so in ways that align with the intended underlying concepts. This in mind, we propose an intermediate representation; one that would guide students' perceptions, support their developing spatial skills, and so bridge the divide between novice and expert reasoning (Roschelle, 1996; Sfard, 2000). Our ongoing work involves the development of computer-based learning environments that feature a technology-enhanced, interactively manipulable cladogram. With this cladogram, learners may rearrange the locations of clades relative to one another by dragging them across the screen, or by clicking to automatically rotate them at their ancestral nodes. Meanwhile, the branches maintain their connections to one another, thus making it possible to create multiple, but topologically equivalent configurations of the same diagram (cf., Halverson, 2009). The features of this interactive cladogram constitute a set of principles, by which effective bridging representations in other scientific domains may be designed to:

1. Make meaningful chunks perceptually apparent.

   Enabling interactions that automatically chunk meaningful units of information may scaffold the development of expert perception and manipulation of those units. Expertly seeing a cladogram means recognizing clades as the perceptually meaningful units of reasoning (cf. Chase & Simon, 1973), and so grouping clades such that they move together might support learning to perceive and reason with those units.

2. Permit exploration of the structure by direct physical interaction.

   Perhaps the greatest affordance of this technology-enhanced representation is that it materializes the imagined objects of experts' reasoning (Sfard, 2000). Because it is in manipulating clades that biologists come to understand their relations to one another, a bridging representation that enables learners to physically do the same may support more meaningful interactions. In their digitally tangible forms, clades become perceptually, kinesthetically, and thus more cognitively accessible. So removed from the confines of two-dimensional graphic space, this pedagogical cladogram would support perceptually-grounded and embodied interactions with its symbolically meaningful units. Additionally, it would guide attention toward topology as a meaningful representational pattern, rather than to the spatial locations that novices tend to inappropriately fill with conceptual metaphors.

3. Make transitions between multiple representations visible.

   Animating the translations between differently configured, but equivalent representations, may relieve the cognitive load entailed in performing such transitions mentally. The visual persistence of the cladogram's nodes and branches as they are manipulated onscreen would allow learners to create, and make associations between its multiple equivalent representations. Moreover, it would makes the transformation of one diagram configuration into the next both transparent, and controllable such that it would support learners' developing spatial skills with visualizing such rotations, and importantly, grant them autonomy to customize the direction and pace of their own learning progressions (Lawless & Brown, 1997).

Embedded within a larger, inquiry-based learning environment that encourages reflection; provides timely and appropriate feedback; and through authentic scientific practices, encourages students to explore and build their own understanding (Collins, Brown, & Holum, 1991; Edelson, 2001; Quintana, et al., 2004; Sandoval & Reiser, 2004), students may come to realize the usefulness of the standard forms, and so develop a deep understanding of the connection between these expert representations and their underlying meaning. Our ongoing work explores the educational possibilities of this interactive, manipulable cladogram on biology students’ reasoning about phylogenies, and more generally, the potential of technology for creating perceptually grounded supports to scientific reasoning; tools that would equip students with the perceptual and conceptual tools for expert phylogenetic reasoning, and so permit students to meaningfully engage in the discursive practices of the discipline (Dorfler, 2000; Sfard, 2000).

Figure captions

Figure 1. A framework of interpreting scientific representations

Figure 2. Four different configurations of the same cladogram. With time plotted vertically from the roots to the branch tips, it is apparent that birds and snakes share a more recent common ancestor at the red node than did birds and fish at the green node. At the same time, birds, snakes, and sheep all shared a common ancestor at the blue node.

Figure 3. A student's sketch of the iconic *March toward Man*. From left to right, captions read "Monkey," Caveman," and "Person." The student describes "a monkey… slowly progressed up from all fours to kind of… a hunchback… And then continued on… just becoming more upright and more upright… until the person was finally kind of standing…. almost as if they're walking towards, like, an end line.

Figure 4. The cladogram shown to students in our interviews. It featured nonsense words instead of the names of real taxa because we wanted students' to base their reasoning in the diagram's structure rather than on knowledge of specific taxa (Spiegel, 2006). The letters above indicate still frames of what different groups of students viewed from a computer screen. Some viewed (A) a static version; and others viewed one of two animated versions in which the cladogram was gradually revealed (B) from the top toward the bottom of the screen, and (C) from the bottom toward the top of the screen.

Figure 5. A map of the cladogram's narrative space. Quality increases upward along a vertical axis, time progresses from left to right along a horizontal axis. The dotted line highlights the prominent triangular shape that lends dynamism and direction to the composition. The *center*

serves as a natural base point. Grey squares mark the actors in the story, and curly arrows show transitions between states. Numbered steps refer to the narrative functions identified by Landau (1997), and shows how they metaphorically correspond to locations in graphic space.

