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Ambiguous Science and the Visual Representation of the Real

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AMBIGUOUS SCIENCE AND THE VISUAL REPRESENTATION OF THE REAL

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ABSTRACT

The emergence of visual media as prominent and even expected forms of communication in nearly all disciplines, including those scientific, has raised new questions about how the art and science of communication epistemologically affect the interpretation of scientific phenomena. In this dissertation I explore how the influence of aesthetics in visual representations of science inevitably creates ambiguous meanings. As a means to improve visual literacy in the sciences, I call awareness to the ubiquity of visual ambiguity and its importance and relevance in scientific discourse. To do this, I conduct a literature review that spans interdisciplinary research in communication, science, art, and rhetoric. Furthermore, I create a paradoxically ambiguous taxonomy, which functions to exploit the nuances of visual ambiguities and their role in scientific communication. I then extrapolate the taxonomy of visual ambiguity and from it develop an ambiguous, rhetorical heuristic, the Tetradic Model of Visual Ambiguity. The Tetradic Model is applied to a case example of a scientific image as a demonstration of how scientific communicators may increase their awareness of the epistemological effects of ambiguity in the visual representations of science. I conclude by demonstrating how scientific communicators may make productive use of visual ambiguity, even in communications of objective science, and I argue how doing so strengthens scientific communicators' visual literacy skills and their ability to communicate more ethically and effectively.

DEDICATION

To Macie and Madison, whose energy and enthusiasm for life proves that there is so much more. And to Jackie, for making it easy to have energy and enthusiasm.

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VISUAL LITERACY AND THE EMBRACING OF AMBIGUITY

> "Seeing is metamorphosis, not mechanism."
>
> -James Elkins, *The Object Stares Back*

The Scientific Visual Literacy Conundrum

The *Inner Life of a Cell* series, part of Harvard University's BioVisions project, is a collection of artistically rendered simulations—complete with mesmerizing colors and music—that exhibit microscopic biological processes. The animations are produced and distributed by a by an assembly of Harvard scientists, faculty, students, and multimedia professionals who do not hide their bold philosophy behind the multimedia simulations:

> Research in the biological sciences often depends on the development of new ways of visualizing important processes and molecules. Indeed, the very act of observing and recording data lies at the foundation of all the natural sciences. The same holds true for the teaching and communication of scientific ideas; to see is to begin to understand. (Stimolo)

A very serious endeavor to instruct students in the biological and life sciences, Harvard's BioVisions project is intended to be much more than an entertaining, artistic composition of scientific phenomena (see **Figure** 1.1).

Figure 1.1: "Mitochondria," from BioVisions' *Inner Life of a Cell* Series

Although developed to subsidiarily astound, lure, and intrigue audiences, these high-tech and acutely designed renderings are primarily intended to instruct with scientific accuracy. According to the BioVisions website, "this new generation of science visualizations are not meant to simply be simulations or mirrors held up to reality, rather they are designed with a specific pedagogical goal in mind. This means that each decision on how to represent a given biological process also includes consideration of how to best visually communicate particular aspects of the process" (Stimolo). Imbedded in this statement is an intriguing perspective on the way reality—the objective world—is epistemologically framed within the visual communication of science. Well-respected scientists at Harvard see the confluence of art and science in these visual representations as an important epistemological and pedagogical practice for clarifying the processes of scientific phenomena.

The visualization of science is nothing new, of course, but the deluge of technologies (such as the animation tools used at Harvard) that has recently inundated nearly every discipline has raised a host of questions about the pedagogies and epistemologies that surround such technologies. In serious scientific endeavors like the BioVisions project, visual representations and simulations are, undoubtedly, developed using intensely “rigorous scientific models” as the BioVisions website claims. Yet there can be no denying the epistemological influence of the perhaps more subjective, ambiguous interpolations of aesthetics in such representations. Further, the communicative decisions and the technological limitations underlying the development of such representations inevitably create visual ambiguities—regardless of the “scientific rigor” involved—that affect viewers’ interpretations.

The observation of a simulation of something scientific—whether it be of brilliantly colorful protein crystallography or of gracefully “swimming” mitochondria—makes it difficult for most viewers to imagine what that scientific phenomenon might have looked or acted like previously in their mind’s eye. By the time they have viewed and accepted the simulation or image as part of methodical science—and hence as simply “accurate”—they have forgotten that they have been captivated, persuaded. As Sherry Turkle claims, visualizations and simulations cause viewers to get caught up in the visual glamour and the “dazzling environments. … We [become] witness to our own seduction,” she says (80).Visual elements—particularly those touted as“scientific”—seem to have a unique and influential power to seductively persuade, causing viewers to believe that representations built from scientific models do not lie, and that the ambiguities of their composition do not matter (or, worse, do not exist). The accusations against language and rhetoric as impediments to science over several centuries has made scientists alert to *verbal* nuances and ambiguities that detract or distort meaning. However, based on the dearth of scholarship about ambiguity in visual representations, we might conclude that those communicating scientific phenomena often fail to realize that simulations encompass *visual ambiguities* as well, and that what scientific communicators see or communicate does not necessarily tell the whole or accurate picture.

This is not to say that visualization projects such as Harvard's BioVisions are inherently (or, by any means, *intentionally*) misleading or misguided. Without a doubt, students of science are gaining valuable understanding from these meticulously composed renderings. But the advancement and widespread use of visualization technologies, which more readily and frequently converges artistic practices with those scientific have necessarily raised questions about how viewers may unquestionably accept visual, simulated representations of science as mimetic duplicates of the real world without reflecting on the artistry and ambiguity present within the representation. The acquiescence to and quick embracement of scientific representations by scientists as accurate (or, at least, accurate *enough*) is an interesting conundrum that Turkle demonstrated in *Simulation and Its Discontents*. Visualization technologies are now too often complex beyond the knowledge of scientists who do not specialize in such technologies. But the questions scientists may raise have not necessarily been about whether or not *to use* visualization technologies in science (that seems a futile endeavor).

But appropriate answers about the communicative enigma that circulates the widespread use of artistically rendered visualizations in the sciences have been fragmented at best. It seems that answers to such questions ought to focus on how visually literate scientists and scientific communicators are when composing and viewing the material these technologies help scientists produce. And, it seems, one particularly important question that emerges when addressing how to improve visual literacy in the sciences regards the role, function, and ubiquity of visual ambiguities in scientific representations.

As we shall see, viewers' understandings are shaped by the visual nuances—the ambiguities—that exist as a result of technological impositions and artistic, rhetorical choices that superimpose the raw objectivity of the scientific phenomena. Furthermore, I shall demonstrate how representations are displayed in perhaps even more complex socio-cultural contexts that share in the epistemological framing within the viewer's understanding. Representations, in other words, must be contextualized within broader communicative frameworks in a digital age where scientists and non-scientists alike are being taught, in many ways, by the ambiguities in the image.

Searching for a "Scientific Visual Literacy"

Amidst an increasingly visual scientific culture, where visualization is a pervasive and penetrating part of most, if not all, scientific disciplines, it seems that scientific communicators (the scientists themselves and the people and organizations who publish their work) would be paying close attention to this ambiguity. It seems logical that they would be well-versed in the visualization techniques, theories, potentials, and the rhetorical/epistemological conundrums that generate visual ambiguity. The need for such a “scientific visual literacy” seems imperative. A dearth of scholarship on visual ambiguities, particularly in the sciences, has already been mentioned, but more particularly, many have recently addressed a real lack of systematic attempts to increase literate awareness of scientific representations. According to scientific communication scholars: there are “remarkably few systematic attempts that have been made” at developing common visual theories and frameworks for the sciences (Pauwels 1); there is “scant research on the role of visual literacy and science visualization among scientists or scientific communicators” (Trumbo “Seeing Science” 386); and there has been “relatively little attention… directed toward the challenge of building visual literacy among scientists, communicators, and the public” (Trumbo “Making Science Visible” 266). Instructional communication scholars Mayer et al. have further claimed that, despite scientific textbooks’ compilation consisting of approximately one-third illustrations, little is known about the communicative and cognitive effects of design elements (“A Generative Theory”); and Barbara Stafford has persuasively suggested that literacy education is so emphatically reliant on textual communication that “the aesthetic…dimensions of perception remain virtually absent from the new interdisciplinary matrix in which cognitive being is about to become embedded” (“Visual Pragmatism” 3). Even as recent as 2005, surveys of this topic suggested that little attention has been given to the influences of images in the sciences. Hüppauf and Weingart note:

> The conditions of [science images and] their emergence, genesis, and continued production, their fashions, impact on research, philosophy, and the general perception of nature had attracted surprisingly little interest. This indifference was often associated with contempt for the visual in relation to abstract discourse. (3)

This lack of interest in visual literacy has continued to exist despite the fact that “life scientists take as a given that simulations [and visualizations] can *deceive*” (Turkle 59, italics mine) and that “beautiful images mislead because they imply a finished result even when research is at an early stage” (78). And there is little research done in visual literacy in the sciences despite the acknowledgement that we learn from visuals often “viscerally” rather than intellectually or empirically (57). Furthermore, visualization is not a part of most scientists’ training despite scientific communicators having access to myriad assorted technologies that facilitate the creation of images. Roald Hoffmann writes:

> Chemists are not selected—nor do they select themselves—for their profession on the basis of their artistic talents. Nor are they trained in basic art techniques. My ability to draw a face so that it looks like a face atrophied at age ten. So how do they do it, how do we do it? With ease, almost without thinking, but with much more ambiguity than we, the chemists, think there is. (69)

Scientists in almost any field will, for various reasons from journal publications to presentations, produce visualizations. And they will, as Hoffmann admonishes, do it with ease. The tools available make it simple and fast.

Hüppauf and Weingart note that scientific illustrations were historically used to lay claim to truth but the invention and pervasiveness of digital images has changed that. “This cannot be read,” they say, “but as a plea for developing a new image literacy capable of coping with a new situation brought about by the contingency of digital images” (4 – 5). Without literacy training, visual ambiguities will have the potential to infect and distort the communication of scientific ideas. For ethical reasons, if nothing else, improved visual literacy that pays attention to ambiguity is a necessary step forward in scientific communication.

The incommensurability between *science* and *communication* might be one explanation for this hole in scientific visual literacy research; many scientists may simply have a lack of interest or understanding in communication practices—where the rhetorical, cultural, subjective nature of understanding materializes. But another, more likely explanation, might be that the infusion of images, reproductions, and visualization technologies in science and culture in the past 30 – 40 years has simply been difficult to keep up with. The sudden pervasiveness of animations, videos, photographs, X-rays, CAT scans, printouts, advertisements, websites, and digital renderings—not to mention the accessibility of digital tools such as Photoshop, AutoCAD, Maya, and Flash and advancements in color printing and publication—has made visualizing science so fast and easy that scientists have, possibly, inadvertently allowed visualization technologies to become prematurely “black boxed.” The imaging of science has, perhaps, developed and improved so quickly that scientists have just had to (maybe even begrudgingly) accept it and acquiesce to it.

Sherry Turkle describes how scientists that came into the field after 1980 have become much more likely to just accept simulation tools as accurate. The glamour, dazzling effects, beauty, and high-tech complexity of the machine make technologies hard to deny. The fear, then, becomes that “if [aspiring scientists in the classroom perform] enough ‘experiments’ in simulation, they [will] become accustomed to looking for nature in representations they [do] not fully understand” (40). They will assume nature and the visualization of it are no different from each other, creating an eerie paradox that Turkle points out: “the virtual [will make] some things seem more real” (13). And this problem only exacerbates as technologies become more and more powerful. Technologies (microscopes, cameras, software) built to produce high-fidelity renderings with sophisticated algorithms and complex computer code are often advanced beyond the knowledge of any one user. This makes the visualizations these technologies produce easy to simply trust. And in our acceptance and amazement of the wonderful image, visual ambiguities are often overlooked. Ironic, perhaps, since ambiguity has been the bane of scientific discovery since the 16th century empiricists demanded formality, method, and clarity.

The visualization of science has been evaluated, as Trumbo remarks, “indirectly” from many angles, but little research has been conducted that directly gets at the heart of improving visual literacy in scientific communication. More specifically, little if any scientific communication research addresses the inescapable presence of *ambiguity* in visuals. Related research in communications studies has addressed the visual “selling of science" through journalism practices (Nelkin *Selling Science*); the socio-cultural influences of popularized scientific images (Hüppauf & Weingart *Science Images*); and the evolution of science perception through writing and imagery (LaFollette *Making Science Our Own*), but none address practical and theoretical applications to dealing with ambiguity. Edward Tufte has provided invaluable contributions to the visual displays of technical and quantitative information, though his work typically only emphasizes readability, which fails to recognize more holistic perceptions of meaning-making (Tufte *The Visual Display of Quantitative Information*). Committees such as the Council of Biology Editors have established protocols for printing and publication of images in the sciences, but they tend to address, like Tufte, best practices for quality prints, use of color, and readability (Anderson *Illustrating Science*). Works have been produced that teach the "art" of illustration in science, though they demonstrate how to practically, skillfully draw images "without impressions" and fail to critically address the stylistic omissions and inclusions and other ambiguities that affect interpretation (Papp *Scientific Illustration*). Historians have attempted to capture the importance of scientific images over the centuries but broadly address the social/historical impact of such images with little investigation into the root of the nuances that shape the impact of the image (Ford *Images of Science*). And, of course, copious handbooks on scientific communication have been produced that fleetingly mention the inclusion of pictures, graphs, and illustrations, though the emphasis has been overwhelmingly focused on the writing (Christensen *The Hands-On Guide*; Laszlo *Communicating Science*; Montgomery *The Chicago Guide*; Wilson *Handbook of Science Communication*).

Specific visual design elements that affect meaning making have been, generally speaking, ignored by the scientific community. What does the colorization of a cell do to its interpretation? How does the juxtaposition of two scientific images inadvertently relay a "between the lines reading" of a concept? How does cropping the representation of an organism divert attention away from the "big picture"? How do cultural interpretations of scientific practices (such as gene modification) redirect attention to specific elements of an image? When looking at an image like Barker's "Osteoperosis," our gut reaction is to accept the rhetorically emotive argument that osteoporosis *looks like that!* But a more visually literate response would be—and *what else* might it look like? What are the visual ambiguities present in this representation that muddy, divert, or concentrate my understanding? A lack of engagement in specific visual ambiguities dangerously fails to consider important epistemological, pedagogical, and ultimately ethical questions about the visual communication of science. The present investigation is one attempt to establish a stronger visual literacy in the sciences from a theoretically-driven, praxis oriented perspective that exploits visual ambiguities in the imaging and design of science. The goal is not to eradicate visual ambiguities in scientific images, but rather to know of their influence and presence and how to make productive use of them.

Overcoming the Urge to Eradicate Uncertainty

In the late 1970s, investigations cropped up that explored the use of visuals in scientific communication, particularly in an effort to clarify (for instructive and usability purposes) scientific concepts—and essentially remove ambiguity. Scholarship interested in cognition and retention that emerged in the past 50 years attempted to learn how to weed out design elements that obscured understanding. This research was useful to evaluate student retention for the improvement of textbook design, but it did little to develop a broadly useful theory of design that would improve visual literacy. A sampling of this research has suggested that text juxtaposed with illustrations improves recall (Mayer "Systematic Thinking); that using *relevant* pictorial information improves cognitive processes (Mayer et al. "A Generative Theory"); that "seductive illustrations" impair understanding; that fostering "cognitive interest" is better for learning than "emotional interest" (Harp & Mayer "The Role of Interest); and that "seductive details…promote affective arousal" but do not "lead to better understanding" (Harp & Mayer "How Seductive Details").

Such scholarship has suggested that empirical research would be able to eventually pinpoint the myriad nuances of design (even artistic representations) and that the ambiguity present in scientific representation can be taught to be eradicated—for the improvement of learning (following research agendas and protocols that date back to Bacon's, Sprat's, and the Royal Society's attempt to formalize scientific language and practice). Researchers of design with proclivities toward empiricism have argued that visual and informational design principles are universal and stay faithful across languages and cultures (see Tufte *Envisioning Information*); that aesthetics and beauty can be codified (see Hassenzal "The Interplay of Beauty"; Norman, *Emotional Design*; or Tractinsky, "Aesthetics and Apparent Usability"); and that grammars and frameworks can be established for understanding images (see Krees & van Leeuwen *Reading Images*;

or Bang *Picture This*). It can be inferred from this work that researchers have often felt that ambiguity in visualizations often emerges *primarily* as a result of the inclusion of precise communicative elements (words, shapes, juxtapositions) made by the communicators and that, through thoughtful consideration, it can be eliminated. While there is certainly *usefulness* to the findings in this research, broader explorations into the complexity of visual communication suggest that ambiguity, to some extent, is *always* present, impossible to completely eradicate. In this light, to better understand the role of ambiguity in visual representations of science, it is better to dissect, codify, and evaluate *ambiguity itself* and its components, investigating its presence and influence on a given representation, rather than simply evaluating the contents of representations in order to (futilely) remove ambiguity.

Such a claim does not discredit previous scholarship that has sought clarity principles. Clarity-driven research in scientific communication has helped visual communicators across disciplines to know how to better approach the practicality and expediency of using images to further knowledge. It has helped designers to think consciously about what *not* to do. Such clarity-driven scholarship addresses the human need and desire to progress and produce, to understand, control, and frame the entropic and abstract universe in which we live in order to make sense out of chaos. At the same time, however, this scholarship often fails to address John Dewey's admonition that we cannot ever effectively approach cognition and learning without recognizing that each observer, reader, or learner is an individual with dispositions toward certain things and that interest and learning is dependent upon a host of factors nearly impossible to quantify.

We may interpret from the aforementioned empirical scholarship on visualizations that form dictates cognition and that content can be objectified. Ann Wysocki, referring to a *technically* well-designed advertisement displaying a nude woman, notes the ethical and *affective* problem with this theory of cognition. She says as form becomes valued, context becomes insignificant, and we fail to realize the "consequences of us somehow being shaped by the viewing" (152). Many visual theorists have raised similar issues about affect and interpretation, noting that images and visualizations evoke obtuse and subjective meanings (see Elkins, *The Object Stares Back*; or Barthes, "The Third Meaning") or that images evoke self reflection where identity emerges (see Mitchell, *Picture Theory;* or Barthes, *Camera Lucida*). This theoretical scholarship suggests that ambiguity and subjectivity are impossible to *avoid* and that interpretation, affect, interest, and cognition lie outside the bounds of empiricism yet always within the bounds of meaning-making.

This theoretical, ontological scholarship is likewise valuable as it addresses the ethical and cultural nuances, the socio-political and auto-reflective meanings that affect understanding. Such scholarship gives practitioners and educators an opportunity to reflect upon the individualistic impact of the usage of visual representations on users and learners beyond sheer output, retention, and production. Perhaps ironically, though, this more qualitative and theoretical work often is intended to *complement* empirical research, yet it rarely works *in tandem* with it. Such ontological and theory-driven philosophies are often viewed from an objectivist, empirical perspective as interesting thought experiments but rather out of touch with reality. As Eric Eisenberg has recently noted (and Donald Levine before him), Western culture has seen a “flight from ambiguity”: there has been a fear of chaos caused by a sense of urgency to formalize, methodize, and institutionalize the world. The dichotomy that divides the theoretical/ontological from the practical/empirical has, I suggest, impaired educators’ and communicators’ ability to approach visual literacy from both pragmatic *and* humanistic perspectives. When we demonize and flee from ambiguity, we fail to remember that no representation of science can ever be faithfully mimetic. Ambiguity is a part of human communication. And if this is the case, then we must first be willing to grapple with ambiguity to improve literacy. Unfortunately, this is not an easy task.

The (Rhetorical) Issue of Ambiguity

Francis Bacon famously declared: “Words plainly force and overrule the understanding, and throw all into confusion, and lead men away into numberless empty controversies and idle fancies” (*Novum Organum* section XLIII). Broader than words, of course, what Bacon is referring to as the impediment to scientific progress is rhetoric. And, without a doubt, rhetoric, deemed an *art* by Aristotle, has the ability to culpably reframe and reconstruct scientific arguments. From certain ethical positions and with a sense of urgency to make science efficient, it is no wonder why early empiricists (and eventually the Royal Society of London) sought to formalize scientific discourse, establishing research protocols and “plain language” practices to distance itself from rhetoric. But as most anyone willing to critically examine communication would admit, it is simply not possible to avoid rhetoric when communicating, *including* in science. And, as it might be inferred, ambiguity has a monumentally close relationship with rhetoric. David Blakesley has convincingly argued that rhetoric functions as a byproduct of ambiguity, "[exploiting] ambiguity to influence people's attitudes and actions" (9). Because ambiguity is always present in scientific communication, and because this ambiguity rhetorically affects human understanding, it becomes a complicated but inescapable part of the visualization of science that deserves attention.

Of course, what makes this challenging is that Francis Bacon was absolutely correct. Communication practices (he referred to words, but we can easily make the connection to visuals as well) give *frames of reference* to ideas but often fall short in "truthfully" representing scientific concepts, often "[overruling]…understanding" and initiating confusion (XLIII). Such complicated notions of human understanding have made the production of accurate and faithfully mimetic representations of scientific phenomena seem a daunting, if not impossible, task. As Luc Pauwels has noted in *Visual Cultures of Science*, "mimesis without expression is virtually impossible" (3). If expression, then, is almost always present, so too is persuasion. And, as Kenneth Burke states, "wherever there is persuasion, there is rhetoric. And wherever there is meaning, there is persuasion" (*Rhetoric of Motives* 172). Where there is expression, persuasion, and rhetoric, we might also suggest that there is "uncertainty." This iterative rhetorical-ambiguous issue of communication festers at the root of visual literacy conundrums in science.

In the instruction, visual replication, and communication of scientific phenomena, there is, undoubtedly, polarizing schisms in the way science is taught and demonstrated. The abstract concept of *affect*, the human element of emotion, and the complex multi-sensorial and extra-sensorial (dreams, imagination, spirituality) components of human experience and cognition often encumber scientists', educators', and communicators' ability to effectively *integrate* quantitative and qualitative approaches to understanding cognition, retention, and overall experience and understanding. The challenges arise as we try to tackle such complicated topics as the "subjective [processes] of interpretation and a social construction of models" (see Katz 6); "tacit knowledge" (see Polanyi 30 – 31); a learner's "disposition" towards a topic (see Dewey 7 – 10); and the "oppression" that comes from societal, educational, and linguistic apparatuses (as argued by Paulo Freire), among other complex matters.

Ambiguity—both in language and in visual representation—propels rhetorical motives. Because rhetoric is both visual *and* linguistic (as well as aural and gestural, which I will not be addressing), there is obvious overlap in the discussions about ambiguity in scientific representation as language *and* as visual. When scientists communicate research and findings, the definitions and descriptions of substances (of ideas, people, places, contexts, etc.) are at the mercy of ambiguity's influence. And because scientific communication is an attempt to persuade or argue for results, findings, and phenomena, rhetoric becomes necessary artillery for scientific communicators to battle with the ambiguity. Blakesley has suggested that rhetoric is necessary only when there might be place for a counterargument (9). Counterarguments —and thus ambiguities—are possible in just about any scientific communication; thus exploitation (whether thoughtful, careless, or unknowing) of ambiguity is a regular function of scientific representation. This is, perhaps, why one might say that dialectical argumentation in the sciences, which is reliant on the concept of *endoxa* (opinions held by the majority of people or by the educated), is faulty. Rhetorical argumentation in the sciences—which constantly works through and exploits ambiguity—is a much more reasonable perspective.

Embracing Ambiguity

Traditional empiricists and positivistic thinkers in the sciences, however, are not likely to readily jump on board the ambiguity bandwagon. Aristotle, Francis Bacon, John Locke, Charles Darwin, and many others, after all, established useful and productive taxonomies and methods that purportedly drove science away from ambiguity and into precision. If we believe, as these empiricists did, that the attempt to eliminate ambiguity is necessary, there is no need for rhetoric in scientific discourse. This does not mean that scientific research is fruitless, or rhetoric asinine; indeed, the attempts to remove ambiguity and rhetoric through scientific method have led to the establishment of important frameworks for highly successful cognitive and physical production of scientific knowledge, knowledge borne from empirical-analytical and mathematical-logical dimensions of science, as Gerald Holton suggested (46).

But ambiguity in science, we might say, emerges from Hume's take on empiricism: while sensorial experience is at the root of objective science, thoughts and ideas are built out of a principle of copying and reflecting (possibly without end) what our senses and emotions experience. There is always some uncertainty between the way we understand and germinate ideas about our sensorial experience with scientific phenomena (14 – 15). This is especially apparent with causality—one of the central problems Hume grappled with: we never see causality, only a series of effects. With Hume's perspective in mind, it becomes clear that the inability to recognize ambiguity as a prevalent part of science reflects a central principle about how knowledge is constructed in the sciences, and thus brings that process closer to the understanding of creativity and knowledge in the arts and humanities. Overlooking ambiguity, plain and simple, hinders improved visual literacy.

If language and visuals could be "plain," unnuanced, and free of multiplicities of meaning, ambiguity might very well be eradicated. But a brief survey of the nature of understanding (as a byproduct of both visual and linguistic communication) strongly suggests that knowledge is rarely certain and that ambiguity is, in fact, a pervasive part of meaning-making that we must learn to embrace. Empiricists and ontologists alike, after all, have indicated that our senses deceive us—nothing is precisely as it seems. Further, we may note from the works of Lakoff & Johnson or Richard Boyd that language is metaphorical in nature, wrought with undertones, puns, allegories, and that we understand the world not through what is commonly known as "plain language" but through metaphorical connections. Boyd and others like Joachim Schummer in "Gestalt Switch in Molecular Perception" even suggest that scientific knowledge is "rich in anthropomorphisms" (Schummer 61) and created through "theory-constitutive metaphors." (Boyd 373). Jean Baudrillard, Mark Taylor, and Walter Benjamin—to name a few—have demonstrated the multiplicity of meanings existent as a result of mechanical reproduction. Baudrillard argues that nearly everything becomes a replica or copy (*Simulacra and Simulation*); Taylor suggests that there is no end to pictorial rhetoric (pictures within pictures) in art and imagery (*The Picture in Question*); and Benjamin claims that art and images lose their aura in the process of reproduction ("The Work of Art in the Age of Mechanical Reproduction"). Further yet, the nuances of culture emerges in every photo (see Barthes, "The Photographic Message"); values affect, more than anything else, human understanding (see Feyerabend, *Farewell to Reason*); and knowledge is not created autonomously, but through social systems and apparatuses (see Agamben's "What is an Apparatus?"), where bureaucracy, politics, discussions, and values infiltrate knowledge-making (see Latour, *Science in Action*). Gerald Holton has noted that in addition to the traditional experimental-analytical model of creating scientific knowledge—which he labels as the x-y axis—there is a z-axis that must include imagination, dreams, spirituality, and other less quantifiable understandings. Elizabeth Parthenea Shea has also demonstrated that in the construction of facts, histories and narrations change the course of understanding (*How the Gene Got Its Groove*). Further still, the technologies that produce visualizations, or that calculate algorithms, become and remain "black-boxed" (Latour, *Science in Action*) only until anomalies are discovered outside of the predominant paradigm (Kuhn, *The Structure of Scientific Revolutions*).

This brief survey is not, by any means, exhaustive, but serves simply to suggest that ambiguity is a ubiquitous component of human understanding and scientific knowledge. If we are to understand visual literacy in the sciences, we must recognize that in the creation and communication of knowledge, ambiguity is not extinguishable, but rather that it exists in many forms and in many degrees. Ambiguity is complex and ambiguous, but the ability to dissect and investigate it by its many components—even if it is not possible to *entirely* dissect or discover *every* component—will significantly improve our understanding of how it affects communication and understanding.

By embracing ambiguity, we can understand it and effectively employ it. And, by doing so, we will open up channels for theoreticians and empiricists alike where both rhetorical affect and cognitive 'output' are considered. In the end, an embracement of ambiguity in science communication should provide a catalyst into improved visual literacy in the sciences and, thus, strengthened ethical awareness about how what is communicated ambiguously transfers into what is known about reality.

The remainder of this dissertation follows a path for discovering how visual ambiguity might function as an epistemological bridge between the art and science of scientific communication in order to, in a practical sense, improve visual literacy. The chapters that follow do not comprise an in-depth philosophical endeavor to expose ambiguity as an ontological device that reframes the way science, as it exists in the human mind, is constructed. While there is value, no doubt, in that conversation (and some of it is adhered to here), the scope of this work is to more practically, through investigation of how ambiguity works, expose how visual ambiguities can be researched and adapted more readily into scientific communication discourse.

As such, Chapter 2 investigates what visual ambiguity might be said to consist of, and works through the challenges of paradoxically reigning in ambiguity enough to expose where and how it exists in visual representations. Chapter 3 explores how we might further codify visual ambiguity—for the purposes of inserting it into scientific communication and visual literacy discourse—by applying theoretical perspectives on taxonomy. Chapter 4 shows the construction of a Taxonomic Wheel of Visual Ambiguity and further develops a heuristic, a Tetradic Model of Visual Ambiguity, whereby scientific communicators may rhetorically analyze visual representations of science. Chapter 5 then demonstrates the application of the Tetradic Model on Norman Barker's "Osteoporosis" as an example of how we might rhetorically and empirically analyze the role of visual ambiguity in the meaning making process. In conclusion, Chapter 6 addresses the limitations of this theory and Tetradic Model of Visual Ambiguity as we look to further research in visual literacy in the sciences.

CHAPTER TWO

SCIENTIFIC COMMUNICATION AND THE LANDSCAPE OF VISUAL AMBIGUITY

> "One way of considering the invention of modern science is as a transformation of our way of looking."
>
> -Francesco Panese, "*The Accursed Part of Scientific Iconography*"

Allusions to the inescapability of visual ambiguities in most or all representations of science were made in the opening chapter. Such references may be considered audacious, perhaps even brash, to those who seek clarity and precision in scientific communication. The goal of a claim about ambiguity's presence, however, is not to subvert or disavow the importance of clear communication. Rather, such a claim seeks simply to enrich and peer deeper into what "clear" communication might actually mean. Admittedly, though, embracing ambiguity as a viable approach to improved visual literacy in the sciences does require a change in perspective from traditional clarity-driven approaches. It requires an acceptance of ambiguity's influence (perhaps even *fundamental* influence) in the way meaning is made. If ambiguity is *not* pervasive in scientific communication, then it is likely eradicable, and there would be little reason to pursue ambiguity further. If, however, ambiguity is inevitably attached to scientific thought and communication, scientific communicators ought better to understand how, where, and to what extent.

With this in mind, the present chapter operationally explores the ubiquity of visual ambiguity by reviewing perspectives on visual communication from a number of disciplines.

The Paradox: Clarifying Ambiguity

Paradoxically, then, this chapter seeks to first *clarify* ambiguity by attempting to distinguish its characteristics, origins, and effects on meaning-making. Indeed, such an attempt may sound like a deeply philosophical endeavor that may provide more questions than solutions. To those who wish to glean a practical toolkit for designing with/without ambiguity, it might sound like fruitless wishful thinking. After all, ambiguity *is* ambiguous. Doesn't clarifying ambiguity essentially kill it? And is that not what science has been trying to do all along—clarify and eradicate? If ambiguity *is* inescapable, can it really be made clear? Why, then, even attempt to "clarify" ambiguity? William Empson, after all, in his famous treatise on the *7 Types of Ambiguity* suggested attempted delineation of ambiguity might only create more questions than solutions:

> 'Ambiguity' itself can mean an indecision as to what you mean, an intention to mean several things, a probability that one or other or both of two things has been meant, and the fact that a statement has several meanings. It is useful to be able to separate these if you wish, but it is not obvious in separating them at any particular point you will not be raising more problems than you solve. (6)

If delineating components of ambiguity might only raise more questions and problems about the presence of ambiguity in visual representations of science, is there even a point? To this, I would simply but emphatically say, yes!

Literacy, as we well know, does not solve the world's problems, not even communicative ones. It does, however, germinate awareness of the problems' roots and reaches. An attempt at visual literacy that embraces ambiguity acknowledges the nuanced communicative means that inevitably alter meaning. Clearly, the concept "clarifying ambiguity" is a blatant oxymoron. But if nature is to be viewed as the vast and boundless fountain of untapped knowledge and science is the device used to tap into and codify that knowledge, then the idea of science itself is likewise paradoxical. On the one side we believe that the task of knowing everything is beyond the capability of man. On the other, we believe that at least if we attempt it, we will know more than we did before. Any attempt to clarify visual ambigiuity, as Empson attempted with literary ambiguity, ought not be considered *the only* approach, but one of several that provides insight—helps us know more than we did before. The attempt in this chapter to clarify visual ambiguity serves not as *the* authoritative review that dictates all of visual literacy in science. Rather, it is a working codification of how human nature and nature itself have worked together and at odds with each other in order to *better* understand the communicative effects of visual representations.

To clarify how ambiguity functions in scientific communication, science must be viewed, at least in part, as socially constructed. Effective visual literacy in the sciences embraces the idea that histories and societies, indeed even the histories of institutions and their socio-cultural underpinnings, shapes the very way in which knowledge is perceived and gained. Blind acceptance of scientific method (and, particularly, images produced with that method) as knowledge naively fails to consider that science as we know it is restrained and formulated by economic, political, moral, and technological conditions that have evolved and shape-shifted in time. Despite the controversy over his work, a scientist wishing to embrace ambiguity as an integral component to improved visual literacy must accept Bruno Latour's admonitions about science as a humanistic endeavor: that it is always "in action." Science as we know it is a construction of facts through complicated decision-making processes that mold the formation of a scientific theory or experiment. While it is convenient and often politically correct (in many scientific circles) to claim that science is simply based on strict method, rationality, and procedure and that is all that matters, true visual literacy in the sciences recognizes that the visualizations juxtaposed with a scientific argument have been produced throughout a timeline of actions and decisions much less "scientific." Latour states:

> Some scientists talk about science, its ways and means, but few of them accept the discipline of becoming also an outsider; what they say about their trade is hard to double check in the absence of independent scrutiny. Other people talk about science, its solidity, its foundation, its development or its dangers; unfortunately, almost none of them are interested in science in the making. They shy away from the disorderly mixture revealed by science in action and prefer the orderly pattern of scientific method and rationality. (15)

Science is, in reality, a social endeavor, informed by men of antiquity where the conversation contemporarily spills into journals, media, universities, laboratories, politics, board rooms, and marketable products. The images that are produced for scientific purposes do not magically appear, without context—they are the derivative of thoughtful (and sometimes painful) processes that involve technologies and technological know-how, finances, politics, publication restraints, and so forth.

After all, what we know to be scientifically "true" is only so until new knowledge, epiphanies, or "anomalies" make people think about reality in a new way, when they break away from what Kuhn has noted as the accepted paradigm (*The Structure of Scientific Revolutions*). An image that might stand as representative of osteoporosis today could by tomorrow exhibit a new nuance that will be rejected by the osteology community. New knowledge is always lurking at the crux of ambiguity circumnavigating a scientific thought. What we perceive to be accurate in a visual representation of science has been "black-boxed" by the authority of the scientist, journal, or organization who published it. In other words, if we view a scientific representation published by someone or some entity of credibility in the field, it is easy for us to disregard any present ambiguities created in the history behind its production. We naively make direct correlation between the image and the real world.

But I do not use the term 'naively' in contempt or as an insult. Human nature somehow leads us to accept that "seeing is believing." It is our imperative, then, to unlearn what we see as clear and expose and exploit what ambiguities are hiding behind the rocks.

I am not the first to address this; certainly there is recognition that ambiguity affects understanding. However, a common contemporary method for improving our understanding of ambiguity in science and instruction has been to understand how ambiguity *infects* communication, rather than how it more broadly *affects* communication. This method has been used to discover concepts that disrupt communication and learning. Researchers in instructional communication, for example, have attempted since the 1970s to understand how clarity can improve learning retention in scientific instruction. To do so, they have assigned concepts related to ambiguity such as "vagueness terms" (Land); "discontinuity" (Smith & Cotten); "seductive details" (Harp & Mayer); and "affect cues" (Titsworth). Terminologies like these have provided productive points of reference for those creating particular documents. Textbook designers, for example, have been able to learn from this scholarship that certain types of images and stories about images (like a person being struck by lightning in a chapter on meteorology) have the ability to "distract," "disrupt," and "divert" attention from the concepts intended to be taught (Harp & Mayer 1998). Hence these ambiguous elements are encouraged to be left out of certain communications. What is left out of this research, of course, are the places where ambiguity is inescapable. Or, where it is actually useful.

Chapter 4 references this kind of scholarship, though in a different light, particularly focused on the broader effects of ambiguity. Using terminology to categorize, a taxonomy is established in order to demarcate useful terms associated with visual ambiguity. However, it is clear that stronger literacy in visual communication stems from a more thorough investigation that looks beyond the formal elements (design, colorization, cropping, and so forth) of scientific images. Ambiguity materializes in visual communication of the sciences as a result of a host factors beyond just the details of design and imagery. Societies, histories, rhetoric, and human disposition play a much more fundamental role in the way visual representations are understood than the more streamlined and perfunctory ambiguous visual elements might. This chapter establishes a "landscape" of visual ambiguity, a socio-historical, rhetorical, technological, and metaphysical approach to the presences of ambiguity in scientific communication. Here, I address a foundational review of how ambiguity makes its presence in scientific communication and thought.

Socio-Cultural Histories of Visual Ambiguity in Scientific Communication

To begin with, a review of the societal and organizational influence over visualization practices follows. A society's social and cultural value system has incredible influence on the way that science is practiced, communicated, and accepted. Societies in history have altered the direction of science as they determined what was valued and what belonged in certain social and political circles. As Paul Feyberabend has indicated: "Even efficient knowledge may be rejected because of the way its acquisition disturbs important social values" (29). And further: "Values affect not only the application of knowledge, but are essential ingredients of knowledge itself" (28). An exploration into visual literacy in science must evaluate the social histories that have shaped the way science has been and continues to be visually represented. Much has been documented in regards to the histories of visual communication in science (see Brian Ford's *Images of Science*; Lynch & Woolgar's *Representation in Scientific Practice*; Brian Vickery's *Science Communication in History*; or Peter Achinstein's *Scientific Rules* as a starting point) thus this section makes no attempt to capture an entire history of scientific communication. Rather, it summarizes perspectives about the socio-cultural role in forging milieus of ambiguity in scientific representation.

The production and acceptance of scientific visualizations has had a unique historical background that has wrestled with socio-cultural influences of art and imagination in contrast to science since man walked the earth. In the present dissertation, the subject is approached in the same manner that Judith Wechsler has done, claiming that with art and science, "there is no *a priori* essential epistemological way of seeing" and that "aesthetics [are]… a mode of cognition which focuses on forms and metaphors used in scientific conceptualizing and modeling" (6). Because ambiguity often finds itself positioned within the locus between artistic expression and objective reason, improved visual literacy must include recognizing the historical divisions between art and science. Scientific movements (or paradigms) in history have swayed in and out of acceptance of expressionist art and meaning making, therefore, has been reliant upon both aesthetics *and* reason, though the focus has shifted in different cultures and time periods. Improved visual literacy in the science, thus, means apprehending that histories of scientific representations have experienced varied cultural acceptance of certain kinds of images for certain purposes and at different times, sometimes favoring aesthetics, other times favoring methods. In Western culture, we must recognize that for centuries, emphasis has been placed on methods, marginalizing aesthetics in epistemological debates. In other words, societies and cultures have been the dictators of what is accurate, oft times disjointing science's and art's epistemological imbrications. Ambiguity, it might be inferred, frequently finds itself where the clarity of science is interrupted by the influence of aesthetics, and, by association, the values, bureaucracies, and social systems that play within that bifurcation.

While some have claimed that the oldest of cave paintings are the beginnings of art, Ford emphatically suggests that, because of their obvious instructive and diagrammatical nature, “these images were not art, but science” (7). According to Ford’s perspective, art came later with the development of weaving and pottery and the images of prey and war eventually turned to images of decoration. But it might easily be argued that there has always been a great overlap between the two. Expression, after all, is imaginative and for millennia humans were reliant upon the imagination to visually depict phenomena they were trying to understand. This becomes clear as we reflect on Galen’s work around A D 200, where he imagined the inner workings of the human body without ever dissecting one (although he dissected animals.) Interestingly, though, during what Westerners often consider the birth of scientific thought at the time of Plato and Aristotle, there seems to be little attempt to *visually* represent science. Aristotle classified plants and animals verbally and textually (which led to encyclopedic compilations of nature by Lucretius and Pliny the Elder), but attempts to do so visually in a scientific way came much later (Ford 17, 31).

Seventeenth century science and those associated with the development of what we now call the *Scientific Revolution* made it a priority to separate artistic visuals from those scientific. Objectivity became an ideology that eventually polarized the two domains. Hüppart and Weingart note that 17th century illustrations of science tended to include works that could be seen as aesthetic works of art and scientific collections at the same time (making reference to Joan Blaeu's *Atlas Major* and Albertus Seba's *Thesaurus*). However, Hüppart and Weingart further note that while acceptance of these works was given in important scientific circles, the illustrations had to be representative and justifiable to popular narratives of the time. As Da Vinci, Newton, Descartes, and others that initiated important strides in scientific development produced scientific works, new standards were being built for what could be defined as truth and objectivity. Eventually, they Hüppart and Weingart continue, "a separation of aesthetic values from the information value" emerged (7). Visually representing science became a practice not of imagination and exploration, but a way of visually *copying* what scientific research had already discovered. The introduction of photography into science continued this tradition (and still does, in many ways, today). Illustrations and photographs quickly became ancillary devices that were helpful to inform, but did not *produce* the knowledge. Hence, aesthetics have been, for the most part, ignored (8).

Ford's extensive collection of images in his *History of Scientific Illustration* tells a similar story. While images of science persisted through the middle ages (Ford depicts a 13th century English diagram of the nervous system and an Arabic portrayal of the human eye around 1000 AD, among others), the domains of aesthetics and art for decorative purposes—rather than for science and medicine—tended to dominate the production of visuals for centuries. As the Scientific Revolution gave rise, the imaging of science resurfaced as an integral part of scientific thought. The convergence of art and science in visual representation during this time created a hotbed of controversy over what should be accepted as scientific and what should not. Depictions of science such as Jean Bauhin's *Historia Plantarum Universalis* and the *Physica Curiosa* by Caspar Schott—despite their meticulous attempts to understand nature and inexplicable phenomena through visual representation—were discarded by the Royale Society because of their connections to religion, mythology, and curiosities. Scientific images that attempted to mix folk knowledge with empirical knowledge were simply considered idealized, much like our science fiction images might be today (Panese).

Francesco Panese describes the events of the 17th century focus on empirical, objective representations as a direct byproduct of the Baconian proposition to archive nature as accurately as possible—which quickly included the visual cataloging of known species of plants and animals. What initially emerged were narrative compilations that integrated ideological understandings of nature with scientific ones, where illustrations demonstrated a "visual and ideological synthesis of a system of knowledge in which things seen and things said are linked to one another" (64). According to Panese, religion, politics, ideologies, *as well as* descriptions of plants *all* initially found their way into the account of nature. Bauhin's *Historia Plantarum Universalis*, an attempt to create a universal botany through depictions of plants, narrates a story beyond inclusion of strict scientific method as we know it. *Historia*, rather, infiltrated conversations with and images of classical Greek authorities and philosophers and God himself. The production of knowledge from works like these established broader understandings of science as they were perceived by human curiosities. Blaes' *Anatomie Animalium*—a similar endeavor in scope (to describe animal species) but very different in communicative approach—on the other hand, represented nature not through dialogue of the ancients or by giving a socio-cultural history, but by simply giving wordy descriptions of images. Consider what Panese says demonstrates the way modern science views nature similar to Blaes' method as opposed to the way Bauhin depicted it:

> [In the *Anatomie Animalium*] we no longer find any trace of the ancients at all, nor of time, nor history. In an open space, the lantern of Reason, armed with a magnifying glass and a scalpel, unveils a bountiful Nature around whom presses a docile crowd of animals. The entrails of these are displayed for us by two innocent cherubs. The right-hand angel rolls them out like a portraitist across a canvas, where they acquire a new visibility. He holds his scalpel—or his lancet—as we would a pen to fix the form of an organ on paper. This allegory of the world in writing deploys an idealized knowledge in which description *immediately* adheres to the real without recourse to any other register. (64)

Panese suggests that in Blaes' work, although still very different from the way science is often portrayed today, there is something very similar to the way science is contemporarily represented: "wordy descriptions that adhere to the visible without recourse to the commentaries of preceding observers or commentators. Its descriptions are ordered in classes, within which species are listed in alphabetical order. The image…is inseparable from the text" (67). Acceptance of Blaes' approach over those similar to Bauhin's by those in the appropriate social ranks eventually led to images published in scientific journals without reference to God, ideology, politics, and so forth.

What was seen was supposed to represent *precisely* what it depicted. The visual referent, in other words, was to be considered a faithful simulacrum of the real thing and aesthetics, once again, was set aside.

Other visualizations that made direct connections to nature as it could be practically observed and experimented upon—images of insects, machines, anatomical formations, and plant life—were given the thumbs-up for educational use and were filtered into classrooms as wall charts and textbooks. And it appears that, as long as a visual gave the appearance of scientific and empirical rigidity (that it did not attempt to address the metaphysical world or obscure, inexplicable deformities of nature), it was given clearance. Panese writes: "From the experimentalists' perspective, curiosities were not…worthy of consideration unless it was possible to fix them somewhere within the regularly ordered system of nature" (80). This system of nature somehow did not seem to include aesthetic consideration. Hence, what was produced in relation to the sciences in the 19th century was much more diagrammatical, the intention being to supplement the science, but without regards to its influence *on* the science. Under this mindset, a sudden surge of scientific images were used to communicate anything from "Greek and Roman war machines," to "[processes] of beer production," to "health and hygiene" campaigns (Bucchi 91 – 93). Within a short period of time, scientific images transformed from "capturing" and "cataloging" nature, to teaching and disseminating it, without much reflection into aesthetics, histories, and cultures.