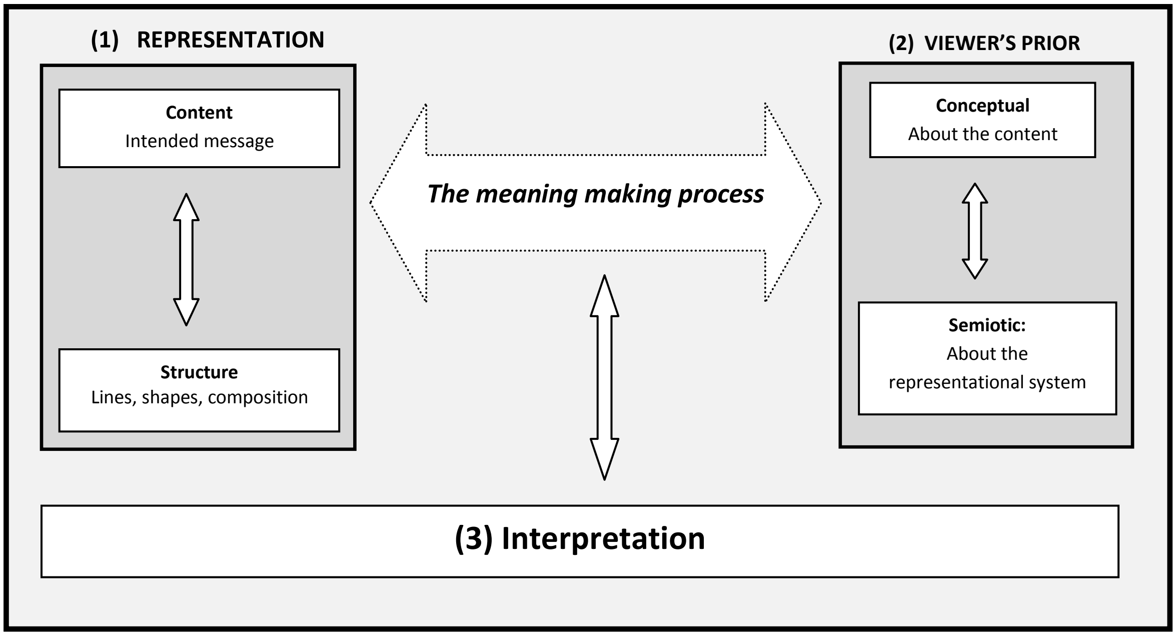

(1) REPRESENTATION
Content
Intended message
Structure
Lines, shapes, composition
The meaning making process
(2) VIEWER'S PRIOR
Conceptual
About the content
Semiotic:
About the representational system
(3) Interpretation