As the 20th century approached and as printing and publication technologies improved, mass production of scientific images became a norm, although always under the guise of objectivity. Despite the socio-political processes for creating and disseminating images, visual representations just became the ancillary component of science and they were simply expected to faithfully mimic the rigorous research that informed them. Mark Tansey has suggested that "in a world increasingly driven by advertising and governed by televisual technologies and computer networks, things become images and images become real" (20). Scientific illustrators were hired to observe and replicate and it was just assumed (as it often is today) that the images are a product of truth, a simply re-mediated version of the science experiment, phenomenon, and writing. What becomes ambiguous is when we investigate the production cycle of the image and the organizations that oversee its dissemination and the aesthetics that exist but are not attended to. What a society chooses to value greatly changes what is both represented *and* "seen." In Western culture, this often means that aesthetics are devalued or disregarded in appraisal of the scientific method.

Perhaps one of the most widely used scientific textbooks in human history is Henry Gray's *Anatomy*. In 2008, the 40th edition of the book was published and is still circulated and used by medical students today, nearly 150 years after its first publication. In 750 pages, with over 350 meticulously drawn illustrations, this book has become known as a staple for understanding the human body. Ford suggests that such a book was the product of an evolution in scientific communication. While images have been purportedly used for scientific (rather than artistic) purposes since the earliest known man, their use, function, and acceptance has varied widely throughout the annals of time. Gray was a Fellow of the Royal Society (elected at the young age of 25), a good indication that his publications and the illustrations within them were widely accepted by the scientific community of his time. But illustrators and scientists over the millennia have not been similarly praised for their attempts to visually document nature and scientific phenomena.

Science, as a function within a culture, is reliant upon the values systems of governments, institutions, and religions—established by small and large groups of people with divergent perspectives. This might be best clearly explained by referring to Ford's example of Arab scientist Avicenna (Abu 'Ali al-Husain ibn Abdallah ib Sina at Ashana, his birth name) who used others' descriptions of medical science because he was forbidden to dissect a human body himself, as it was outlawed in the Qur'an (34 -35). The communication of science is heavily contingent upon societal apparatuses that dictate the processes for developing and disseminating research and observations. Our present day Institutional Review Board (IRB) and the Health and Science Communications Association (HeSCA) are examples of the protocols and communities with which scientists have to adhere. Modern-day imaging of science comes with newfound challenges that might superficially seem to present more potential for visual ambiguity than in the past. Sixteenth century sketches of da Vinci's complicated machines and biological formations, for example, did not have to deal with the same kind of print publication pressures that scientists today do. Nor did Da Vinci develop his *Embryo in the Womb* drawing, for example, with color printing, design software, publication, and global distribution in mind. Today's visualizations are often created and published with myriad sophisticated visual/digital editing techniques coupled with a necessity to connect to theory, practice, and cultural acceptance that scientific communications of the past were not. Yet all visuals in the sciences, past and present, have dealt with socio-cultural, ambiguous nuances that affect meaning. Histories and societies *become* part of the ambiguous display in the scientific visual.

Current acceptance of the image's non-aesthetic role in the sciences has come in large part because of this history. But as technologies move us into an era where a very artistic rendering of cells is being used for instruction in Harvard medical schools, it's time to rethink the ambiguities that are lost or disregarded because of social, historical value systems in the sciences.

Linguistic-Rhetorical Ambiguity in Visual Representation

Ambiguity is not present, however, simply because the histories and societies that produced an image are unclear or mistaken. We might be well aware of the socio-cultural history surrounding the production of an image. Certainly, reduction of historical, socio-cultural ambiguity is feasible as a scientist or observer becomes aware of the social and historical circumstances that led to its production and acceptance. A much more difficult kind of ambiguity to work with is linguistic-rhetorical ambiguity.

Francis Bacon's disdain for rhetoric is evident from his statements in the *Novum Organum*. But he, an empiricist, shares a very similar view on language as Noam Chomsky, a linguist: words are too "pliable" to be fixed by definitions (Bacon LX; Montgomery x). There is no escaping a word's ability to alter or affect meaning. The difference between Bacon and Chomsky, perhaps, is that Bacon hoped to somehow reign in the rhetoric. Undoubtedly, the methods he and others produced did well to productively serve empiricist guidelines for scientific communication. Whether linguistic or visual, though, many scientists of the past have followed Bacon's perspective, trying to resist the notion that rhetoric is a part of their communication. After all, rhetoric and ambiguity often become synonymous and they, from many scientists' perspective, hinder scientific development. But as Randy Allen Harris has argued rhetoric (and by association, ambiguity) is not an impediment to science—rather it is what allows progress by working through incommensurable perspectives in scientific communities (91 – 98).

It is true that rhetoric's inescapable relationship with science *is* becoming more and more familiar, though it is not yet accepted as a part of mainstream science. Latour, Feyerabend, and Kuhn, all renowned philosophers of science, have raised awareness of the subjectivity of scientific practice and the role that language, rhetoric, and values play in the development of scientific discourse and argument. Stephen Toulmin, a philosopher of reasoning, has likewise made important contributions to the way we understand argumentation in the sciences. Of particular note, Toulmin has emphasized how modal qualifiers, rebuttals, claims, and grounds are just as influential in daily conversation as they are in published scientific articles. And contemporary textbooks and handbooks geared towards scientific communication repeatedly emphasize that subtle nuances in language have great impact on interpretation of scientific knowledge (see Penrose & Katz's *Writing in the Sciences* or Russel's *Communicating Science*, for example). *The Chicago Guide to Communicating Science,* a book written in 2003 entirely for scientists, actually states "the flow of science, in form and articulation, has always been diverse, offering reasons for writers and speakers to both adapt and explore" (Montgomery x).

This same book also devotes an entire chapter to “creativity and elegance.” The term “rhetoric,” however, is almost entirely removed from these latter works.

A growing perspective, however, in the past decade or two has been a *tacit* awareness and acceptance of the role that rhetoric and language plays in scientific discourse. Chemistry Nobel Prize winner Roald Hoffmann, for example, has claimed that the publication of scientific information and research is wrought with ambiguous, rhetorical nuances (though his phrasing is different) that we often do not consider in relation to scientific method. On the publication of scientific articles in academic journals, he says:

> Much more goes on in that article than one imagines at first sight; that what goes on is a kind of dialectical struggle between what a chemist imagines should be said (the paradigm, the normative) and what he or she must say to convince others of his argument or achievement. That struggle endows the most innocent-looking article with a lot of suppressed tension. To reveal that tension is…not at all a sign of weakness or irrationality, but a recognition of the deep humanity of the creative act in science. (57).

Even still, despite the intermittent acquiescence to rhetoric in the sciences, rhetoric is not a widely praised area of discussion in scientific circles. “Rhetoric is a fascinating albeit despised discipline,” Latour states (30). Harris has suggested that this is a longstanding perspective that dates back to Cicero, when rhetoric increasingly became associated “with aesthetics at the expense of argumentation.” Harris further sheds light on this: “with the rise of scientific rationalism and the empiricist craze of the early modern period, aesthetic elements of discourse came to be seen as worse than merely pretty; they came to be seen as misleading, corrosive to truth and knowledge" (14 – 15). But the rhetorical means that human beings have to communicate information necessarily create ambiguous relationships between the scientific experiment and the communication of it. Whether or not it is accepted as a viable component to scientific discourse, it certainly has powerful effects on communication.

It is worth noting here Kenneth Burke's take on John Locke's description of *substance*. Science, by default, must have a subject matter. That subject matter, upon which a scientist bases his argumentation and experimentation, is defined and explicated in terms and in visuals. This "substance" is, for the scientist, his greatest strength of credibility. After all, Burke notes that, in his dramatistic method, *substance* is a scenic word—it is affected by the situation in which it is described. If the substance of a scientific report (argument) is accepted by the community for which it is written, the scientist has succeeded in moving that strand of research forward. What complicates this is that substance can never be fully understood by using words. Our communicative methods as human beings are limited by "antinomies of definition" and "[paradoxes] of substance" (*Grammar* 21). John Locke, describing the infinitude of description (using the example of an Indian man who says that the earth is supported by a great elephant, which, when asked, is supported by a tortoise, and so forth), suggests that "in all…cases where we use words without having clear and distinct ideas, we talk like children." Eventually, he says, we often have no response when asked deep enough about the substance of a thing or idea other than, "*it is something*" (qtd. in Burke 22).

Burke suggests that to get at the root of the substance of some *thing* or idea, we are reliant upon defining it in terms of something that it is not. We try to mark boundaries around an idea by using terms that "possess…contextual reference" (24). Thus, there is an "inevitable paradox of definition, an antinomy that must endow the concept of substance with unresolvable [sic] ambiguity" (24). Rhetoric from this perspective is necessary artillery for scientists—whether they like it or not—to work within communicative systems. And, regardless, communicative ambiguities will persist. What the scientist is required to do, then, is to establish the parameters ("circumference") of his or her scientific argument. "For we take [the scientist's experiment] to indicate," Burke suggests, "with the utmost clarity possible, the terministic relationship between the circumscription and the circumscribed. For no matter how much a matter of purely empirical observation it may seem to be, it actually is a very distinct choice of circumference for the placement of human motives" (78). In other words, we might ask: are the action(s) that the scientist is motivated to perform within the scope of the entire scientific community, or will he/she be trying to persuade only a small group of colleagues at a local research forum? And how will the communicative choices—the words, tones, and images shift as a result of this circumference? What is implied here is that ambiguity fluctuates within different circumferences, that it is always present, and that rhetoric is both a causer of—and a tool for working with—ambiguity.

What Burke discusses is primarily focused on the linguistic function of rhetoric as it is related to human action and understanding. But I would argue that these ambiguities present in linguistic argumentations in science are equally (though differently) present in visuals.

We might consider the work of Richard Boyd to make this transition between the rhetoric of linguistic ambiguities and that of visual ambiguities. In his article “Metaphor and Theory Change,” Boyd convincingly suggests that scientific theories are frequently built upon visual metaphors. Metaphors that scientists can mentally envision (examples he gives include electron clouds, worm-holes, or atoms as miniature solar systems) become part and parcel of the way the science is communicated and understood. And because “the establishment of a fundamental new theoretical perspective is a matter of persuasion, recruitment, and indoctrination,” visual metaphors rhetorically alter perception (359). Like within Burke’s antinomies of definition in linguist rhetoric, ambiguity infiltrates science as a result of *visual* metaphors in other but similar ways. Visual ambiguities crop up where there are gaps between the metaphor and its relationship to the scientific phenomenon; where one metaphor might be equally substituted by another metaphor to describe the same thing; or where the metaphor might make a loose connection between the theory and the real thing. Perhaps ambiguity is most prevalent, though, because of what Boyd argues is a principle of *ostension*, where scientists come up with metaphors to make connections between ideas that are otherwise difficult to define or explain in words. In an effort to understand, and to provide “epistemic access” to a community of scientists, metaphors are created (358). And while this is a very valuable, rhetorical practice for educative and communicative purposes, it seems apparent that this will often leave holes between the real thing and the way scientists perceive it.

Joachim Schummer, in an article on the origins of molecular nanotechnology in supramolecular chemistry, goes so far as to suggest that the aesthetics of shapely molecules "attract" chemists and cause them to assign metaphorical concepts to the way they look. Molecular images that look like baskets, he says, have been named "basketane" and ones that look like rotors have been named "rotane." Such images are "aesthetically attractive to chemists" Schummer states, "because they establish a symbolic link between the world of ordinary objects and the chemical world of molecules because of their interpretive ambiguity" (59). Perhaps even more interesting, scientists tend to assign functions to these molecules based on this visual metaphor. Basketene, because of their relationship with baskets, are suddenly thought to carry things. From a visual-rhetorical perspective, we might say that scientists themselves are being persuaded by visual metaphors assigned by nature and then interpreted. The ambiguity of these images rhetorically shapes they way science is constructed and perceived.

If we were to define visual ambiguity in a single word (and this is a big, hypothetical *if*), one term we might use to shed light on its rhetorical nature is 'polysemy.' Roland Barthes used this term to explain that images consist of a "floating chain of signifieds" where those observing an image have the ability—even if unintentional—to choose which signified is best representative of the signifier. Images inherently carry with them a multiplicity of meanings and it is the role of the author of that image and the society in which he or she produced it to direct an intended meaning at the viewer. "Hence in every society," Barthes says, "various techniques are developed intended to *fix* the floating chain of signifieds in such a way as to counter the terror of uncertain signs" (39). One way, Barthes suggests, to direct attention to the intended signified is through linguistic persuasion. When I initially viewed Barker's image of osteoporosis, for example, I mentally reverted to a dried oceanic sponge my parents collected when I was a child and displayed on their bathtub mantle for years. The caption atop the image, however, quickly took me fleetingly away from the depths of the ocean and my childhood memory straight to a woman's femur. Linguistically, rhetorically, my interpretation was diverted. The polysemy (the ambiguity) of the image was still there, but my attention—my understanding—was deflected.

In science, as mentioned above, images rarely stand alone—they are supplemental to the text and to the experiment. It is the connectedness of the image and language, perhaps, that makes the use and display of images seem so innocuous—if we explain the image in the text well enough, all pejorative ambiguity will be removed, right? As Barthes says, "The text *directs* the reader through the signifieds of the image, causing him to avoid some and receive others; by means of an often subtle dispatching, it remote-controls him towards a meaning chosen in advance" (Barthes 40). There is an interesting phenomenon that occurs when text and images are juxtaposed. Symbolic messages that relate to the observer's past, culture, and understanding are subdued by the text. Barthes mentions further: "the linguistic message…[constitutes] a kind of vice which holds the connoted meanings from proliferating, whether towards excessively individual regions or towards dysphoric values" (39). What Barthes is suggesting is that images have an initial power to project and shape understanding—that they tell us something before we can put words to it. The words then codify the image and mask (though not remove) the polysemous attributes.

The great fear here is that the image, again, is seen as supplemental. Text is perceived to dominate the understanding and what is seen is not considered as important as what is read. Yet the underlying polysemous nature of images makes them rhetorically powerful in often unforeseen ways. The image is not simply an auxiliary component to scientific communication—it shapes the way the science being communicated is understood. Punyashloke Mishra has commented on this rhetorical role of the image in science:

> Scientific illustrations function within the matix of science, with its hidden assumptions and biases. Quite often these biases are invisible to us at this moment in time and thus are quite insidious in their effect. Illustrations in a given domain are very dependent on the theory they are based on. This is not a one way street—a theory helps us "see" certain facts and then illustrate them; and these illustrations, in turn, support the theory. (193)

While it is convenient and optimistic to assume that plain language can trump the rhetorical nature of visual ambiguity, many image scholars have hinted that the ambiguities of the image (though they do not always use the term "ambiguity") have a profoundly rhetorical ability to persuade and shape understanding despite what the text juxtaposed to it says. W. J. T. Mitchell, for example, has argued that *ekphrasis* (where a person uses language to describe something visual) is virtually impossible. James Elkins, likewise, has suggested: "No two people will see the same object" (41). Regardless of what is written about an image or how an image is used as an ancillary device to the text, rhetoric will ambiguously alter the dimensions in which two people are capable of understanding it. Referring to Gorgias' argument in Plato's work about how sayings cannot describe colors, and further addressing Lyotard, Dobrin and Morey echo their arguments: "[Language] may rely upon the metaphor of sight and convey images within the mind, but ten words in a poem will necessarily omit the other 990 signifiers that real images can convey" (5). There is, in other words, no way to effectively override or completely steer meaning of a visual representation through linguistic control as Bacon had hoped. Visuals are simply far too rhetorically nuanced to be reined in by language.

Visual ambiguity, perhaps to the chagrin of inflexible, hard-nosed empiricists is an inescapable consequence of rhetoric's communicative influence. While control of language and the inclusion of linguistic classifications and nomenclature are productive scientific tools (placed in juxtaposition to images as a sort of meaning-making steering wheel), visually literate scientists must be cognizant of the conspicuously rhetorical affects on understanding that create inescapable ambiguities.

Ambiguity and "Black-Boxed" Technology

Further, improved visual literacy grasps the concept that technology mediates between real scientific objects under investigation and the images that display them. To assume that the visuals we observe are precisely mimetic representations of the real object is to simultaneously accept that the technologies that produced the representations are and always will be flawless. Paul Virilio has reminded us why we so often quickly, without compunction, accept photographs as accurate: because the machines that produced them (the cameras, microscopes, and telescopes) can do things our eyes simply cannot—they capture speeds and sizes and distances beyond the ability of the human eye (21). Perhaps intimidated by their superiority, it is easy for us to surrender to their remarkable sophistication. If we cannot see it with the naked eye, then the machine that can *must* provide accuracy, right? Perhaps these technologies are more capable than the human eye in certain domains, but they are still not necessarily capable of producing faithfully mimetic representations. And a representation that cannot be considered as accurate as the real thing ought to be considered a reproduction affected by technological ambiguity.

One of the conundrums with technologies of our time is that they are often complex beyond the knowledge of any one user. A microbiologist, for example, would likely know *how to use* a spectrometer, electron microscope, an electronic sterilizer and the high-tech software that accompany them to identify microorganisms, count cells, and compare their results with other studies. More than likely, though, many contemporary microbiologists would not know *how to develop* any of these tools on their own, nor fix them if a serious malfunction occurred. They may have cursory or even advanced knowledge of how tools are calculating and capturing their science. Likely, though, they do not know it well enough to understand all the technological nuances that shaped the results. The tools they use simply become "black boxed" (Turkle 59), a result nowadays partly because technology companies have a high stake in keeping their products' inner workings somewhat hidden from view, "keeping it a secret" (61). Sherry Turkle described a disconcerting (to some) dilemma that seems to be occurring as technologies improve: scientists, unable to fix or create technologies on their own, become hostages to the sophistication of the tools they use and the visual glamour they produce to the point where anomalies, glitches, shortcomings, and other ambiguities are ignored. Describing her colleagues' experiences, she recounts,

> When simulation pretends to the real, buildings look finished before they have been fully designed and scientists find no fault in "impossible" molecules that could only exist on a screen. Computer precision is wrongly taken for perfection. The fantasy, visceral in nature, is that computers serve as a guarantor, a "correction machine." (80)

It may not necessarily be that scientists do not acknowledge these shortcomings with technology (in fact, it is likely many do), but that with the pervasive influence of advanced technologies of today, scientists simply are learning to acquiesce. In this acquiescence, ambiguities in the coding of software and the function of hardware become less likely to be given attention. When the advancement of technology is reliant upon capitalistic enterprises and science becomes more and more reliant upon technologies produced by these entities, the tools that scientists once felt they had control over are no longer so controllable. Sure, there are gatekeepers who monitor the use and acceptance of certain technologies for certain scientific purposes, but assuring—through personal knowledge and technological training—that these technologies are entirely reliable is becoming less and less feasible.

This technological impasse in the sciences was perhaps first brought to the attention of scientists by Latour. Just as the discoveries of theories and methods are introduced to science through social, collective undertakings, Latour argues, so too do technologies undergo a process of trial and error. No machine is immediately capable of working out the glitches on its own—human intervention, decision-making, and a process of removing "endless little bugs…, each being revealed by a new trial imposed by a new interested group" will "eventually and progressively" make the technology do what it is intended to do (11). It might be inferred from this perspective that no technology can be considered error-free. Technologies are designed with purposes specific to the scientist, to an organization, or to an industry and they are only as powerful as contemporary human knowledge makes them.

Literate observers of visuals in the sciences, as a consequence, must attempt to recognize where technology has given or removed emphasis on a scientific idea. Formal elements of visual representations such as colorization, cropping, layout, and other forms of display include some of the more obvious technological ambiguities in scientific representations. Some of the less obvious technological ambiguities include the shutter speed of a camera, the algorithmic formulas that calculate size, width, and distance of objects in a telescope, or the subtle (perhaps non-existent to the human eye) distortions caused by a microscope lens.

Metaphysical Ambiguity and the Question of the Real

Lastly, visual literacy in the sciences recognizes that, outside of method, the human mind is prone to learn and develop science through creativity, imagination, dreams, and extra-sensorial affects caused by communicative elements. Ambiguity, in other words, infiltrates the design and representation of science as a result of the communicator's and the observer's sense of self. Scientists may hope that a visual representation used to explain a phenomenon provides clear, straightforward understandings of information that will lucidly translate to their audience. Artists and graphic designers, however, often contend that interpretations of visual information are based on human experience that trumps methodical and organizational processes. One might recognize metaphysical knowledge as the wedge that commonly divides the design fields of usability and user experience. The former will generally contend that the design of information follows "universal principles" (Tufte *Envisioning* 10), that information design is synonymous with "efficiency and effectiveness" (Horn 16), and that if it is effective, the design should never be noticed (Albers 6). The latter, however, will often argue that traditionally scientific approaches to design consider only "predictability, repeatability, and mathematical quantifiability, …[precluding] intuition, subjective judgment, tacit knowledge, dreams, imagination, and purpose" (Cooley 60).

What is in question here is the way in which information is processed and whether or not the visual display of it is affected by individuality. It is a question of epistemology in relation to visual communication. Can, as Albers suggested, information be designed so that the design is not noticed? While his point is made clear, and there is value in attempting to make the design of information perfunctorily straightforward, it can easily be said that design *always* affects understanding, whether it is noticed or not. Visual literacy in the sciences, as a result, must be willing to accept that, epistemologically, ambiguities emerge as components of the design affect individual understanding.

It is not the intent of this section to exhaust the countless and sundry ways in which human knowledge has been philosophically explored and how systemic organization of information affects understanding. Whether the mind is logical and knowledge can be traced through experiences (as John Locke argued) or whether the mind functions primarily on *a priori* subjective senses of being (as Hegel suggested) or whether knowledge is a built upon some combination of the polarizing viewpoints of empiricism and metaphysics (as Kant and Ficthe claimed) we may never entirely resolve philosophically. But it may be inferred from the landscape of ambiguity that I have outlined in this chapter that I believe effective visual literacy in the sciences must at least lean towards Kant's and Ficthe's arguments: that metaphysical, "spiritual" (Fichte's term) knowledge informs experience-based understanding and when they work in tandem, human knowledge is more complete. Fichte claimed that the spirit of human consciousness "is the ability of the productive imagination to convert feelings into representations" (Breazeale 199). His argument was that the function of the human spirit was to inform and raise awareness to what we experience in the real, physical world. Kant's description of the way we cognize an image in the mirror provides similar understanding. "These objects [hands, ears, faces in the mirror] are surely not representations of things as they re in themselves," Kant says, "and as the pure understanding would cognize them, rather, they are sensory intuitions, i.e., appearances, whose possibility rests on the relation of certain things, unknown in themselves, to something else, namely our sensibility" (41). What we might pay attention to in these lines of thought is that empirical knowledge gained from experience and experimentation will be informed by ambiguous and malleable subjective interpretations.