Figure 1

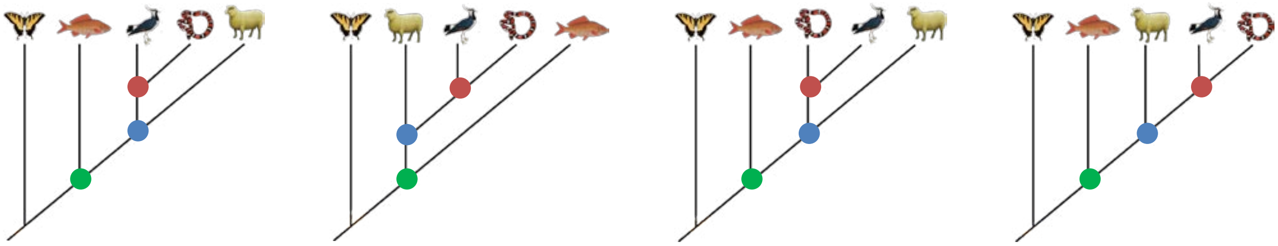


Figure 2

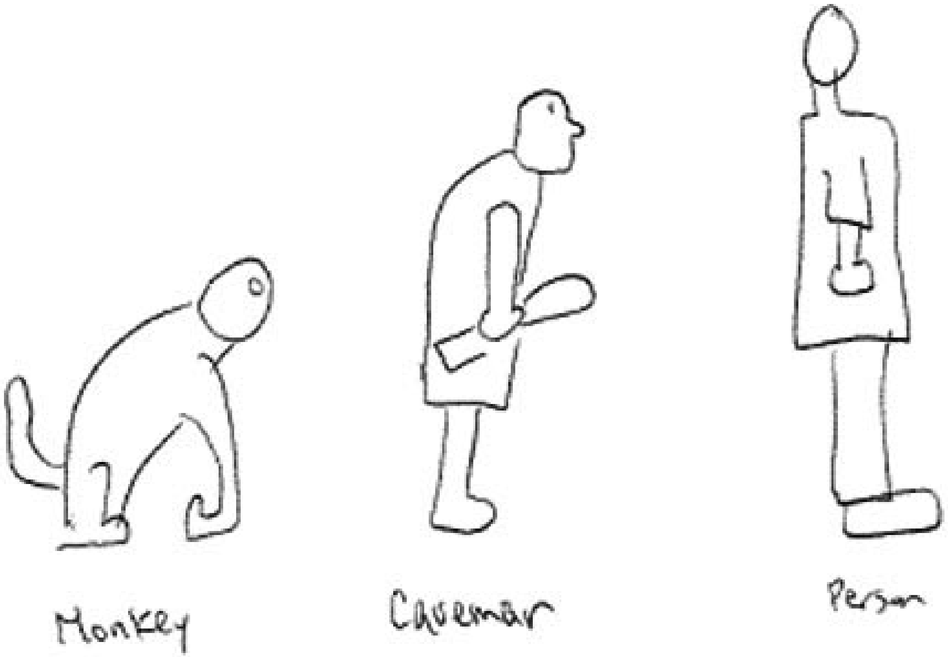
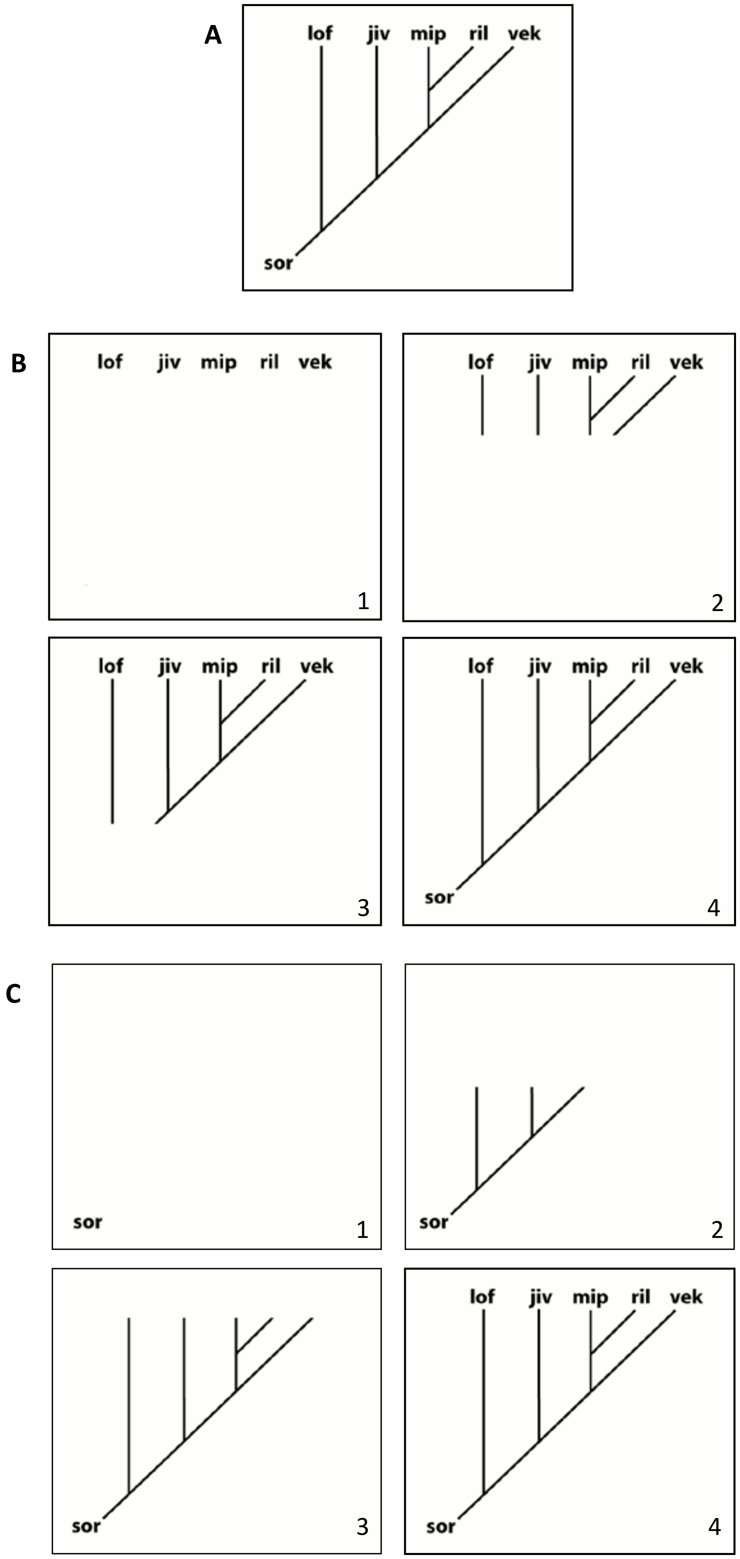