Partly in response to the crisis in empiricism based on Hume's critique of Locke and others, Heisenberg provided a radical and important way to look at the seemingly "non-objective science" of quantum physics. Rather than be grounded in *a priori* knowledge, where our "sensibility" affects our "sensory intuitions" (Kant 41), Heisenberg worked with this problem of uncertainty and argued that accounts of subatomic reality must include probability functions to account for the uncertainty of knowledge in science at the subatomic level. In discussing quantum theory, Heisenberg notes that a probability function is built into the way the Copenhagen school of science recorded the motion of an electron in order to account for what we cannot know. In the Copenhagen School of quantum mechanics, at least, probabilities are used to fill in our deficiencies of empirical knowledge. "The probability function combines objective and subjective elements," Heisenberg argues; "It contains statements about possibilities or better tendencies ('potentia' in Aristotelian philosophy), … and it contains statements about knowledge of the system, which of course are subjective in so far as they may be different for different observers" (53). The issues of subjectivity and objectivity in science are many, but we might at least acknowledge this: that because of the dichotomy between mind/senses/technology, and nature, *a priori* knowledge (whether Kant's 'categories of pure reason' or Heisenberg's probability function) reveals the existence of ambiguity in accounts of quantum mechanics—whether in expert or public scientific communication—and although not widely accepted in science, perhaps in nature itself (Heisenberg 58).

One way to look at the metaphysical ambiguities in scientific representation is through the metaphorical *x-y-z* axes described by Gerald Holton. Holton suggests that, in traditional scientific practice and thought, science is thought to be discovered and represented in two important ways: empirically (which he labels the x-axis) and heuristic-analytically (which he calls the y-axis). Western scientific discovery has found these two axes to be the most convenient and efficient way of propagating science. Quoting Karl Popper, however, Holton suggests that there is a third dimension that greatly influences the way we understand and explore scientific concepts: through "faith in laws," "anticipations, rash and premature," and "prejudices"—which he labels as components of the z-axis. "This third dimension," Holton says, "is the dimension of fundamental presuppositions, notions, terms, methodological judgments, and decisions" (41). As scientists explore and investigate topics, they are influenced by human nature, which drives them to be influenced by metaphysical characteristics outside of traditional scientific boundaries. Holton suggests that as human beings, we live effortlessly in the z-axis, that without training or "conscious formulation," we interpret communicated subject matter in particular ways. Scientific practice, he says, teaches scientists to think differently, though, leading their discussions and research through a perhaps narrow-sighted x-y axis that doesn't recognize the z at work (46).

This *z-axis* is an inescapable part of scientific discovery (and by association, scientific communication). We learn through a series interconnected ideas that are influenced by our personal histories, life experiences, and worldviews. Michael Polanyi labeled this mode of understanding as "tacit knowledge," where "a range of conceptual and sensory information and images that can be brought to bear in an attempt to make sense of something." The idea of tacit knowledge suggests that when discrepancies occur in science between theories and observations, personal assessments and judgments must be made about what to do next. "We may conclude," Polanyi says, "that no science can predict observed facts except by relying with confidence upon an art: the art of establishing by the trained delicacy of eye, ear, and touch a correspondence between the explicit predictions of science and the actual experience of our senses" (31). The observation of a scientific representation will be reliant upon z-axes, and tacit knowledge domains, influenced by areas difficult to define within the scientific method.

We might question, then: what is to be considered real? If scientific communication only accurately represents science to the extent that the mind is able to remove itself of human penchant and blurred connections between the self and the world, can science ever be thought to be "accurately, one-hundred percent correctly" represented? The short answer is "probably not." What the visually literate scientists takes from this, though, is that these ambiguities in human understanding shape our knowledge into what we perceive as real—perceptions that are, undoubtedly, real. And while there is nothing wrong with perceiving scientific discoveries as real and accurate (we must, else we drive ourselves crazy)—we must be willing to accept that while reality *does* exist, what is *communicated* as real is only ambiguously so.

CHAPTER THREE

AMBIGUOUS APPLICATION: FROM LITERATURE TO PRACTICE

> "Instead of considering it our task to "dispose of" any ambiguity by merely disclosing the fact that it is an ambiguity, we rather consider it our task to study and clarify the *resources* of ambiguity."
>
> -Kenneth Burke, *A Grammar of Motives*

Making Use (and Sense) of Visual Ambiguity

The landscape of literature on visual ambiguity discussed in the previous chapter places scientific representations in a frustratingly complex matrix of meaning making. As I have described, past rubrics that have identified grammatical and formulaic elements of visual representation and design—while useful in their simplicity—seem to fall significantly short of a holistic understanding of visual communication that addresses this matrix. Perhaps inferred from the literature in Chapter 2 describing socio-historical, linguistic-rhetorical, technological, and metaphysical loci in which visual ambiguity emerges, the inescapability of visual ambiguity presents a pressing problem: not only is visual ambiguity ubiquitous, but the broad ways in which it is present is seemingly so ambiguous in and of itself that it is beyond our ability to effectively approach or harness it. The trick, then, is to discover the nuances of visual ambiguity and its effects on communication in a way that we can productively make use of it—that is, make it applicable to improving visual literacy—while not denying its own ambiguous nature.

As I pointed to in the first two chapters, scholarship in visual communication has indeed addressed the sundry ways in which visual elements affect understanding. (For the purposes of this chapter, "visual elements" refers loosely to *any* perceptible visual component of an image or design, including shapes, colors, or pixilation, as well as entire objects, like a cell or human being). However, literature on the visual communication of science seems to be fragmented, usually focusing on only one domain of meaning-making. Graphic and information design specialists, for example, tend to rely heavily on concepts related to usability and readability. Tufte's *Envisioning Information*, for instance, has presented concepts like "chartjunk," "flatland," and "micro readings" to address the practical, mechanical elements of visual usability; Williams' *Non-Designer's Design Book* has proposed "contrast," "repetition," "alignment," and "proximity" as four primary design strategies to improve readability; and Bang's *Picture This* has suggested smoothness, rigidity, color, and location of shapes affect understanding (*Picture This*). Those in social studies have pointed to "social semiotics" (Van Leeuwen, *Introducing Social Semiotics*) and "grammars" (Kress & Van Leeuwen) of visual design, where societal values influence design characteristics. Many others have addressed the broadly construed concept of language and rhetoric and their synchronous relationship with visual representation (Roland Barthes' "The Photographic Message" is a good example of the language-image juxtaposition discussion). Each of these areas of visual communication tend to be treated solitarily, which seems to (even if unintentionally) autocratically pigeonhole and elevate one area because it ostensibly pulls more communicative weight than another.

While visual ambiguity has not been expressly discussed as an important part of visual literacy in these works, ambiguity does, in fact exist in each of these areas, functioning much like a network of communicative tributaries that, streaming simultaneously through multiple visual channels, feeds into a larger communicative body, like an estuary of mental interpretation. Utilizing the concept of visual ambiguity for research and practice, in other words, means embracing the *many* diverse streams of visual design that share part—sometimes equally, sometimes not—in developing the body of understanding.

To carry this metaphor further, we might look at it this way: Chapter 2 established at least four major tributaries, or what we might call "domains," in which visual ambiguity overtly affects interpretation: socio-culturally, linguistic-rhetorically, technologically, and metaphysically. Under this four-part perspective of visual ambiguity, a viewer's "estuary" of interpretation and reaction to visual elements of a design or image is influenced (fed) by one or multiple domains (tributaries) and even more dimensions and types (brooks or creeks) of visual ambiguity. These domains, dimensions, and types of visual ambiguity are outlined in detail in Chapter 4. The present chapter identifies reasons, complexities, and ways of doing so.

As an attempt to improve visual literacy in the sciences, it seems appropriate—even imperative—to develop a systematic (though still ambiguous) map or grid that categorizes and directs researchers and practitioners to the domains of visual ambiguity.

This means generating something that, in reality, is not entirely possible, at least not in totality: a taxonomy of visual ambiguity as a means to approach meaning-making and literacy from divergent but equally valid communicative domains. All of the possible nuances of visual ambiguities will likely never be exhaustively delineated, but an attempt to do so makes effective visual literacy training in the sciences at least more feasible.

Reverting to the oxymoron about "clarifying ambiguity" that I mentioned in Chapter 2, classifying visual ambiguity in a taxonomy—separating it into domains (and further into dimensions and types)—appears on the surface to be inherently flawed because of its inability to be complete. It may be argued, in other words, that visual ambiguities will always emerge in new and unexpected ways as societies, languages, technologies, and people continue to evolve—thus a taxonomy of visual ambiguity will forever exist with gaps and holes. As I mentioned earlier, however, this is not much unlike the relationship with science and nature. Science (a metaphor in this case for taxonomies) will never be able to completely define and codify nature either, despite what empiricists and positivists have long argued.

Thomas Sprat and the Royal Society, as we know, hoped science could effectively systematize and catalogue nature; these empiricists (and their predecessors centuries before them) worked to set up standards so that science could be, in Sprat's words, "[rendered] an instrument whereby mankind [could] obtain a dominion over things" (62). Empiricist philosophies in antiquity hoped for scientific practice whereby "the colors of rhetoric, the devices of fancy, or the delightful deceit of fables" could be entirely removed or at least minimized (62). This "naïve empiricist" perspective sought to understand how the world could be best discovered, epistemologically, while minimizing the effects of language and metaphysics. Naïve empiricists, despite this hope, were always cognizant of a blurred reality affected by faulty sensoria and the complex epistemological problems created with language. They may have loathed these inhibitions, but they would not disregard them. For many, empiricism transformed (evolved) into what is often referred to as "logical positivism." Positivists, such as Alfred Ayer, have more recently suggested that if any meaningful problems are to be resolved in any meaningful way, they must be evaluated with rational methods, protocols, and verification practices. He stated:

> No statement which refers to a "reality" transcending the limits of all possible sense-experience can possibly have any literal significance; from which it must follow that the labors of those who have striven to describe such a reality have all be devoted to the production of nonsense. (34)

Under this logical positivist perspective, science could not only be entirely objectified, controlled, and discovered, but limited to sense experience. Over 350 years since the induction of the the Royal Society, many scientific disciplines have attempted to grapple with these conundrums. Some recognize science as objective *but also* impressionable and socially constructed (Latour) and always evolving (Kuhn). Paul Feyerabend's argument for "epistemological anarchy" (which suggests that scientific practice is built upon the premise of a multiplicity of incessantly overlapping theories) as more logical than the reductionist perspective of methodological monism is particularly poignant. Science, according to the philosophical movements brought about by these scholars, is an evolutionary process, rooted in society and culture, affected by values, and much more open to interpretation. A taxonomy of visual ambiguity derives from these perspectives. Even though modern empiricism has its roots in Baconian science, which openly acknowledged that the human senses can deceive and that rhetoric is difficult if not impossible to escape, Western science has tended to often remain in a chokehold with the strict propositions of scientific method, the eradication of subjectivity, and the early works of the Royal Society. A taxonomy of ambiguity embraces the hope of early empiricists; its purview involves epistemologically reigning in otherwise abstract communicative practices of science. Yet, at its heart, such a taxonomy encourages adaptability and interpretation; it isn't entirely anarchist, but it is not unbendingly regulated and objectified either.

Furthermore, it may be said that the complexity of concepts like society, culture, rhetoric, technology, and metaphysics, not to mention ambiguity itself, resists the notion of being reduced to the static nature of a taxonomy because taxonomies suggest an inflexible framework and terminology. While there is certainly value in this claim, depending on perspective, a taxonomy does not have to be comprehensive nor does it have to be rigid and unbending to be useful. Rather, we might look at it as serving as an important *first step*, always evolving, because it provides the basis for a lexicon and nomenclature from which to work and further investigate. As Robert Houghton noted in relation to the widely recognized Bloom's Taxonomy, "before we can make [the nature of thinking] better, we need to know more of what it is. [Bloom's Taxonomy] helped to create a standard around which further work could be done" (Houghton). Additionally, we might view a taxonomy not as a one-size-fits-all categorizing *solution*, but as a rhetorical device with which to shape interpretation of visual ambiguity. Alan Gross, for example, suggested that while taxonomies are intended to concretize science by differentiating species, they are in themselves rhetorical; he hints that they *persuade* by means of their practicalities of classification while being susceptible to change and interpretation. Consider his statement here on taxonomies built for evolutionary biology:

> By means of rhetorical reconstruction, evolutionary taxonomy is transformed into an interlocking set of persuasive structures. *Sub specie rhetoricae*, we do not discover, we create; plants and animals are brought to life, raised to membership in a taxonomic group, and made to illustrate and generate evolutionary theory. (93)

A taxonomy is dually systematic *and* evolving. It is intended as a heuristic guide that appropriates language to concepts—perpetually *creates* concepts, not *discovers* them—and cannot be perceived as a final-copy blueprint.

Developing a taxonomy of visual ambiguity provides a point of reference for the development of heuristics, which can in turn be useful in pedagogy, research, and practice where visual literacy is at stake. It might be said that such a taxonomy, which essentially *deconstructs* ambiguity, appropriates theories of aesthetics, rhetoric, culture, technology, and metaphysics and applies them in praxis, offering an *adaptable* foundation, from which further work in scientific visual representations can be done.

Methods of Breaking down Ambiguity

Thus, to explore what might be considered a deconstruction of ambiguity, foregrounding a taxonomy ought to, at least loosely, consider the perspectives of *deconstructionism*. Referencing Derridean and Saussurean perspectives on structuralism and semiology, I suggest that the overarching effect of a visual representation is influenced by the relationships and hierarchies of one visual element to another. Perception of any visual element will ignite mental interpretation based on a network of meanings derived from the visual texts. In other words, understanding that is gleaned from the viewing of any image is influenced by not any single element in the present image, but by a series of viewable elements in *any* image upon which the viewer might be able to reflect, consciously or otherwise. One visual element will always be speaking in relation to another. Grossly simplifying Derrida's famous axiom, "there is nothing outside the text," we might say that any text will be *informed by* and in turn *inform other* texts. While Derrida was suggesting that our very perception of the world, all that we consider to be in existence, is merely text, his point is relevant to observable signs and signifiers: the signifieds they ostensibly represent will always be somehow connected to other signs and signifiers. They belong to a perpetual matrix of episteme. Understanding from this perspective is derived from the connections made between a network of texts. Under this pretense, the concept of deconstruction flatly rejects the notion that *a priori* knowledge has the ability to construct a reality. Simultaneously, though, it suggests that reality may only ever be understood ambiguously, since it will always be built upon seemingly endless rhetorically nuanced and subjective connections between texts and signs.

Such a reality conundrum understandably makes scientists squeamish. Western science in general's ideologies, after all, continue to seek—adamantly—avoiding subjectivity in an effort to discover Truth. Reality must exist or there is nothing for science to research. A taxonomy built and used with the understanding that it is codifying the subjective, even if only in part, might hopefully ease these concerns, especially if we consider that the scope is communicative in nature. In other words, deconstructing ambiguity helps us better understand how science is *communicated* and *understood*, not what science *actually* proves.

To think of it more objectively, then, deconstruction (of both textual and visual analysis) suggests that an interconnected (and arguably largely ambiguous) network of hierarchical signs "constructs" a reality for the person observing the text. Leonard Lawlor refers to Descartes' metaphor of finding the "foundation" of his knowledge, taking apart the construction of it piece by piece. Both Descartes and Derrida are suggesting a series of relationships that we might look to in order to trace understanding. Proponents of *a priori* meaning-making would likely argue that it is impossible to remove all of the appropriate "bricks" of the knowledge construction to discover the foundation. The bricks that Descartes is referring to, after all, suggest related experiences. Metaphysical knowledge, however, as Kant argued, "must never be derived from [external] experience, …which is the source of physics proper, nor internal, which is the basis of empirical psychology. [It comes] from pure understanding and purse reason" (Kant 13). Kant's perspective suggests that a foundational understanding must include nuanced and idiosyncratically subjective and untainted building blocks outside of experience. Kant would see deconstruction as a fantasy—never quite able to fully root out the pure understanding. Despite the fact that a taxonomy of ambiguity doesn't solve this problem, I would expect that the scientist cognizant of this conundrum would simply respond to Kant and Descartes alike, saying "yes, and that is where ambiguity will always provide opportunity for new discovery."

It is worthwhile to note how Thomas Kuhn addressed a similar issue. From his perspective, knowledge is built upon a series of connected discoveries that construct a paradigm (even if the paradigm is only recognized tacitly). Like Descartes' bricks, the coalescence of scientific discoveries as Kuhn describes it appears traceable to the foundation Descartes was looking for and Derrida hinted at. Deconstruction from this perspective seems very feasible. However, Kuhn likewise considered how understanding alters or shifts, that while paradigms are often manifested, there is no guarantee (in fact it is rarely likely) that the paradigm will forever remain intact. Kuhn addresses what some may observe as serendipitous sparks of genius, perhaps metaphysical illuminations that especially enlightened scientists bring forth from pure reason. Rather than codify this type of knowledge as *a priori*, Kuhn suggested that *anomalies* emerge in foundational, paradigmatic understandings of scientific phenomena. These anomalies, which are necessary for science to progress, have a curious, but ambiguously traceable beginning as well. According to Kuhn:

> [Discoveries] are not isolated events but extended episodes with a regularly recurrent structure. Discovery commences with the awareness of anomaly, i.e., with the recognition that nature has somehow violated the paradigm-induced expectations that govern normal science. … Assimilating a new sort of fact demands a more than additive adjustment of theory, and until that adjustment is completed—until the scientist has learned to see nature in a different way—the new fact is not quite a scientific fact at all. (53)

Kuhn refers to the apparatuses of "normal science," the theories and procedures that combine to create accepted paradigms, as a tentative holding place for scientific understanding. As a result of exhaustive research and reflection, these apparatuses reconfigure as a novel discovery exposes a weakness. In his words: "And even when the apparatus exists, novelty ordinarily emerges only for the man who, knowing with precision what he should expect, is able to recognize that something has gone wrong. Anomaly appears only against the background provided by the paradigm" (65).

Addressing the apparatuses of theory and procedure, it might be suggested that the scientist who exposes the anomaly is required to *deconstruct* the paradigm, making connections between other or new theories and procedures in order to construct the new "reality." The deconstruction of a scientific paradigm, in other words, delineates its many connected parts while embracing the notion that anomalies are lurking, encouraging discovery. In communication, deconstruction operates similarly: communication theories such as semiotics and grammatology function as apparatuses that frame paradigms for subject areas like literary criticism or even usability studies. Communicative apparatuses, when understood with precision, expose anomalies—or ambiguities—that garner new understandings. Collections of visual ambiguities in any visual representation may expose anomalies drawn out of paradigmatic constructions.

Visual communication, particularly in the sciences, wrestles with the very issues addressed here. Hardcore empiricists would consider it ideal to be able to deconstruct, finitely, the visual elements that affect foundational understanding. The goal would be to systematically, through rigorous development of apparatuses, remove all elements that spawn ambiguous interpretation. This, of course, in utopian science, would suggest the utter removal of communication barriers and frictionless progression of science. Deconstructionists, on the other hand, would argue that it is impractical and unwise to disregard the anomalies and ambiguities that are present in visual representations because they present opportunities for discovery that may otherwise go unrecognized.

In scientific communication, anomalies and other forms of visual ambiguity emerge through reflection upon what the visual elements are intended to represent. Lurking amidst the issue of scientific knowledge as it relates to visual communication is, we might say metaphorically, a grammatical relationship: that of subject-predicate. Anomalies emerge as ambiguities existent between the subject-predicate relationship become exploited by in-depth knowledge of *both* the subject *and* the predicate. If the subject at stake is human understanding/interpretation of a scientific concept, the predicate becomes both signifier *and* signified—the visual element(s) *and* the scientific phenomena they are intended to represent. The subject (meaning or interpretation) is *grammatically* informed by the predicate (visual elements and scientific phenomena), which tend to function as a collection of nouns, verbs, and adjectives. Kress and Van Leeuwen, though not the first to do so, most notably use the grammar metaphor in *Reading Images: The Grammar of Visual Design*, where they say, "Just as grammars of languages describe how words combine in clauses, sentences and texts…our visual 'grammar' [describes] the way in which depicted elements—people, places and things—combine in visual 'statements' of greater or lesser complexity or extension" (1). The grammar metaphor is applicable to a taxonomy as we seek to envisage *structural* relationships between individual interpretation and representation by using a systematic approach to something invariably idiosyncratic.

Gregory Ulmer's work on "applied grammatology" is a good example of how we might, through taxonomy, make knowledge connections between visual elements and their signified scientific phenomena. Ulmer cites Derrida's "single most influential proposal—the definition of *differance*"—as an appropriate understanding of how subtleties in language affect the signifier and the signified. Subtle changes in a word, like an 'a' instead of an 'e' in "difference/differ*a*nce," Ulmer suggests, are comparable to the hieroglyphic representations found in Egyptian pyramids. Often the visual representations provided a multiplicity of meanings, depicting one thing, and saying another. *Or* depicting one thing and *sounding* like something else. In a brief reflection on the history of writing, Ulmer points to Derrida's discussion on the role of homonyms and puns in language, which "played a crucial role in extending the resources of language." Citing Derrida in relation to homonymy: "The otherwise motivated sign has acquired arbitrary uses" (qtd. in Ulmer 19). Ulmer further suggests that Derrida relied heavily on using puns "for the generation of his strategies…although he does not always pursue their consequences." Derrida's sign, Ulmer contends, becomes a verb rather than a noun because it is not simply a fill-in for the signified, but rather it urges and exploits, dances around and within meanings. "It is not constituted by the signifier-signified," Ulmer continues, "but by the *signature*" (19, italics mine).

What we have in Ulmer's analysis of Derrida is a clearer understanding of the functions of language. We might learn that inexplicable, bizarre, unconventional, arbitrary, ambiguous, or anomalous injections of language types in writing (including puns, homonyms, homophones, and even images) should not be viewed as merely rhetorically subversive descriptors used by a communicator (although we cannot rule that out, either). Rather, they are a normal and categorical type of communication that does not simply accessorize language, but accommodates it. The interpretation that develops as a reader transitions from viewing a scratch on a page to forming a thought in the mind happens in that "signature" phase.

Derrida's and Ulmer's analyses have linguistic and grammatical terminologies to address where the locus of interpretation takes place: puns, homonyms, and homophones. Other critical literary analyses have a host of other linguistic curiosities from which to draw (synecdoche, anaphora, chiasmus, euphemism, hyperbole, metonomy, and so forth) where interpretation is codified into communicative types, then evaluated against social and cultural characteristics. Indeed, Edward Corbett, in reference to Aristotle, categorized dozens of figures of speech that effectively give "clearness and liveliness to the expression of our thoughts" (424). Of course, the ambiguity present in such figures of speech has been well-documented and loathed by scientists. Consider Longinus' statement: "[The function of figures of speech] is able in many ways to infuse vehemence and passion into spoken words, while more particularly when it is combined with the argumentative passages it not only persuades the hearer but actually makes him its slave" (qtd. in Corbett 424). What is valuable in linguistic and textual analysis, however, is the ability to take these ambiguous categorized figures of speech and investigate their rhetorical and epistemological value. Without clear categorization of similar *visual* ambiguities (figures of *sight*, perhaps?), it has been difficult to similarly document how exactly visual elements accommodate and communicate information.

Developing a taxonomy of visual ambiguitiesfunctions similar to the development of categorized figures of speech. Being able to codify figures of speech improves literary and *literate* analysis of a larger text. Figures of speech, as I have noted, give access to knowledge through unique interpretable clues that move audiences from the signifier to the signified. They have the potential to move an audience, in other words, to discover anomaly by deconstructing foundational origins. Developing and using a taxonomy of visual ambiguity similarly attempts the deconstruction of visual representation while embracing ambiguity's role for new discoveries existing in anomalies, "pure reason" or "*a priori*" knowledge. In essence, the taxonomy bridges empirical, epistemic reasoning with *a priori,* anomalous awareness and insight by providing the clearly describable "planks" upon which literacy can traverse.

Taxonomy, Metaphor, and Epistemic Access

A few words, then, on this "epistemic reasoning." Visual representations are a form of discourse that link *actual* scientific phenomena to the *understanding* of scientific phenomena. They provide access to new knowledge about a phenomenon, knowledge that would likely not have been gleaned otherwise. Terms, definitions, equations, etc. all become part of a scientific discourse that, through unique communicative elements, make phenomena epistemically accessible. William Frawley wrote:

> What discourse does for science, as the arena of the legitimacy of knowledge, is to provide epistemic access to other—even idiosyncratic—versions of scientific knowledge for readers, as for example, scientists. What discourse does for science is to allow language to extend the senses of the sciences by providing coherent articulations of terms which stand in lieu of, and often for only parts of, potentially observable phenomena. Discourse provides scientists with epistemic access to all sorts of phenomena and explanations that are beyond their immediate circumstances, senses, or understandings. (72)

To summarize, we might say that communication (a broader but related term for "discourse") epistemologically links sensoria to physical phenomena, making knowledge accessible at all. Visual communications in this sense function similarly to linguistic communications: each consists of a coalescence of signs and signifiers in relation to some signified and each is intended to provide clarity and understanding to something otherwise abstract, or even something concrete but equally ambiguous or unknowable. Each is also inescapably rhetorical and injects the "interpretive ambiguity" that

Schummer referred to (see Chapter 2). As mentioned, communicative elements—be they linguistic or visual—inevitably possess ambiguities. But these ambiguities possess important virtues: they not only expose the productively present anomalies, but they make science intelligible and accessible.

One of the greatest challenges scientists currently face when using or viewing visualizations is knowing how to describe and talk about the visual elements within them. Richard Boyd noted that with scientific discovery, *catachresis*—the misuse of a term or metaphor—is a frequent occurrence as scientists attempt to explain the previously unexplained. We may argue that there is a similar problem of *catachresis* evident when attempting to become visually literate. That is to say, without an exhaustive, Aristotelian-esque categorization of the "figures of sight," appropriate terminology to describe the visual elements that represent scientific phenomena is gaping at best, and the scientist is often left to use metaphors to describe what they see. Consider what Dr. Alain Viel (one of the writers of the *Inner Life of a Cell* video and Harvard professor) says when describing the BioVisions video developed at Harvard University: "In the animation there's a motor protein that's sort of walking along a line, carrying this round sphere of lipids. …It really does look like it's out for a stroll, like a character in a science fiction film" (Marchant). Of course, such metaphorical description is necessary to adapt to public audiences, but even scientists talking to scientists struggle with appropriate diction to label what they often only see metaphorically. The name "motor protein," for example, has a visual, metaphorical, and epistemological connections to it that scientists use amongst themselves, not just to adapt to public audiences.

Because the entities that scientists experiment on almost inevitably assume a visual form of some kind that is viewable to the eye, it should probably come as no surprise that the terminologies scientists use to describe those entities are frequently metaphorical in nature. When we think of scientific theories and phenomena—like string theory or electron clouds—it is hard not to recognize the metaphor. This is what Schummer was referring to in his description about molecules, suggesting that scientists name molecules that look like baskets *basketane* and ones that look like rotors, *rotane*. A significant reason for this is simply the way in which we understand and use language, in particular English. Linnaean nomenclature, which is discussed in more detail in Chapter 4, is a good example of how language metaphors shape scientific thought. Sean Morey, for example, notes that the permit, a type of fish, is scientifically named "Trachinotus falcatus," which, when translated, means "armed with scythes." The fish is not actually "armed" with anything, but the metaphor is appropriated to discourse, which in turn "[constructs]…association" between image and word. We actually have to work hard to *avoid* using a metaphor to describe something less familiar. Lakoff & Johnson indicated, after all, that language in general is metaphorical, that we "live by" metaphors, and scientific communication is no exception. The use of language to describe something visual, or *ekphrasis* as Mitchell elaborates on in *Picture Theory*, represents the basis of one of the four domains of visual ambiguity—linguistic-rhetorical—discussed in Chapter 2. What we may pay close attention to is the role that metaphor plays in making science accessible and how a taxonomy might assume a similar role.

In "Metaphor and Theory Change: What is a 'Metaphor' a Metaphor for?"

Richard Boyd argues that metaphors function to assist scientists in their understanding. "The use of metaphor," he says, "is one of many devices available to the scientific community to accomplish the task of *accommodation of language to the causal structure of the world*" (358). Metaphors, Boyd suggests, provide two important functions for scientists. At the surface level, metaphors initially provide ostensive power to the description of phenomena that are new to scientists. That is to say, they provide analogous, real-world counterparts, examples whereby terminologies can be drawn in order to conceptualize the phenomena. Perhaps even more profound, Boyd further proposes that metaphors have the unique ability to actually shape the way in which science is conducted, that they epistemologically give form to how scientists view the way in which the world operates. By framing a scientific phenomena within the structure of a metaphor, scientists potentially shape the development of their work, paradigms, and knowledge based largely in part by the metaphor's linguistic relationships with the palpable world. He further elaborates:

> By this I mean the task of introducing terminology, and modifying usage of existing terminology, so that linguistic categories are available which describe the causally and explanatorily significant features of the world. Roughly speaking, this is the task of arranging our language so that our linguistic categories "cut the world at its joints." (358)

If we are to take Boyd literally (even if only on occasion, as Boyd says this is rare) this means that some aspects of the world as we know them are understood, that is *accessed epistemically*, through the lens of a metaphor. The extent to which that metaphor might be stretched may potentially, then, have the ability to limit or alter the way in which we can grasp how that part of the world functions. One example Boyd gives is how the human brain has been metaphorically tied to an information processor. Such a metaphor has become so entrenched within the field of cognitive psychology, that the functions of the brain may never really be able to be understood differently.

What is in question here is how effective language can be in epistemologically framing a scientific community's understanding of the properties of the world. How well, in other words, do metaphors function to provide *epistemic access*—Boyd's phrase to describe how tools (like metaphors and other reference systems) affix language to real world phenomena? Boyd suggests that metaphors can act like ostensive reference terms that not only point to real world phenomena, but open them up in new ways. (Boyd is far less concerned about the vocabulary assigned to scientific phenomena as he is about how science proceeds based on the relationships between vocabularies. His argument, whether a scientist is willing to take it to its extreme or not, at least raises important questions about the role of communication and the development of science.) Because the limited nature of metaphors can only ambiguously—that is, never in perfect mimesis—represent the world in which we live, any scientific concept associated with a metaphor might be considered ambiguous and incomplete. Boyd has suggested that some scientific disciplines are so entrenched in a metaphor, they may always be locked into an epistemic interpretation framed within the metaphor's peripheries. Moving back from Boyd to the grammar metaphor, I suggest that human understanding built upon metaphors is reliant upon a deconstruction of the predicate, or the signs and signifiers that collectively assemble understanding.

In sum, that metaphors—and, really, scientific communication generally—provide scientists with an imperfect but at least accessible epistemic grasp of the reality of the world. Metaphors provide enough substance that a compressible shape or frame can be established, communicated, deconstructed, and analyzed by scientific communities. They can also be adaptable to multiple environments. A taxonomy (or the categories delineated in it), like a metaphor, gives shape and vocabulary to the otherwise inexplicable components of visual ambiguity. In this sense, a taxonomy of visual ambiguity *is* a metaphor: it, like any other linguistic metaphor, represents the framework to *nominally*, rather than ostensively (Boyd), establish relational properties that exist between the terms. A taxonomy effectively encapsulates terminologies for productive usage and further research because it provides scientific communities epistemic access to otherwise abstract notions. Its limitations in trajectory, while certainly present, will never be so great as to trump its practical and adaptable uses.

Toward a Taxonomy of Visual Ambiguity

With these limitations of language in mind, the application of a taxonomy as it relates to visual ambiguity, then, must embrace a dual ideology—that visual ambiguities are both classifiable *and* malleable. A taxonomy of visual ambiguity serves to effectively deconstruct the visual elements that collectively work together to form a scientific representation while simultaneously exposing new relationships and what Kenneth Burke refers to as “alchemic opportunities” that will spawn new investigations (xix). The taxonomy of visual ambiguity expressed in the following chapter is developed from this viewpoint. Its perfunctory goal is to provide a perpetual system for codifying visual elements, a system that functions in an iterative triad that classifies, names, and relates visual ambiguities. By providing a lexicon of visual ambiguity from which to work, its broader scope is to enhance epistemic access through improved literate awareness of the visual meaning making process.

CHAPTER FOUR

A TAXONOMY OF VISUAL AMBIGUITY

> "If it were possible to build the missing bridge between persuasion and scientific knowledge, then one would be in the best position for overcoming the tension between 'internal' and 'external,' and between normative and descriptive philosophies of science."
>
> -Marcello Pera, *The Discourses of Science*

Ambiguity and the Making of Meaning: Converging Method and Imagination

The proposition in the previous chapters is primarily threefold: that visual ambiguities 1) inescapably affect meaning making in nearly all visual representations of science, that 2) their presence provides important ("alchemic") opportunities for new insight and epistemic awareness, and that 3) our ability to harness and effectively preserve ambiguous visual elements is dependent upon the construction of an amorphous framework—a systematic but flexible guide to the visual elements that affect meaning. In essence, I have proposed a foundation for the development of a taxonomy that encourages scientific discovery and meaning making by embracing the communicative ambiguity of art and design. Whether the taxonomy proposed in the present chapter be a productive space for Kant's "pure reason" to emerge, Kuhn's "anomalies" to surface, or Ulmer's "signature" to play out, its purpose is essentially the same: a taxonomy of visual ambiguity establishes stronger literate awareness of the epistemic “happenings” in visual communications that spark scientific imagination—that is, a taxonomy of visual ambiguity potentially triggers insight and foresight into the meaning-making process of scientific communication.

What is at stake in the creation of a taxonomy of visual ambiguity, then, is the ability to approach visual communication of the sciences in a way that promotes the convergence of reason *and* imagination without discounting either. Kenneth Burke draws us to the importance of this convergence when he suggested that the ideological separation of art from science hindered imagination in both areas. Rather than considering reason as “vocational” and imagination as “vacational,” Burke says, a hybrid of the two “represents a joined duality of motives … [symbolizing] the union of a labyrinthine imagination … with the rationality of a poetic medium developed by deliberate conscious sophistication” (224). Burke suggests that we should never pit art against science, but rather we should understand each as an important part of discovering truth (224). In this vein, it may be said that a scientist’s greatest resource for productivity is his or her ability to channel imagination through methodical artistry—that is, through appropriation of a flexible but comprehensible and transferable system. The imagination needs a place to thrive—somewhere between the subject (human understanding) and the predicate (the science and the communication of it), in the “anomalies” and ambiguities of the visual as I addressed in the previous chapter.

The scope of this chapter is to expressly formulate a taxonomy that appropriately systematizes the classifying and naming of visual ambiguities while further establishing ways in which these ambiguities ambiguously relate to and affect each other. Marcello Pera has said: “science is characterized by scientific method, but a precise characterization of scientific method destroys science” (28). With this in mind, my purpose is to methodically categorize visual ambiguity for productive use without destroying it. The taxonomy, as presented, is intended to be an amalgamation of scientific procedure while preserving a space for imagination. It provides, we might say, the legend to a map, but no prescribed journey or destination. It serves as an open-ended method. The idea is that researchers, educators, and practitioners can clearly follow but flexibly adapt the taxonomy to be used with a wide array of visual communications in any of their own specific disciplines.

The first two purposes of the taxonomy presented in the following pages seem, at least superficially, perfunctory (systematic and mechanical) in nature: the first purpose of the taxonomy is to establish categories of visual ambiguities from which we can draw comparisons and relationships; the second purpose is to provide a naming system whereby scientific communicators can appropriate the types of visual ambiguity into discourse and research. The categorizing and naming found in the taxonomy follow traditional scientific models used by scientists such as Aristotle, Linnaeus, and Bloom. Thirdly, and perhaps most importantly, the taxonomy presented in this chapter appropriates the rhetorical model of Burke’s dramatistic pentad (which suggests motives for action involve acts, agents, agency, scenes, and purposes)—reconfiguring it into a visual *tetrad* (where the agent is removed from the analysis)—to show the complexities of the relationships between the types and categories of visual ambiguity. With this third purpose of the taxonomy, ambiguity effectively reigns as a rhetorical device for comparing and contrasting how visual elements work independently and in harmony to affect meaning-making. The parts of the taxonomy (those mechanical and those rhetorical) working in tandem follow what Alan Gross has said about the taxonomies of evolutionary biology: "the relationship between these two [science and rhetoric] is not rivalry but complementary" (50 *The Place of Rhetoric in Science Studies*). Ambiguity, as presented in the tetradic model of visual communication, suggests that ambiguity's presence is a natural and recurrent part of the human imagination and the imagination's affect on understanding science.

The "Paradox of Substance" in Visual Ambiguities

The preservation of ambiguity in visual representations of science, then, seems natural and important. Perhaps paradoxically, however, its classification for the sake of clarity seems to annul its primary role of encouraging discovery in the meaning-making process. One of the paramount functions of any taxonomy, after all, is to establish categories and names of the subjects under investigation so as to systematize and organize practices within a discipline. The systemization and defining practices are often intended to thwart ambiguity in favor of precision. Aristotle's attempt to classify living things, for example, provided names for vertebrate and invertebrate animals so as to clearly distinguish—for future generations of scientists—how they differ. His student, Theophrastus, classified types of plants, some of which to this day are named after his original terms. The clarity and precision of classification has become a staple for scientific discourse. Other taxonomies developed by Plinius, Linnaeus, and, more recently, Benjamin Bloom, have all sought to establish clear-cut descriptors used for identification and separation.

The difference, perhaps, between the taxonomy of visual ambiguity presented hereafter and most other taxonomies of science, is that the former embraces a preservation (as opposed to eradication) of ambiguity. It encourages a conscious awareness of paradox and ambiguity within the categorizations and names. The definitions associated with types and categorizations of visual ambiguities provide more loose boundaries than those often found in traditional taxonomies. The looseness in definitive boundaries provides a space for epistemic alchemy, that is to say, a rethinking or retooling of the way in which a visual element communicates. There are, in other words, multiplicities of ways to define any given type of visual ambiguity (which, in turn, gives flexibility to its scope and influence) because each type of visual ambiguity's *substance* is only explicitly valid in relation to other visual ambiguities.

Burke famously described the complexity of defining anything: "To tell what a thing is," he argued, "you place it in terms of something else" (24). Burke suggests that Aristotle's conceptualization of things (like stones or trees) could be considered without regard to anything else; they could be "considered 'in itself'" (25). Spinoza, according to Burke, had a different take: he suggested that nothing can be defined independently, that "each single object in the universe is 'defined' … by the other things that surround it" (25). Traditional scientific taxonomies often take the Aristotelian perspective—that is, they assume a definition of any given object is noncontextual. The taxonomy of visual ambiguity appropriates Spinoza's view, which recognizes the paradox of substance. Definitions of visual ambiguities are outlined, but only as reference points; it is expected that the reader will observe each definition of the types and categories of visual ambiguities as relational to and contingent upon other types and categories of visual ambiguities.

As such, the following section (which classifies and names visual ambiguities) perfunctorily adapts what appears to be an Aristotelian taxonomic presentation of visual ambiguities. This is the systemic, methodical component of the taxonomy, which importantly (if not dryly) establishes a system whereby visual ambiguities can be appropriated into scientific communication discourse. I encourage the reader, however, to recognize that the definitive classifications and names of visual ambiguities set forth hereafter are only definitive insomuch as they are noncontextual or unrelated to other visual ambiguity types (which is rare if ever). The richer value of the taxonomy emerges in the subsequent section, where I establish a rhetorical model as a means for recognizing communicative relationships (and ratios) between visual ambiguities. A case example of how the rhetorical model of the taxonomy might be heuristically appropriated into research and education is the scope of Chapter 5.

A Systematic Model of Taxonomy: Classifying and Naming

With the paradox of definition and substance in mind, I suggest, then, that the classifying and naming of visual ambiguities is a necessary first step in establishing the exoskeleton of visual ambiguity. Alan Gross argued that in evolutionary taxonomy, "words and pictures [on their own] bring potential species to life" (101 "The Origin"). The categorization of visual ambiguities has the same potential. Categorizing and naming visual ambiguities, I propose, is important for discourse in scientific communication and for the improvement of visual literacy because it (at least foundationally) raises consciousness to the sundry visual elements that affect meaning. Thus, in the following sections, I look to Carl Linnaeus and Benjamin Bloom for widely accepted classifying and naming practices useful for the categorization of visual ambiguity.

The taxonomic system scientists use in biology today, whereby organisms are named after their genus and species, is part of a larger categorical system, taught to most elementary-age children. This system includes a *hierarchical* organization starting with "kingdom" and moving to "phylum," "class," "order," "family," "genus" and "species." Other classification systems, such as Aristotle's and Theophrastus' taxonomies on plants do not show evidence of such hierarchical organization. Regardless of the presence of hierarchy, though, categorization is clearly at the heart of taxonomies. Categorizing, after all, makes application of concepts more accessible. As Tilton noted of Linnaeus' work on *The Species of Plants*: "[His] method, in which plants were grouped together according to the number of stamens in their flowers…was not accurate, but it was easy to use and thus readily adapted by scientists who were continually discovering more new varieties of plants" (Tilton).

A contemporary example of the functionality of categorization is Bloom's Taxonomy of Educational Objectives. In 1949, Benjamin S. Bloom initiated a project that would result in an educational classification system for learning objectives. What Bloom and his colleagues determined to create was a functional system that moved educational theory into practice. The hope was that by classifying learning objectives into a series of terms and definitions, educational research could be more widely applied across disciplines. In other words, if a common language for educators were to be established through taxonomy, curricula and examinations could be designed easier, under much more specific learning objectives. Bloom and his colleagues' hope was that this taxonomy would assist in the development of instruction and examination that needed to meet local, state, and national standards while reducing overlap and redundancy in development (Krathwohl).

To achieve this goal, Bloom's Taxonomy established three domains of leaning: the cognitive domain (where a person learns intellectually, through remembering, applying, and evaluating knowledge), the affective domain (where a person learns emotively, through responding to phenomena and internalizing values), and the psychomotor domain (where a person learns physically, through the development of sensory cues and motor skills) (Martin, "Bloom's Learning Domains"). Each of these domains provided resources for educators to use in order to improve learning objectives. Bloom's three domains of learning objectives effectively did for education what Linnaeus' categorization of the animal kingdom did for biology: they systematized learning objectives by pointing to specific verbs (species or types of actions) that could be applied to learning. Bloom's categorization system, much like Linnaeus', was devised to standardize disciplinary practices. If an educator wanted to teach a student how to "apply" mental knowledge, they could look to the cognitive domain, then the “application” dimension, where he or she could use terms like “modify,” “construct,” or “produce”—verb types that function to improve learning objects and, in essence, pedagogy.

For example, if an instructor wanted her students to learn important events in U.S. history, she might make a vague statement like, “students will *know* major events….” Bloom’s taxonomy, however, would encourage the changing of the verb “know” to *recall*, making the objective to be clearer: “students will *recall* 10 major events of the Civil War” (Cruz, “Bloom’s Revised Taxonomy”). Each of Bloom’s categorical domains is further divided into “dimensions,” which distinguish certain types of cognitive learning (knowledge, comprehension, application, analysis, synthesis, and evaluation). The series of verbs (recall, survey, memorize, model, draw, weigh, etc.) assigned to each learning dimension within the designated cognitive domain made the theoretical approach to learning and curriculum design much more practical and accessible.

The taxonomy posited in this chapter assumes a similar model, placing visual ambiguities in three categorical milieus: domains, dimensions, and types. Based on the literature presented in Chapters 2 and 3, four *domains* of visual ambiguity are most conspicuous: *socio-cultural*, *linguistic-rhetorical*, *technological*, and *metaphysical*. It is under these four broad domains that visual ambiguity is classified. Visual ambiguities can be further classified into two *dimensions*—areas where learning occurs—namely, *affective* and *cognitive* dimensions. Within each domain/dimension, there may be seemingly endless *types* of visual ambiguities to be discovered and named, just as discoveries of species of animals continue to fill voids in family and genus categories. **Figure 4.1**, below, represents the classification system for visual ambiguities.

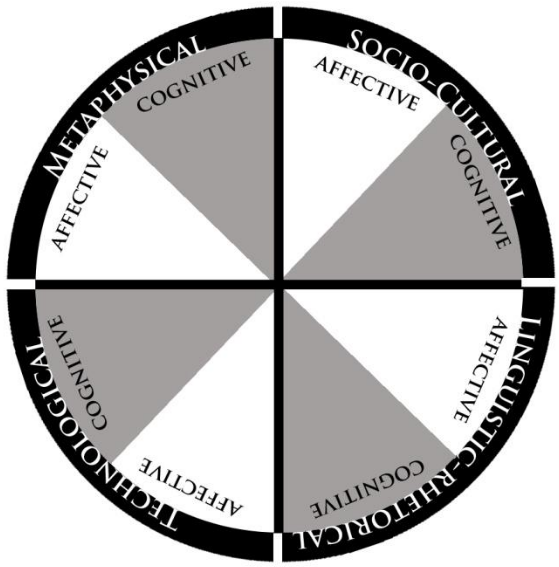

Figure 4.1: Taxonomic Wheel of Visual Ambiguity: Domains and Dimensions

Represented as a wheel, the four domains of visual ambiguity are non-hierarchical. Under each domain, there are dimensions, the *affective* and *cognitive*. The blank areas in each of the dimension triangles represent the areas where *types* of visual ambiguity are placed, after scientific communities label them. Below I describe how each of the dimensions and domains of visual ambiguity are defined, followed by categorical lists of the types (and their respective dimensions and domains)

The Dimensions of Visual Ambiguity

Visual design elements, while epistemologically falling into one (or possibly more) of the four domains defined, must be classified in terms of their individual effects on the viewer—whether they be cognitive or affective. The cognitive and affective dimensions of the four domains suggest two major ways in which viewers are affected by an image—mentally (logically) and emotively (viscerally). It may be determined, for example, that a technological *type* of visual ambiguity, such as image resolution, might evoke a visceral reaction. Lack of professionalism, for instance, may be the emotive response to the ethos of the scientist who produced the image. An empirical study on the psychological reaction to the visual ambiguity type (the image resolution) would be necessary to determine if, indeed, there was an emotive reaction that affected interpretation of the image. If so, "image resolution" could be classified in the affective dimension of the technological domain (but in the malleability of this taxonomy, it may be classified in the cognitive dimension as well). Below, the two dimensions are defined in more detail.