Figure 3

Figure 4


A
lof jiv mip ril vek
sor
B
lof jiv mip ril vek
1
lof jiv mip ril vek
2
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3
lof jiv mip ril vek
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C
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1
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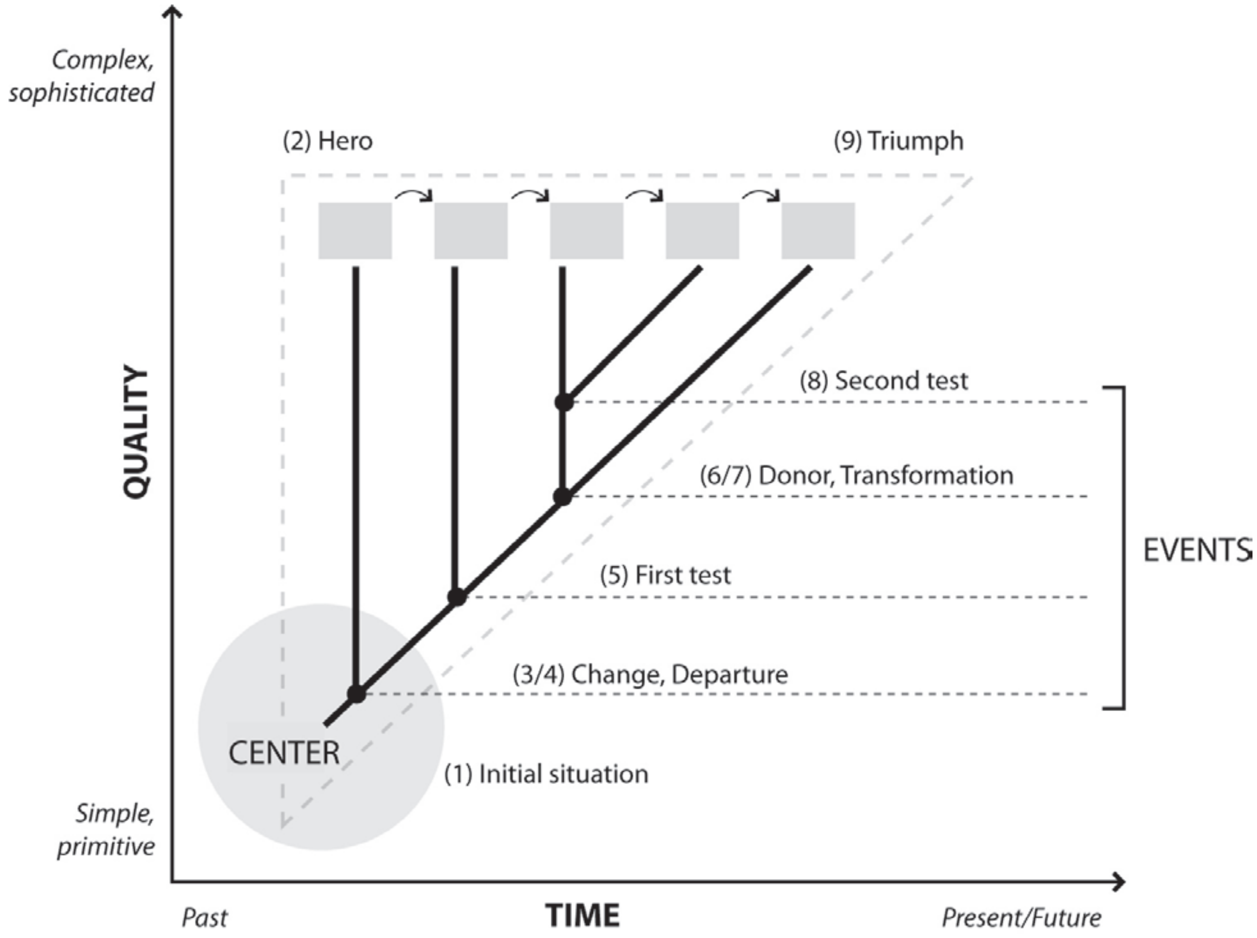
4

Figure 5


Complex, sophisticated
(2) Hero
(9) Triumph
QUALITY
(8) Second test
(6/7) Donor, Transformation
EVENTS
(5) First test
(3/4) Change, Departure
CENTER
(1) Initial situation
Simple, primitive
Past
TIME
Present/Future

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