The Cognitive Dimension

The cognitive dimension of visual ambiguity is the locus of meaning making where design elements affect readability, usability, and accessibility. In other words, the viewer of an image might ask him/herself if some element, which is classified as a specific "type," of the design distracts, distorts, or improves their understanding of it. Is the most important object in the image or design hidden by noise, such as colors or pixilation? Are the elements appropriately arranged? Is the text that supplements it useful to apprehension or is it misleading in some way? The cognitive dimension of specific types of visual ambiguity might be viewed as the superficial and introductory stage in meaning-making, where attention is paid to communicative elements that serve a perfunctory purpose in guiding the viewer to grasp a very specific concept. Emotional reaction and experience in the viewing are not considered in the cognitive domain. This is why the evaluation of visual texts based strictly on cognition raises important ethical issues.

While visual ambiguities that fall within the cognitive dimension of any of the domains plays an important part in affecting meaning making, caution may be expressed to the scientific communicator that assumes the *cognitive* dimension of visual representations is the only dimension at work. Such a “naïve empiricist” perspective has potential to obstruct alertness to perhaps more serious and influential dimensions of visual ambiguity (which is what Ann Wysocki was arguing in regards to the “well-designed” ad of a nude woman, where we fail to recognize how the content is shaping our viewing just as much, if not more so, than the design and layout.) In this light, information design and usability perspectives that value form more than content are treading only in shallow waters of visual literacy (see Edward Tufte, *Envisioning Information*, Robert Horn, “Information Design,” or Albers & Mezur, *Content & Complexity*). Wherever there exists a type of visual ambiguity that cognitively affects understanding, it is imperative that we simultaneously ask: but can/does this type also affect us emotionally? Why? This is not to say that visual ambiguities that fall in the cognitive dimension are not important; indeed, they play a very vital role in how representations are interpreted.

The Affective Dimension

The *affective dimension* of visual ambiguity, thus, is the locus of meaning making where human character, emotion, and values play a significant role in the interpretation of visuals. Richard Buchanan, speaking of design in general (of both two- and three-dimensional designs) noted:

> There is a deep reflexive relation between human character and the character of the human-made: character influences the formation of products and products influence the formation of character in individuals, institutions, and society. (232)

The complexity of Buchanan's statement is reflected in the affective dimension of visual ambiguity, where a person viewing a scientific image cannot escape the influence human nature, idiosyncrasy, spirituality, and socially-constructed worldviews. In many cases, a design element may have little emotive effect on a viewer—like the contours in an abstracted black-and-white diagram of a gene, labeled perhaps as type "abstraction" in the "technology" domain—and in these cases, cognition is the primary influence. However, if the abstracted contours represent genetic modification, an *affective* response to the design is likely to reframe understanding of it. *Or*, if an image simply looks attractive—based on design characteristics like patterns and color scheme—a visceral, affective reaction occurs. Cognitive scientist Donald Norman has suggested that such reactions are both natural (humans generally prefer symmetrical faces) and cultural (some cultures prefer fat people, others thin). Either way, design elements have a powerful ability to affect visceral reaction to and, thus, interpretation of the design (*Emotional Design* 66).

The Domains of Visual Ambiguity

The definitions of the domains below are drawn from the literature reviewed in Chapter 2 and, as such, are only briefly described here.

The Socio-Cultural Domain of Visual Ambiguity

Elements of an image or design that epistemologically affect meaning because of their connectedness to socially-constructed perspectives or values systems fall within the socio-cultural domain of visual ambiguity. Representations of scientific *objects* particularly—like mitochondria, stem cells, or anatomical structures, (but also visual elements like color and patterns)—found within an image or design communicatively affect culturally-contingent, amorphous social histories. As Shea indicated about the socially-developed narratives of genes, only diachronically can we recognize that Mendel's work is only a small part of what scientific societies today consider *Mendelism* (*How the Gene Got Its Groove*). One understood history of a visually represented object may very well be different than an alternative, though equally logical, history. Furthermore, interpretation of visual objects and design elements is affected by social conceptions of aesthetics in relation to spectacle, as Hal Foster has noted (*Design & Crime*); they will be inevitably influenced by what Feyerabend has deemed as "social values"; and they will be conceptually shaped by governments, institutions, and organizations that standardize paradigms. In essence, visual ambiguities of the socio-cultural domain are visual elements that are tied to specific historical narratives, societal aesthetic preference, political influence, socially-accepted values, economies, or otherwise general regulations of institutional apparatuses. *Types* of visual ambiguities that can be found in the socio-cultural domain may include those found in **Table 4.1** below.

Table 4.1: Socio-Cultural Domain of Visual Ambiguity

Socio-Cultural Domain of Visual Ambiguity			
Visual ambiguities of this domain involve visual elements that are tied to specific historical narratives, societal aesthetic preference, political influence, socially-accepted values, economics, or regulations of institutional apparatuses.			
Socio-Cultural "Types" of Visual Ambiguity		**Cognitive Dimension**	**Affective Dimension**
Type	**Description**	**Examples/Sub-Types**	**Examples/Sub-Types**
History	Elizabeth Parthenea Shea suggests that histories of scientific ideas are socially constructed. A visual ambiguity labeled "historical" suggests that the history of the object/element visually represented is interpretable based on divergent histories, constructed and accepted paradigms within a field of inquiry. (*How the Gene Got Its Groove*)	The history of stem cell research is known only fragmentally to a viewer, leaving knowledge gaps in how the image of a stem cell is representative of that history.	
Value	Paul Feyerabend argues that communal values (such the Western concept of expediency) affect acceptance or rejection of a particular concept. Value ambiguities are present when conflicting value judgments are possible. (*Farewell to Reason*)		X-rays might be viewed as an invasion of privacy, thus images of them might spark an emotive, values-laden response.
Spectacle	Hal Foster suggests that societies determine the difference between "highbrow" and "lowbrow" art. Art to some may be considered spectacle to others. Spectacle ambiguities are present when a viewer struggles to determine the difference between authentic visual elements and commercialized ones, or artistic rather than made spectacle. (*Design & Crime*)		Artistic rendering of a mitochondrion, though meticulously designed for education, might be seen as a promotional tool, sparking emotional conflict.
Anomaly	Thomas Kuhn has indicated that new knowledge materializes as an anomalous discovery emerges beyond the peripheries of an accepted paradigm. Anomaly ambiguities are present when a viewer (knowledgeable about the		An image of stomach lining, such as one published by Barry Marshall, shows visual signs of a bacterium, something a particular scientific community

	science under investigation) recognizes something particularly unique about a scientific phenomenon, something that has not been noticed or accepted by a community before. (*Structure of Scientific Revolutions*)		thought was not able to survive in the stomach.
Oikonomia	In his article "What is an Apparatus?" Giorgio Agamben indicates that in societies, there are "[sets] of practices, bodies of knowledge, measures, and institutions that aim to manage, govern, control, and orient…behaviors, thoughts, and gestures of human beings." Oikonomia ambiguities are visual elements that are designed under definitive practices in order to orient the viewer to a common belief or practice that may not have been noticed otherwise.	Standard measurement symbols in certain communities (like the "μ" micro symbol) that orient the viewer to rethink proportions.	An institutionalized image of Mars, taken by NASA, a governmental organization funded by taxpayers who may have conflicting emotional interest in supporting such an institution

The Linguistic-Rhetorical Domain of Visual Ambiguity

Elements of an image or design that epistemologically affect meaning because of their connectedness to language fall within the linguistic-rhetorical domain of visual ambiguity. In other words, something about the visual element is tied to something textual or language-based. For example, Roland Barthes has suggested that whenever images are juxtaposed with text, "the words…are parasitic on the image" (25). Visual elements are interpreted much differently when influenced by the text that describes it. Furthermore, Joachim Schummer has indicated that when visual objects look like objects in the real world, we make a connection through language, assigning metaphorical descriptions to the phenomenon, "[establishing] a symbolic link between the world of ordinary objects and the [world of visual scientific phenomena] through their interpretative ambiguity" (59). The linguistic metaphor, in other words, redefines the visual interpretation. Visual ambiguities, hence, of the linguistic-rhetorical domain involve visual elements that are either placed directly in juxtaposition with text or that are defined and explained with metaphorical or tropological terminologies. *Types* of visual ambiguities that can be found in the linguistic-rhetorical domain may include those found in **Table 4.2** below.

Table 4.2: Linguistic-Rhetorical Domain of Visual Ambiguity

Linguistic-Rhetorical Domain of Visual Ambiguity			
Visual ambiguities of this domain involve visual elements that are placed in juxtaposition with text, exhibit metaphorical or tropological characteristics, are related to grammatical counterparts such as subjunctive verb tense, or qualify as if a hedging verb to demonstrate strength or weakness			
Linguistic-Rhetorical "Types" of Visual Ambiguity		**Cognitive Dimension**	**Affective Dimension**
Type	**Description**	**Examples/Sub-Types**	**Examples/Sub-Types**
Juxtaposition	In "The Photographic Message," Roland Barthes, suggests that text "changes [the] structures" of an image, "[signifying something different to what is shown." Juxtaposition ambiguities are places where text influences and orients to understand something not necessarily perceptive from the visual alone.	Captions, labels, titles, headings that are juxtaposed, aligned, or placed in close proximity to visuals, affecting readability and cognition	Captions, labels, titles, and headings that, through rhetorical word choice, affect emotional response of a visual
Symbolism	Joaquim Schummer suggests that images of scientific phenomena often assume shapes that symbolically link to something in the world of ordinary objects. Symbolism ambiguities are present representations where the viewer makes a link between the shape/appearance of an abstract phenomena to something tangible in the "physical" world.	A molecule that *looks* like a basket affects the way the viewer thinks that molecule is supposed to *act* (as if like a basket)	
Anthropomorphism	Joaquim Schummer argues that concepts/terminologies related to human capacities are often assigned to otherwise difficult-to-understand scientific phenomena.	Visual conceptions that encourage a viewer to associate human characteristics to a non-human object, like when	Visual conceptions that encourage a viewer to associate human characteristics to a non-human object, like when

	Anthropomorphism ambiguities are visual elements that are linguistically assigned human characteristics.	bacteria have to make a "choice," making viewers *cognitively* interpret the phenomenon differently	bacteria have to make a "choice," making them *emotively* interpret the phenomenon differently
Ostension	Richard Boyd has suggested that metaphors "[accommodate] language" to the causal structure of the world. Other related linguistic devices use *ostension*, making use of examples to describe phenomena because it is difficult to explain. Ostensive ambiguities are uses of visual elements	Visual analogies, puns, allegories, synecdoche, and so forth that affect readability and understandability, as in an infographic that uses pictograms to describe populations	Visual analogies, puns, allegories, synecdoche, and so forth that affect *emotional* response, as in the pictograms in an infographic used especially to appeal to emotional response

The Technological Domain of Visual Ambiguity

Elements of an image or design that epistemologically affect meaning because of their connectedness to technologies fall within the technological domain of visual ambiguity. Mark J. P. Wolf suggested that technology is often used to enhance, conceptualize, or otherwise render visual objects to show what "could be, would be, or might have been" (417). In other words, renderings are often created to portray what our eyes cannot see, but what we "might" see, if our eyes were capable (420). In a similar vein, ambiguity emerges as a result of technology when interactivity (like in a simulation or video game) is unpredictable (see Gasperini's "The Role of Ambiguity in Multimedia Experience"); when images are abstracted and simplified with technology (see McCloud's *Understanding Comics* or Mishra's "The Role of Abstraction in Scientific Illustration"); or when images are otherwise artistically rendered with technology, as in an animation. Visual ambiguities of this domain involve visual elements where technology affects resolution, true color, magnitude, interactivity, abstraction, or conceptualization. *Types* of visual ambiguities that can be found in the technological domain may include those found in **Table 4.3** below.

Table 4.3: The Technological Domain of Visual Ambiguity

Technological Domain of Visual Ambiguity Visual ambiguities of this domain involve visual elements where technology affects resolution, true color, magnitude, interactivity, abstraction, or conceptualization.			
Technological "Types" of Visual Ambiguity		**Cognitive Dimension**	**Affective Dimension**
Type	**Description**	**Examples/Sub-Types**	**Examples/Sub-Types**
Interactivity	When visual communication becomes interactive—like in a simulation, video game, or on a website—technological limitation affect the extent to which a simulated experience is open-ended. Choices become clear or obfuscated as a person moves within the interactive medium. The narrative, affected by interactive technology, affects interpretation. Ambiguity in these instances is closed-ended if a certain conclusion is inevitable. It is open-ended if there is no certain outcome or choices. Video game developer and information designer Jim Gasperini has compared this kind of "open-ended" and "closed-ended" ambiguity to the uncertain experiences and outcomes in media such as Choose Your Own Adventure novels, video games, and interactive plays.	Any visual depiction that gives a viewer choices about what to see or where to go, as in a virtual simulation of a surgery, where the participant moves ambiguously through pre-determined, technology-restricted boundaries that limit or control usability.	Elements of a visually simulated design that affect user experience—that please, anger, or frustrate—because of limitations or strengths in technological capacity
Modality	Kress and Van Leeuwen claim that visual modalities include colors, hues, contrast, or a host of other design elements that embolden or lessen the emphasis. Similar to a modal qualifier used in language, visual modalities refer to aesthetic elements that give weight to argumentation.	Visual elements that draw particular attention over other elements, such as a yellow circle on a black background, affecting readability and usability.	Visual elements that draw particular attention over other elements, such as a yellow circle on a black background, affecting emotional interest and response.
Noise	Luc Pauwels indicates that "inadequate resolution or insensitivity caused by a	Pixilation, jaggies, blurriness, incorrect color, and so forth that are present (because	Pixilation, jaggies, blurriness, incorrect color, and so forth that are present (because

	limited spectral range" of instrumentation can cause noise (9). Technological noise ambiguity refers to unnecessary, superfluous, or distracting visual elements created as a result of inferior technology.	technology inadequately captured a phenomenon's true qualities) and affect readability—such as in a dark, black and white photo.	technology inadequately captured a phenomenon's true qualities) and affect how a viewer *feels* about the scientific concept being represented.
Abstraction	Rudolph Arnheim and Punyashloke Mishra have each mentioned that abstraction causes the viewer to mentally fill the blanks that the abstracted image leaves out. Scott McCloud has suggested that the more abstract an image is, the more people or things it can be said to represent. Abstraction ambiguity refers to images that remove realistic details to demonstrate either something incomprehensible (like in the Rorschach inkblot test) or to universalize a concept (like a stick figure for a human being).	Visual designs that, though technological manipulation, have been modified to be more visually simplistic, like in a diagram of a dragonfly where colors, shadows, etc. have been removed to enhance usability and readability	Visual designs that, though technological manipulation, have been modified to be more visually simplistic, like in a diagram of a dragonfly where colors, shadows, etc. have been removed, subsequently affecting emotive response to an image
Subjunctive	Mark Wolf, in "Subjunctive Documentary: Computer Imaging and Simulation" suggests that simulations are designed to show what a scenario "might be" like. Simulations are not always accurate, but they show a rendering of how we think something would or could be. Sometimes colors (and other design elements) are included in simulations—like to view the waves in an CAT scan or an MRI—to improve understanding but the waves are not actually colorful. Yet, the colorization allows the viewer to *imagine* what is happening, even though his eyes cannot view it naturally or without the help of instrumentation.	Visual elements conceptualized using technological applications (like Photoshop or animation software) to show something that the human eye would not have been able to see otherwise, making usability and readability even possible	
Variance	With language, when describing a species or type, it is easy to indicate that there is a variance in the way something looks. ("A German Shepherd stands *between 24 and 36* inches tall). However, in an image, as Luc Pauwels argues about representing a bird species, "one is…forced to show a particular specimen of the species…of a particular age and sex, and in particular circumstances (habitat, weather, time of day, season)" (14). Variance refers to static images produced by static technologies that represent only one archetype of a class of things that could be portrayed in multiple ways.	A visual element that is representative of only one position, shape, species, size, etc. of an object that could likely be represented in other ways, like how the static image of an ant, shown from the side, climbing a tree could also be shown from the front, walking on a leaf.	

The Metaphysical Domain of Visual Ambiguity

Elements of an image or design that epistemologically affect meaning because of their connectedness to human character and personality fall within the metaphysical domain of visual ambiguity. W. J. T. Mitchell identifies gestalt psychology and Rorschach inkblots as idiosyncratic ways of interpreting information—individualistic interpretations affected by character, personal background, personality, and psychosis (*Picture Theory*). Roland Barthes has indicated that inexplicable visual elements, called *punctums*, will penetrate or "prick" an individual, distracting their attention to something unrelated to the message of the image (like a boy's bad teeth in an image where a gun is pointed to the boy's head) (*Camera Lucida*). *Punctums* remain outside of rhetoric because they are understood only idiosyncratically. Furthermore, in Fichte's writings (as one example among many), we learn that human spirit and "productive imagination" have the ability to conjure images within our consciousness (203). Visual ambiguities of the metaphysical domain involve elements that spark unpredictable and individualistic reactions like gestalt switches or Barthes' *punctum*, imagination, spiritual connection, or dreams. *Types* of visual ambiguities that can be found in the metaphysical domain may include those found in **Table 4.4** on the following page.

Table 4.4: The Metaphysical Domain of Visual Ambiguity

Metaphysical Domain of Visual Ambiguity Visual ambiguities of this domain involve elements that spark unpredictable and individualistic reactions, imagination, gestalt switches, spiritual connection, and dreams.			
Metaphysical "Types" of Visual Ambiguity		**Cognitive Dimension**	**Affective Dimension**
Type	**Description**	**Examples/Sub-Types**	**Examples/Sub-Types**
Punctum	A concept primarily tied to the work of Roland Barthes, *punctum* refers to accidental "pricks" in an image or work of art that strikes the viewer in unexpected ways. *Punctums* cannot be planned by the communicator, but they nonetheless inflict new meaning on the viewer. *Punctum* ambiguities possess a somewhat uncanny ability to divert or distract the viewer from the message of the image. (*Camera Lucida*).		Anything that is strikingly odd or that captures unsolicited attention to an individual viewer. Barthes uses the example of how in a photo of a young boy with a gun to his head, Barthes is distracted, for whatever reason, by the boy's bad teeth
Gestalt-switch	Principles of Gestalt psychology indicate that the brain puts pieces together into whole, connecting dots that are not necessarily there, to understand how visual pieces work together. Gestalt switches happen the brain sees multiple things from these pieces at the same time, in what W. J. T. Mitchell has called "multistable" images. Gestalt-switch ambiguity involves visual elements that collectively might be perceived as multiple things at the same time.		
Rorschach	The widely used Rorschach inkblot test uses abstract images to determine personality. In a similar vein, Rorshcach ambiguities exist in images where the viewer is unclear what an image represents in reality, and is hence required to simply suggest what it "looks like" to him or her	Elements of an image that appear too abstract—at least beyond the knowledge of the viewer—to be decipherable, and thus affect the usability of the image	Elements of an image that appear too abstract—at least beyond the knowledge of the viewer—to be decipherable. Because of this abstractness, viewer interprets the image to look like something that it is not, but something tied to his or her emotional response to the image
Spiritual	Ficthe has suggested that the human spirit is the "ability of the productive imagination to convert		Visual elements that affect the imagination in relation to personal experience, conjuring mental images outside of the

	feelings into representations" (199). Spiritual ambiguities, thus, emerge from personal experiences and feelings where a viewer's imagination pictures something that is not even present in the physical image.		physical image. For example, a viewer may look at a close-up photograph of osteoporosis, but mentally picture something else, like a sponge, and then be "spiritually" reverted to a time when his/her parents found a live sponge on the beach.

Developing a Naming System

Beyond classification, the development of a naming system is the next logical step for a taxonomy of visual ambiguity. Sandra Knapp, author for the Natural History Museum in London, in a short anecdote about taxonomies noted that early problems with the naming of plants caused not only miscommunication but mistaken scientific function. The name of the tomato, for example, was translated into different Latin terms, including *poma di Mori* and *poma di ori*, meaning the "apple of the Moors" and the "golden apple," respectively. It is believed that these names may have combined to be *poma amoris*, meaning the "love apple," and that it was eventually suspected that the tomato was a powerful aphrodisiac. Perhaps just as problematic, if not worse, Knapp notes what later became the official Latin name of the tomato: *Solanum caule inerni herbaceo, foliis pinnatis incises*, "which means the 'solanum with the smooth stem which is herbaceous and has pinnate leaves'" (Knapp). Just as multiple terms for the same item is overtly problematic, the lengthy names of scientific concepts also made it most certainly difficult to communicate coherently and effectively.

Perhaps obvious, the history of nomenclature in the sciences led to a pointed binomial naming system, most widely recognized as being developed by Carolus

Linnaeus in the 18^{th} century (even though binomial naming systems, really, can be dated back to Aristotle in his work *Historia Animalium* and later polished by his student Theophrastus in his categorization of plants) (Tilton). Linnaeus' simple, systematic naming system transformed science with its simplicity and functionality. The *genus* > *species* system of nomenclature profoundly simplified terminology that in turn simplified and expedited scientific discourse. Cultural and communal shifts in the naming of plants and animals no longer hindered effective progress. The streamlining of the system in fields like botany and medicine was so effective that it has been used for nearly 250 years.

To apply the effectiveness of naming systems to visual ambiguity, in the tables above I established a short taxonomic list of visual ambiguities as a sampling of how a naming system might work. The taxonomy presented in the tables is far from exhaustive—indeed it merely scratches the surface—but it demonstrates the practical, systematic method in which scientific communicators might improve visual literacy through a simple naming process. In the preamble to the *International Code of Botanical Nomenclature*, it states the very perfunctory scope of an effective naming system:

> This *Code* aims at the provision of a stable method of naming taxonomic groups, avoiding and rejecting the use of names that may cause error or ambiguity or throw science into confusion. Next in importance is the avoidance of the useless creation of names. Other considerations, such as absolute grammatical correctness, regularity or euphony of names, more or less prevailing custom,

regard for persons, etc., notwithstanding their undeniable importance, are relatively accessory. ("Preamble")

The taxonomic descriptions above lists the types of visual ambiguity as they might be construed in such a mechanical fashion. Each of the domains and dimensions, as well as numerous types, of visual ambiguity is defined. The primary function of this portion of the taxonomy is to develop a series of definitions under which a viewer of a scientific representation could classify meaning-making phenomena they cognitively see or emotively experience. A viewer (and, obviously, the author) of an image, in other words, can take something they see in any image or design (a wavy line, a color, a little girl, a sponge, a pixilation), and categorize it under a specific class of ambiguous meaning-making.

To illustrate, a person looking at a computer-produced image of a pixilated typeface might notice "jaggies" or "aliasing"—technical terms for wavy, stair step effects that show up on straight and curved lines due to low resolution screens or printouts. These jaggies might be identified under the *type* of visual ambiguity "noise" which further falls under the technological *domain*. Researchers, practitioners, or educators might then determine which of the meaning-making dimensions this design element most likely affects: cognitive or affective, or a combination of the two. To classify the ambiguity and its locus of effect on a particular visual design element, the person working with the image would label it in a trinomial nomenclature pattern, not unlike the Linnaean classification system, in this order: Domain > Dimension > Type. For example, if the usability/readability of the image is affected by jaggies, the jaggies could be labeled as Technological-*Cognitive*-Noise ambiguities. If the viewer's *emotional* response of the image is also affected by the jaggies, they could also be identified as Technological-*Affective*-Noise ambiguities. Here, the ambiguity of the visual element is preserved—its name(s) do(es) not entirely define it because it can be classified under two names. Each name, though, specifies a point of focus. Scientific researchers, communicators, or educators may wish to evaluate the jaggies from either visual ambiguity name. The visual element remains the same, but its function, its ambiguity, changes. The potential, of course, of doing this is to provide researchers and practitioners with a guide and terminology for evaluating particular responses to images and designs while cognizant of the indeterminate.

Ambiguous Relationships: A Tetradic Model

The names and categorizations listed in the taxonomy above is helpful, but the productive application of a taxonomy for visual ambiguity must go one step further than naming and categorizing. It must, as I mentioned earlier, seek to bridge the divide between method and imagination, or science and rhetoric. As Kenneth Burke noted in *A Grammar of Motives*: "Accordingly, what we want is not terms that avoid ambiguity, but terms that clearly reveal the strategic spots at which ambiguities necessarily arise" (xviii). Naming and categorizing visual ambiguities can only get scientific communicators so far—recognizing their affect when they work in tandem with each other is far more productive (and even more ambiguous). A frequently proposed problem of taxonomies is that by categorizing parts of a larger system, we begin to assume that each category or type is mutually exclusive, that there is no overlap. A taxonomy of any communication, be it linguistic or visual, would be problematic if we were to assume that each defined category were perfectly delineated. That would suggest an unalterably prescriptive definition of each area of visual ambiguity, which seems a superficial and inaccurate approach because it doesn't embrace how types of visual ambiguity relate to each other.

In what might be deemed a taxonomy of rhetorical motives, Burke is widely known for the development of the dramatistic pentad, which establishes a systematic investigation into a "grammar" of rhetorical motives. This taxonomy has been extensively used to critically analyze anything from gay rights controversies (Brummet) to W. D. Hamilton's work in genetic evolution (Journet). Burke's five terms—"act," "scene," "agent," "agency," and "purpose"—serve as rhetorical categories which affect an event. The delineation of these terms effectively produces the "stage" whereby we can formulaically analyze human motives and actions. What I wish to emphasize here is that Burke suggests that awareness of the *relationships* between these categories is what strengthens analytical effectiveness. "Certain formal interrelationships prevail among these terms," he says, "by reason of their role as attributes of a common ground or substance. Their participation in a common ground makes for transformability." Perhaps even more importantly, Burke then continues: "At every point where the field covered by any one of these terms overlaps upon the field covered by any other, there is an alchemic opportunity, whereby we can put one philosophy or doctrine of motivation into the alembic, make the appropriate passes, and take out another" (xix). The reference to an alembic is particularly poignant, as it suggests that by developing relationships between multiple categories, we refine our understanding about each.

The goal of a taxonomy like Burke's is to point out specific areas from which we can work without pigeonholing or marginalizing any of them. A systemic categorization useful for analysis, such as Burke's, recognizes that categories affect each other and that together they have a synoptic function, that they collectively extricate principle elements in order to make an educated generalization. In Burke's words, a taxonomy like his methods of dramatism

> Offers of system of placement, and should enable us, by the systematic manipulation of the terms, to "generate," or "anticipate" the various classes of motivational theory. And a treatment in these terms…reduces the subject synoptically while still permitting us to appreciate its scope and complexity. (xxiii)

Burke's purpose for using the pentadic terms was to produce a system whereby we would be able to conjure a synopsis of an event, evaluate the happenings or actions of that event as they relate to each point in the pentad, and predict future actions based on the causes of action identified in the "stage" under investigation. When we evaluate the possibilities that a "scene" (the background or situation in which an action takes place) provides, Burke suggests, we might be able to also determine how the act came to fruition. Thus, there is a relationship between the scene and the act, identified as the "scene-act ratio" (3). Burke points out that with his five terms, there are ten possible ratios: scene-act, scene-agent, scene-agency, scene-purpose, act-purpose, act-agent, act-agency, agent-purpose, agent-agency, and agency-purpose. These ratios provide insight into determining how actions come to pass.

In relation to a taxonomy of visual ambiguity, I propose not a pentad, but a tetrad, where the agent is removed from the ratios. Burke's taxonomy of dramatistic terms was intended to investigate what moves people ("agents") to *action* ("act"). Despite the fact that an agent commits the act, his or her motivations for doing so are not necessarily reliant upon him or her, and thus a rhetorical analysis of the motives can be explored without investigation of the agent. At least, motivations can be investigated from perspectives outside of the agent (a person might kill another person, but we may investigate it from the perspective of how the *scene* and *purpose* encouraged it). In other words, for an investigator to evaluate motives for actions caused by an agent, critical analysis using Burke's pentad allows for the person conducting the analysis to remove the agent entirely from the analysis. Observation of *why* an act happened might simply be evaluated on circumstantial properties of the scene regardless of the agent's role in it. The Tetradic Model of visual ambiguity differs from this in an important and somewhat paradoxical way. Rather than using the taxonomy to discover what moves people to *action*, it is intended to investigate what moves people to *understanding*. In this regard, the agent *cannot* be removed from analysis, and *must* be removed from the ratios. This is because the ratios that move a person to understanding will *always* be affected by the person's (agent's) idiosyncratic interpretation and, thus, intrinsically included in any analysis of the visually communicative ratios.

From a tetradic perspective, then, I propose that visual ambiguities function within a visual "stage," which actively contains dramatistic parallels to Burke's terms. Burke's terms seek to answer the five classic questions: who (agent), what (act), when/where (scene), how (agency), and why (purpose). If the agent is *always* necessary for effective analysis, then an investigator evaluates how the other four dramatistic terms impact understanding. While Burke's stage/drama metaphor is appropriate to predict and analyze the motives of human action, I prefer to use a slightly more visual metaphor for the analysis of visual representations' effect on understanding, where the stage becomes the visual field, or a cinematic *mise en scène*, which describes the arrangement of scenery in a visual field. If the observer of a scientific communication is the *agent*, then we know *who* is being affected by the communication. The other four terms in question, appropriate to the *mise en scene* metaphor are as follows:

1. Subject (*what*): the thing or things being communicated, the visual subject of a representation

2. Scenery (*where/when*): the information that surrounds the subject, either directly within the visual field, or without

3. Makeup (*how*): the ensemble of visual elements that collectively construct the subject and scenery

4. Scope (*why*): the purpose of the representation in relation to the scientific phenomena it is intended to represent

The tetrad represented in the *mise en scene* of a scientific visualization represents the visually communicative components in play whenever a person observes the visualization. Visual ambiguities, specifically, become part of the *scenery* and *makeup*. The interpretation of any of the four parts of the tetrad is affected by how the agent responds to the visual ambiguities' relationship with other parts. Just as we can use Burke's pentadic ratios to determine motives for actions, we can assemble ratios of the tetradic *mise en scene* to determine possible reasons for interpretation. Analysis of the subject-scenery ratio, for example, investigates how the *subject* of a representation is communicatively affected by the *scenery* (which might include a "Linguistic/Rhetorical-Cognitive-Juxtaposition" visual ambiguity) in relation to the agent's interpretation of both. A heuristic investigation, using a case example, of how the tetrad might be applied to research and instruction is explained in Chapter 5.

Ambiguous Conclusions about the Tetradic Model of Visual Ambiguity

In sum, the taxonomy presented here is a convergence of method and rhetoric, designed to promote awareness into the epistemology of the scientific imagination as the imagination is shaped by visual representations. The categorizing and naming systems, drawn from Linnaeus and Bloom respectively, shape the methodical portion of the taxonomy. The tetradic model, adapted from Burke's pentad, shape the rhetorical portion. Each of these portions work together as a holistic model for the interpretation of visual communication; however, each portion is, fittingly, wrought with ambiguities.

The categories developed, for example, are most certainly incomplete. Within each of the four domains, there is assured overlap in definitional properties (or, Burke's "antinomies of definition.") A linguistic-rhetorical visual element, for instance, might be identified simultaneously as a socio-cultural element because, clearly, linguistic elements are inherently cultural. Additionally, it is conceivable that other domains of visual ambiguity (beyond the four presented in the pinwheel at the onset of this chapter) may be conjured. The dimensions, too, are limiting and incomplete. In fact, Bloom felt it necessary to include a third dimension of learning altogether in his taxonomy (though, in his, it was labeled a "domain"): the psychomotor. For the purposes of visual communication and the improvement of visual literacy, affective and cognitive interpretations seemed the most poignant for this discussion and are the only two I included in the taxonomy. However, the physical, psychomotor components of meaning making could—and probably should—be investigated as well.

The rhetorical component of the taxonomy further obfuscates the clarity drawn from the classified and named visual ambiguities because it suggests that any named/classified visual element has the ability to affect meaning from multiple rhetorical perspectives (visual elements can, after all, shape-shift between subject, scenery, makeup, and scope). Ironically, however, the ambiguities of this taxonomy might be seen as its greatest strength because they provide nuanced flexibility for understanding how understanding is made. The taxonomy, in other words, through ambiguity, provides the practical wisdom of method for the sake of usefulness and application while appropriating artistic adaptation for the sake of imagination. As such, a more appropriate diagram of the taxonomy established in this chapter looks something like the representation in **Figure 4.2** below, where boundaries become blurred between dimensions, domains can be rotated to include different types, types "float" to move between dimensions and domains, and ratios of the tetradic *mise en scene* can be temporarily applied to any component of the taxonomy, much like a dart would be stuck to and removed from a dartboard.

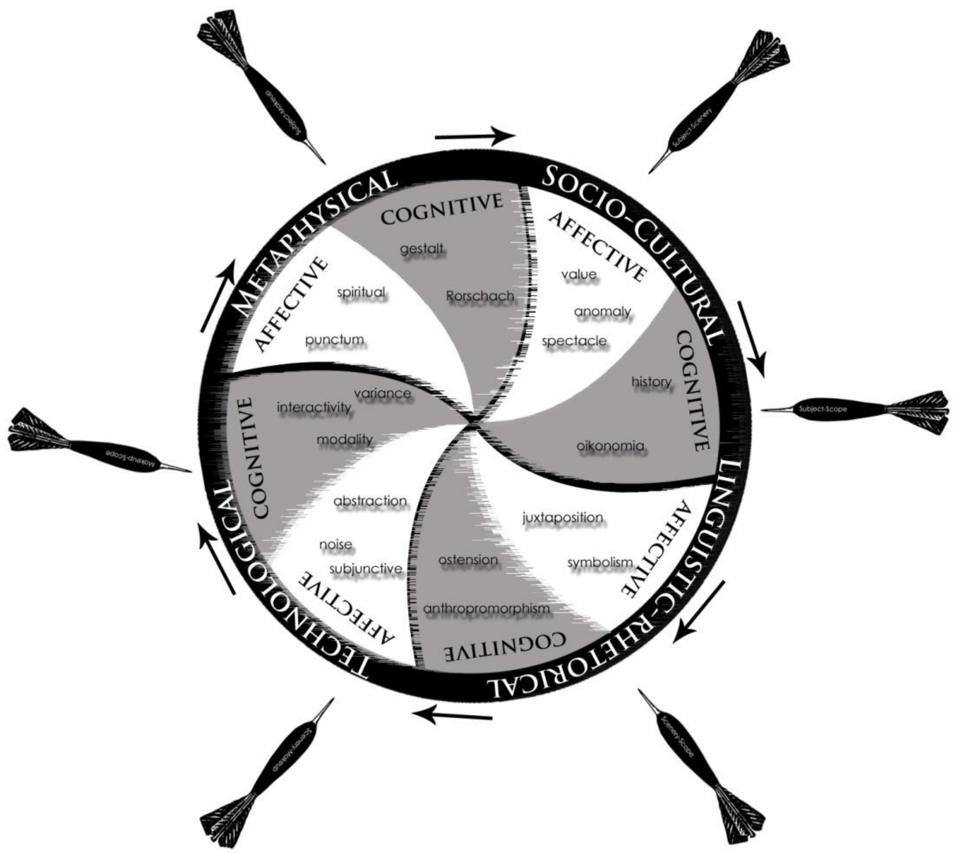

Figure 4.2: The Tetradic Model of Visual Ambiguity

CHAPTER FIVE

AMBIGUOUS HEURISTICS: A TETRADIC CASE ANALYSIS

"For apart from inquiry, apart from the praxis, individuals cannot be truly human. Knowledge emerges only through invention and re-invention, through the restless, impatient, continuing, hopeful inquiry human beings pursue in the world, with the world, and with each other."

-Paulo Freire, *Pedagogy of the Oppressed*

Back to Literacy: An Ambiguous Proposal

The preceding chapters of this dissertation have been written in response to one primarily looming issue in scientific communication: a hope for a stronger visual literacy has been subdued by a historical resistance to ambiguity in the sciences. The epistemic conundrum, as proposed, is that despite aesthetics' role as a nearly inescapable component of visual imagery, science, considered broadly as an area of inquiry, often expects visual representations to be productively mimetic of empirically drawn data. The ambiguity, however, that emerges in most or all visual representations—as discussed throughout this text—has been widely ignored as an inescapable, functional, and even productive part of scientific communication. In fact, visual ambiguity, if addressed at all, has frequently been deemed a hindrance to scientific communication (the efforts of instructional communication research to eradicate ambiguity in textbook representations addressed in the opening chapter is evidence of this).

Adopting ambiguity as a normal and expected component of visual representations reframes the way we approach visual literacy in the sciences. Inserting visual ambiguity into the conversations about ethically and appropriately representing science, likewise, brings to the forefront the visual literacy skills that seem to often elude scientific communicators. Roald Hoffmann's admonition to chemists about the lack of scientists' skills in visually representing information might be broadly applied to scientific communicators in many fields: "The group of professionals to whom this visual, three-dimensional information [graphical representations of science] is essential are not talented (any more, any less than the average person) at transmitting such information" (69). Hoffmann suggests that without training, scientists can—and will—still communicate visually. There will just be "much more ambiguity than [they] think there is" (69). … The process," he says, "is representation, a symbolic transformation of reality. It is both graphic *and* linguistic. It has a historicity. It is artistic *and* scientific" (69). Despite ambiguities functioning as a normal and inevitable part of the science *and* art of scientific communication, acquiring skills to work effectively within the communicative dichotomy will be challenging without awareness of how such ambiguities work. The Tetradic Model of Visual Ambiguity does not provide a clear-cut answer to how aesthetics, art, and design impact understanding. But it is not intended to. It is not the visual equivalent of an encyclopedic catalogue of a visual representation's effects on meaning. Communication is, after all, far too complex for such a prosaic rubric. The Tetradic Model functions as an adaptable, and perhaps richer, heuristic for strengthening awareness and the "talent" that Hoffmann refers to.

Etymologically, *heuristic* finds its roots in the Greek ideas of discovery, inventing, and finding. The Tetradic Model moves towards this concept of heuristic—that is, it gives scientific communicators a rudimentary toolkit for discovering, inventing, and finding ways to improve visual communication in science. Thea Van Der Geest and Jan Spyridakis suggest that the real value of a heuristic is that it provides procedures that systematically move a person or group of people toward a discovery, decision, or solution. Further, and perhaps more importantly, they claim that heuristics are valuable especially when there is not a clear-cut right way of approaching problems, when multiple solutions are possible (301). The visceral nature of visual communication and the presence of *affectively*-charged visual rhetoric in scientific representations (which unavoidably capture at least some emotion or nuanced character trait of the viewer) suggest that a multiplicity of communicative interpretations will likely be inevitable *and should be* expected.

A heuristic of visual communication, then, should not be intended to serve as a problem-*solving* mechanism, but as a problem-*approaching* iteration (and by "iteration," I mean a recurring, solution-*seeking* method). In mathematics, "iteration" suggests repetition and succession of imprecise conclusions in order to arrive at the best or "most" accurate one. This type of iteration has also been labeled as a "successive approximation," a concept that encourages repeated estimates, building upon previous ones in order to achieve a desired degree of accuracy. As Callahan et al suggested in their

Calculus in Context project: the method of successive approximation "builds succession of better and better estimates that get us as close as we wish to the true values" (61). Approaching visual communication from the perspective of an iterative heuristic encourages not necessarily the *precise* use and awareness of the communication's ambiguity in order to reach understanding; rather, the proposed heuristic encourages visual literacy through successive, iterative appropriations of visual ambiguity until "desired degrees" of literate awareness of meaning-making are achieved. Epistemological ambiguities that exist in scientific representations—because of the categorical and imbricating domains of visual elements—offers the visual communicator no clear strategic plan for communicating with precision. For the communicator, there are only visually communicative options wrought with communicatively ambiguous projections. Hence, to improve visual literacy in the sciences *types*, *dimensions*, and *domains* of visual ambiguities can be (paradoxically) procedurally applied to a system of approximations where visual ambiguities can be better understood (though never precisely) as they relate to the complexities of context and human nature.

The rhetorical, Tetradic Model of Visual Ambiguity, then, intentionally wrought with ambiguous application, serves as a loosely formulaic approach for *recognizing* how art (even if unintentionally *artistic*) and the ambiguity that comes with it, epistemologically informs science, and vice versa. Visual literacy, it might be said, emerges from this recognition; if this is the case, bridging where art and science overlap in visual representations becomes an important, necessary skill for any scientific communicator. Paul Messaris, in his book *Visual Literacy: Image, Mind, and Reality*, provides insight into how we might approach visual literacy. He has argued that visual literacy is 1) an attempt to acquire "familiarity with visual conventions…through cumulative exposure to the visual media"; that visual literacy 2) means garnering an "awareness of visual manipulation"; and that 3) visual literacy is a "basis for informed aesthetic appreciation" (3). My hope in presenting the taxonomy is that each of these components—familiarity, awareness, and appreciation—of visual communication in the sciences emerges from application of the Tetradic Model. *Familiarity* and *awareness*, it would seem, come from systemization and repetition, which can emerge in scientific fields through naming and categorizing visual ambiguities. *Appreciation*, particularly of aesthetics and visual design elements, comes from "getting to know" how the elements relate to each other and how their "relationships" evolve or dissolve in differing communicative circumstance. Messaris indicated the importance of becoming aware of how "visual effects" work in representations, suggesting that "such knowledge is self-evidently a prerequisite for the evaluation of artistic skill" (3). Knowledge of ambiguity's influence, similar to that of Messaris's "visual effects," sheds light into how epistemic, visual meanings are derived; this knowledge, hence, might be viewed as a precursor to effective evaluation of the visual communication of science.

The Tetradic Model and the Taxonomy: How They Work

The Tetradic Model of Visual Ambiguity (and the taxonomic wheel within it) introduced in the previous chapter (see **Figure 5.1**) thus become part of a heuristic toolkit for conducting a *tetradic analysis* of the visual representations of science.

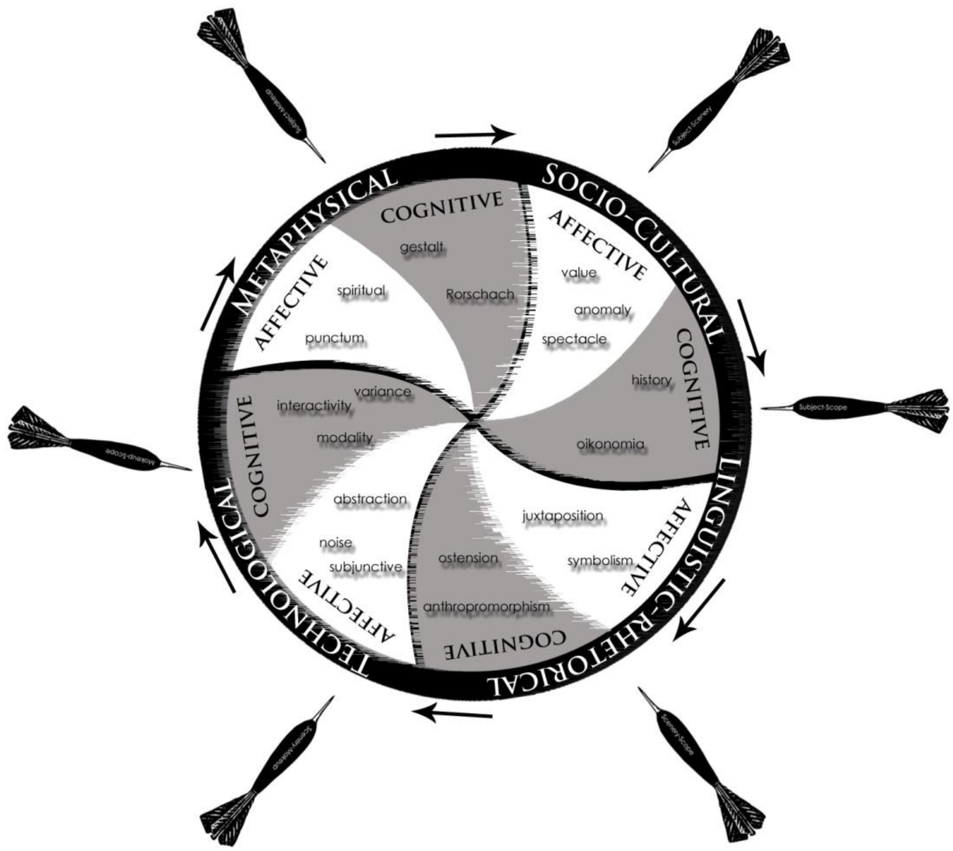

Figure 5.1: Taxonomic Wheel and Tetradic Model of Visual Ambiguity

Using this taxonomic wheel, a scientific communicator can take a visual element, assign it a *type* that has been defined and categorized into a given *dimension* and *domain*, and then analyze that type from the perspective of any of the six Tetradic ratios (which are represented above as darts that can be “attached” to any of the domains and dimensions within the wheel). Tetradic analysis of a visual representation of science, using this taxonomic wheel, thus opens windows into the ways in which socio-cultural, linguistic-rhetorical, technological, and metaphysical ambiguities affect meaning-making in scientific communication.

Thus application of the heuristic as a means for discerning communicative effects on viewers means distinguishing first between science as it exists in the mind and science as it exists materially. Qualitative investigations would use the Tetradic Model to explore how visual elements rhetorically, perhaps metaphysically, create an idiosyncratically mental understanding of scientific phenomena. *Quantitative* uses of the Tetradic Model, conversely, would explore how concretized and defined *material* scientific phenomena are cognitively understood across a more generalized viewing audience. The difference between the two might be best understood from the perspective of Cartesian dualism and materialism. Descartes argued that consciousness defined reality. Materialists argue that matter and energy define reality. Visual ambiguities can be explored from either of these two perspectives: either as an entity within consciousness that helps shape idiosyncratic (qualitative) awareness of scientific phenomena outside of the physical world, or as a physical entity that disrupts or distorts cognitive (quantitative) interpretation of materially existent scientific phenomena.

Case Analysis: Image, Taxonomy, Tetrad, and Ratios

The subsequent pages of this chapter investigate how we might utilize the Tetradic Model from Chapter 4 to conduct a "Tetradic Analysis of visual ambiguity" of a visual representation of science. In effect, the following Tetradic Analysis provides an example of how scientific communicators might make use of the taxonomy to strengthen awareness of how science and art work in tandem to produce meaning. Thus the bulk of this chapter serves as an ambiguous heuristic—that is, it provides a series of "suggestions" for improving visual literacy by creating familiarization, awareness, and appreciation of the visual ambiguities that help shape meaning.

The Image: "Osteoporosis"

To highlight the exigency that underlies literate awareness of visual ambiguities in scientrific representations, we may consider just how visual elements epistemologically shape our understanding. One such example is a conceptualized image of osteoporosis, a photo taken and edited by photomicroscopy specialist and natural science photographer Norman Barker (see **Figure 5.2**).

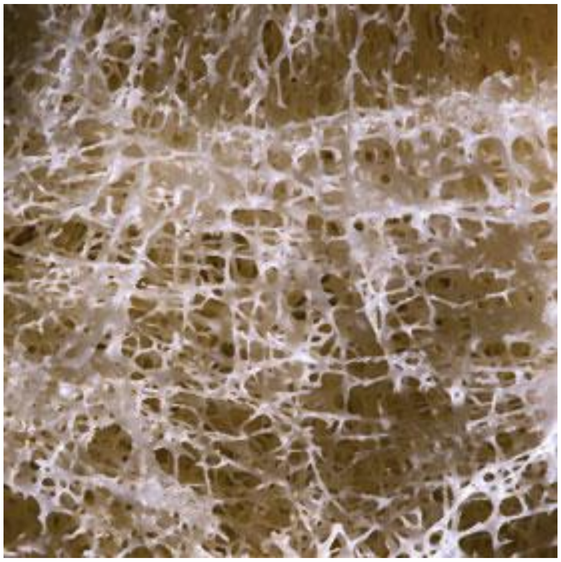

Figure 5.2: Norman Barker's "Osteoporosis"

In this image, viewer's see a "spongy," "lacelike," "network of interconnected spicules" enhanced and enlarged to show texture and form (Chin 23). The image is of a woman's bone diagnosed with osteoporosis, but the image stylistically appears like an amalgam of intricately woven fabric or a close-up of a delicate sea creature. This image persuasively, epistemologically "instructs" the viewer as they piece together what it is intended to communicate. It is likely hard for any viewer not to say to him or herself, as he or she gawks at the fascinating design, "oh, wow, osteoporosis looks like *that*?" Despite the caption superimposing a portion of the image that reads "using new software tools, [Barker] *stitched* multiple images together to create an unlimited depth of focus," viewers will likely take this image (at least upon first glance) at face value, to be the visual definition, the truthfully factual depiction, of a cancellous, osteoporosis-stricken femur (23, italics mine). Like the images of cells in the BioVisions project, this image of osteoporosis is grounded in scientific procedure, but influenced by technology, human decision-making, artistic flare, and production/dissemination methods. This image is a "metapicture," as Mitchell has suggested, a "place where pictures reveal and know themselves, where they reflect on the intersections of visuality, language, and similitude" (82). In other words, it is an image that, despite its seeming simplicity, complexly communicates multiple things at once. Visual ambiguities exist in this composite image that displays natural beauty from an unnatural composition process.

The "stitching" of images with software tools has become an inescapable part of the scientific process or, at least, the communicating of it. Barker's image of osteoporosis, as a common example of visualized scientific communication, is at once instructive and clear, and also conceptualized, artistic, and ambiguos. Barker's "Osteoporosis" only shows *one* part of *one* woman's bone; it is greatly enlarged (like the foodstuffs on the cover of a cereal box) to show texture; and it has artfully removed noise, color, and other unwanted visual "material" in order to highlight key elements and to beautify the image. And, despite the advancement in imaging technology, the image is still affected by the lighting, angle, shutter speed, and so forth in the technology—the photographic device—that captured it.

Barker's image, while certainly aesthetically attractive, is nothing exceptionally dramatic or fanciful in its depiction; it serves, however, as a good example of how aesthetics in scientific representation affect understanding and why we might look to visual ambiguity to strengthen our familiarity, awareness, and appreciation of the epistemic qualities of visual elements. Barker's image is representative of a particularly common medical photograph, an image that could be displayed in a popular science magazine (like *Scientific American*, where I first came across it), or in a textbook, journal, or museum (places where many others of Barker's similar images have been published). Like many visual representations of science, it has been photo-edited and rendered for a number of reasons, not the least of which is for "readability." But the caption atop the image, which touts the stitching of images, describes the possible misunderstanding of how art and science—and ambiguity—work simultaneously within an image. This caption, perhaps, is representative of the visual literacy problem: it points to the *clarity* that artistic rendering provides, and does not consider the *ambiguity* that emerges from such rendering. "Osteoporosis," we might say, is prototypical of the kinds of images in science that amalgamate artistic aesthetics *and* scientific rigor. It is an image, like so many others, ripe with visual ambiguities that frame interpretation and there is much that can be gleaned from evaluating the role of visual ambiguity within it.

The Taxonomy: Types, Domains, and Dimensions

Duotone as a "Type" of Visual Ambiguity

In *every* scientific representation, there are visual elements that communicate *something*. In Barker's representation of a human bone, a duotone color scheme with a sepia hue is used to highlight particular features. The duotone itself is a visual element within the image (and is one of possibly scores of visual elements that could be investigated). Like most other visual elements in any image, the duotone in this image has the ability to produce multiple understandings and interpretations, even if subtle. The duotone is, in other words, a *type* of visual ambiguity. A visual element's *type* emerges as the scientific communicator reflects on how the element conveys ambiguous meaning. A type listed and defined in the taxonomy in Chapter 4 that is appropriate to the visual element, duotone, under investigation is "modality." According to the definition listed in the taxonomy, a "modality" type may be defined as a visual element that

> "embolden[s] or lessen[s] … emphasis. Similar to a modal qualifier used in language, visual modalities refer to aesthetic elements that give weight to argumentation."

Because the duotone highlights and obscures—emboldens and lessens emphasis—we might label the duotone in "Osteoporosis" as a "modality."

Duotone within the Cognitive Dimension

Furthermore, the duotone of this image, undoubtedly, might directly affect both the cognitive components of meaning-making and the affective components. Analysis of the duotone spurs questions about which meaning-making dimension—cognitive or affective—it should fall under. Does the visual element directly affect readability or usability? Or, does the element affect emotional response? For the analysis of "Osteoporosis," I opted to evaluate the element from the perspective of the *cognitive* dimension (not necessarily because the duotone is more prevalent in this area, but simply because one had to be chosen for analysis). Because the duotone contains characteristics that would likely affect readability (cognition), the duotone in this image might be said to lie within the "cognitive" *dimension* and be labeled as a "modality" *type*.

Duotone within the Technological Domain

Placing the duotone within a *domain* further raises questions about the characteristics that inform the dimension it is in. Does the duotone have a particular history within a discipline (*socio-historical* domain)? Might the duotone evoke personal reflections unrelated to the science itself (*metaphysical* domain)? Is there a particularly close relationship with the duotone and something linguistic (*linguistic-rhetorical* domain)? Answers to such questions assign the duotone, as a *type* of visual ambiguity, within a *domain* particularly relevant to specific research questions. Because the image editing and coloring in Barker's image can be seen as technological superimpositions, the duotone in this analysis was said to be influenced by the "technological" *domain* of visual ambiguity.

The duotone in Barker's "Osteoporosis" was thus be labeled a *Technological-Cognitive-Modality* ambiguity (see **Figure 5.3**).

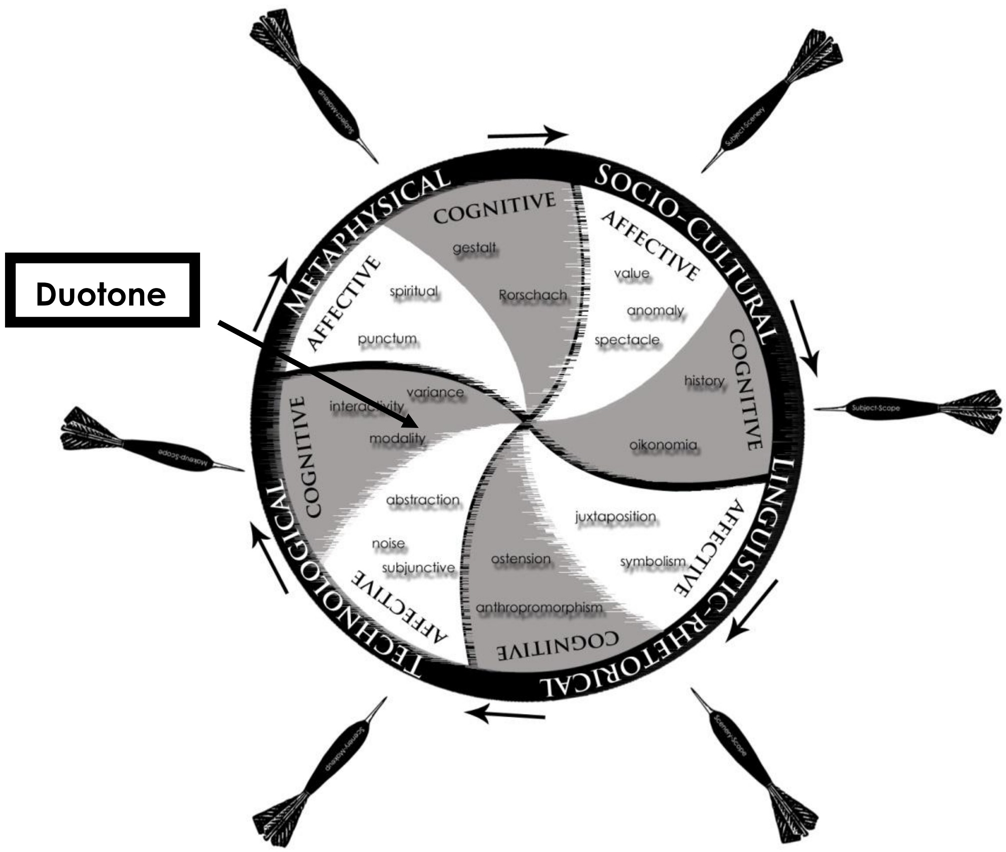

Figure 5.3: Duotone as a "Technological-Cognitive-Modality" visual ambiguity

This is not to say that the duotone could not have been labeled as something else entirely, however (and hence preserving the productive ambiguity of the taxonomy). Indeed, the duotone is tied to particular social histories as well; a viewer may reflect on his or her own affective perceptions of the sepia coloring as it relates to a history of its use or development. In this case, a researcher may wish to label the duotone differently, as a *Socio/Cultural-Affective-History* ambiguity. And, there are a number of other ways a researcher might be able to label the visual ambiguity present in this element. For the purposes of my investigation hereafter, the visual element duotone was analyzed as a *Technological-Cognitive-Ambiguity*.

The Tetrad: Subject, Scenery, Makeup, and Scope

The tetradic parts of the *mise en scéne* described in the previous chapter—the *subject*, *scenery*, *makeup*, and *scope*—further serve as communicative variables that contextualize the ambiguities that are defined and drawn from the taxonomy. For my analysis, the *mise en scéne* thus function as a rhetorical framework in which I was able contextualize the duotone. Like any visual representation of science, "Osteoporosis" as I found it was presented as a visual representation in a much broader *mise en scéne.* My scope, using the Tetradic Model, was to draw conclusions (or, at least, raise more questions) about how the duotone, in its broader rhetorical context, may shape meaning. In other words, how does the visual situation in which the duotone is placed affect understanding beyond the duotone itself?

The Subject

Most representations of science will exhibit some primary subject that is intended as the focal point that is intended to draw the viewer's attention. This subject is supposed to reflect (or visually mimic in some way) the actual scientific phenomena it represents, even if said subject is widely abstracted or conceptualized. In "Osteoporosis," the *subject* (as defined within the Tetradic Model) of the image is the bone itself (or, at least, the parts of the bone that we see).

The Scenery

The *scenery* is shaped by where the image is physically found, such as in a publication or as a photo in a lab. Also according to the Tetradic Model, the *scenery* includes any and all text and visuals that are in juxtaposition or circumnavigation of the image in the visual field in which it is found. For our example, "Osteoporosis" was located in the pages of *Scientific American*, a popular science magazine. The image had no article associated with it, though a small caption in a black textbox superimposed the image. Also within the scenery, seemingly unrelated advertisements surrounded the image and a short article on treating Tourette's sundrome was adjacent to it.

The Makeup

According to the Tetradic Model, the *makeup* consists of the collection of visual "pieces" that jointly construct the subject and its surrounding environment. If the *scenery* is said to be the collection of information *surrounding* the image, the *makeup* can be said to be the collection of information *within* the image. In complex (and perhaps "busy") representations of science, like in Da Vinci's drawing of the fetus in a womb, we see a host of things that make up the subject, including the fetus's toes, the layers of the womb, the blood vessels attached to the womb, and so forth. In "Osteoporosis," the visual "pieces" that construct the subject appear to be minimal, though we can see a network of spicules that we are expected to interpret as the bone.

The Scope

Finally, in the Tetradic Model the *scope* determines why the representation was made and what it was intended to represent. The scope may be one of the most challenging components of the Tetradto uncover, without knowing the person or organization that produced the image. However, a *scope* can often be inferred by textual cues in juxtaposition with the image, or by simply evaluating the likely *scope* based on the *scenery* in which the representation was produced. In the caption in *Scientific American*, the scope of "Osteoporosis" is explained as a way to expose "an unlimited depth of focus" on the far-reaching effects of the disease. The audience for whom this image has been produced (which for "Osteoporosis," in *Scientific American*, might be considered a high-school-educated, science-interested, but non-expert audience) would also be determined within the *scope*.

The purpose of appropriating the Tetradic Model to analyze an image like "Osteoporosis" was to determine which of the four parts of the *mise en scène* revealed the most interesting rhetorical nuances. Indeed, it is here where visual literacy was improved as evaluation of context emerged. As I evaluated "Osteoporosis," each of the four parts of the Tetrad revealed something interesting to me. The most difficult component of the Tetrad for me to evaluate, based on my background in medicine (which is very little), was the makeup. Because of my (in)experience, I was led to believe that the makeup of the image was mostly rhetorically interesting for what was left out of the image. The image makeup itself, from my perspective, did not offer much in terms of evaluation. Of course, experts in osteology, orthopedics, or even medical photography would likely disagree. For experts in those areas, there may be a host of rhetorical nuances exposed in the makeup of the "Osteoporosis" image. Such differences in the rhetorical purviews of the makeup between audiences expose the epistemic nuances that shift based on audience knowledge of the subject matter being communicated. The multiplicity (ambiguity) of rhetorical projections that emerge from the makeup of this image address Boyd's perspective on epistemic access. Background knowledge of the *subject* and the *makeup* of that subject will provide varying levels of epistemic access to osteoporosis. As a viewer of the image, I become the agent that was affected by the communication and my ability to access, epistemically, the communicative nuances of the image depended on my individual, idiosyncratic experiences with such images and with such scientific phenomena. As the agent being moved to understanding, then, my interpretation was shaped by my relationship with each of the parts of the Tetrad.

The Ratios: A Rhetorical Approach

With this in mind, I evaluated the duotone as a visually ambiguous design choice that needed to be evaluated from some or all of the four parts of the Tetrad. Questions that were raised included: How does the duotone affect the *subject* in relation to how the viewer previously understood the subject? Would the duotone be more or less appropriate for the viewer amidst different *scenery*? If the *scope* were different, should the color scheme be as well? Such questions encouraged critical analysis of how *visually* contextual elements shape the meaning drawn from a representation.

The communicative power of visual ambiguity can be best understood as we complicate the Tetrad by establishing ratios, as Burke did with his pentad. To illustrate just how the Tetradic Model was used to critically examine the rhetorical influence of visual ambiguity in "Osteoporosis," attention may be drawn to a particularly relevant rhetorical analysis by Debra Journet. In "Metaphor, Ambiguity, and Motive in Evolutionary Biology," Journet uses Burke's pentad to critically examine *textual* ambiguities in the scientific writing of evolutionary biologist W.D. Hamilton. Conducting a close reading of Hamilton's work on genes, Journet uses the pentad to uncover the epistemological effects of using ambiguous metaphors about genes to describe their functionality. Journet suggests that evaluation of Hamilton's writing exposes numerous instances where metaphors of motives given to genes (where the gene "struggles," or "adapts," or "behaves selfishly") shape scientists' understanding of how genes work. Specifically, Journet argues,that Hamilton's writing identifies the gene as an agent *and* an agency. She states:

> The metaphorical language of motive [in Hamilton's writings], what I also call a "grammar of selfishness," allows Hamilton to represent genes ambiguously and simultaneously (often in the same sentence) as both the agents of evolutionary action and as the agency or mechanism by which organism agents act. The difference between these two ways of understanding evolutionary processes is not trivial, as ongoing controversy in biology suggests. Instead, the textual ambiguity generated by the grammar of selfishness both reflects and constructs a conceptual ambiguity in the way evolutionary processes are theorized. (380)

Journet's scope was to uncover how textual metaphors, or ambiguities, in Hamilton's writing rhetorically—and hence epistemologically—gave agency to an object of inquiry, the gene. She used the agent-agency ratio drawn from Burke's pentad to determine the extent and effect of assigning such roles to genes. Drawing from her rhetorical analysis of how Hamilton's terminology shapes the function of the gene, she further concludes:

> Insofar as evolutionary theory is constructed from a "gene's point of view," it is a story of selfish gene-agents acting to ensure their own continued existence, even at the expense of the organism by whose agency they survive. But insofar as evolution is constructed from the organism's point of view, it recounts a story of selfish organisms or agents who, by using their gene-agency, act in ways that

> allow them to maximize their own inclusive fitness. These narratives are perhaps complementary but not identical. (408)

What we see in Journet's analysis is the appropriation of pentadic ratios to gene theory as it is explained in Hamilton's text. Ambiguities—in this case textual metaphors for how genes behave—are assigned to parts of the pentad to garner insight into how the ambiguities epistemologically encourage scientists to think about genes. Journet's close reading and rhetorical analysis through the pentad allows us to compare and contrast how textual ambiguities frame genes and, in essence, reconfigure theories of evolution. "Evolution seen from the perspective of the organism results in one story; but re-seen from the gene's point of view, its meaning is transformed" (407).

Using the Tetrad, we can draw similar conclusions about visual ambiguities, though perhaps not always as drastic as what Journet uncovered in Hamilton's writings. Generally speaking, when a visual ambiguity becomes labeled and visually understood as a certain part of the Tetrad, that label uncovers particular epistemological understandings. For example, when the duotone was viewed from the lens of the *subject*, the human bone (and osteoporosis) became interpreted *as* dichromatic, simplified, no doubt, from its "natural" state. In other words, representation of osteoporosis with a duotone may (depending on the background of the viewer) epistemologically encourage scientists (or, more likely in this case, a non-expert audience) to perceive the ailment from a reductionist perspective. Even more revealing, however, is when a ratio between two parts of the Tetrad is established.

When, for example, the duotone in "Osteoporosis" was evaluated from a *subject-scenery* ratio (depicted as one of the six darts in **Figure 5.3** above), the visual ambiguity was represented as also inclusive of the location (scenery) in which it was found. When in the Tetrad the duotone became part subject *and* part scenery, I could draw conclusions about its epistemological range within the visual communication in terms of how it ambiguously represented the scientific subject and the audience for whom it was published. When the duotone was represented as a quality of the subject (which is an osteoporosis-stricken bone) and when the duotone was visually displayed within a unique scenery (a popular science magazine, surrounded by captions and advertisements), it was learned that the *subject* of the representation may epistemologically *become* understood as dichromatic and simplified to the audience. Questions that surfaced as the duotone was evaluated from the *subject-scenery* ratio included: *To what extent is the duotone expected to be viewed as mimetic to the* actual *object that it signifies? To what extent is the duotone represented as such to accommodate an audience? Is the subject represented as duotone for publication purposes (to save money), for aesthetic purposes (to enhance appeal), or for accuracy purposes (to instruct)?*

With the four parts of the Tetrad, six ratios may be established—*subject-scenery, subject-makeup, subject-scope, scenery-makeup, scenery-scope,* and *makeup-scope*. Analysis from each of these ratios can, ambiguously but in productive ways, shed light on the epistemic weight—and perhaps even communicative prowess—of visual elements. Journet suggested that textual ambiguities are essential to understanding scientific concepts. "My analysis [of Hamilton's writing] … ," she says, "emphasizes the productive, even necessary, function of ambiguity. … I believe that it is the very possibility of ambiguity that helps make the text so powerful" (381). I likewise believe that ambiguity in visual representations is necessary and productive; analysis through ratios exposes new and important ways in which it is such.

From Ratios to Research: A Discussion

The ubiquity of ambiguity in any given visual element is once again shown in the multiplicity of types by which any visual element may be named. The taxonomy, though, as an amorphous structure for naming and cataloguing types within disciplines, provides a more pointed perspective for research. Specific research questions can be drawn just from the naming of the visual element under investigation. If, for instance, a researcher labels the duotone as a *Technological-Cognitive-Modality* ambiguity, he or she can draw research questions around the *technology* that produced the image, how well the viewer is able to *cognitively* process what he or she is looking at, and how those particular colors *modally* highlight and obscure precise components of the image. The research questions developed for this type of visual ambiguity would likely take on a material, usability-based approach to understanding viewer effect. It is, after all, labeled within the *cognitive* dimension. If the type of ambiguity associated with this visual element were to be investigated from the *affective* dimension, the research questions would, obviously, shift significantly, focusing more on qualitative, idiosyncratic meaning-making experiences.

In *Composition Research: Empirical Designs*, Lauer and Asher suggest that qualitative research studies such as case studies, ethnographies, and sampling and surveying are used to “generate variables, to operationally define them, and to develop early understandings of their interrelationships” (82). Drawing from the taxonomy, researchers and educators should be able to position scientific representations within scholarly contexts in order to determine some of the more profound, important, and anomalous instances of visual ambiguity affecting the viewer’s response and meaning-making. Initially, the idea would not be to, as Lauer and Asher further suggest, “establish cause-and-effect relationships among variables; [this kind of qualitative research] seldom has that kind of explicit power” (23). Rather, the idea ought to be focusing a research design around a specific type or dimension of visual ambiguity in order to raise awareness, to identify important variables, and to, in the types of ambiguity where it seems feasible, establish interrelationships between variables in order to set up quasi and true *quantitative* research designs.

To illustrate, a researcher who wishes to investigate the communicative effectiveness of the duotone and labels this visual element as *Technological-Cognitive-Modality*, may develop research questions such as the following:

> *What features of the image are viewers most drawn to? How does this change when the duotone changes to a cyan or magenta hue? How does the duotone—as opposed to the “natural” colors of the bone—affect an orthopedic surgeon’s ability to give an accurate prognosis? Does he or she seem to place emphasis on a particular part of the image as a duotone rather than full color image?*

But while these questions are good introductory inquiries into the communicativeness of the visual element, such questions remain superficial and static without context. As Wysocki argued in “The Sticky Embrace of Beauty,” when we look simply at visual elements’ acute effects solely within the frame of the image under investigation, content somehow gets sidestepped in favor of form. Investigation of the type of visual ambiguity as it relates to the broader *mise en scéne*—within which the formal elements of the representation plays only one small part in meaning-making—raises important questions about how an image and its visual parts always emerge out of broader contexts. Simply labeling visual elements and establishing research questions based on those labels, after all, is not much different than traditional research processes that seek to define variables (though the taxonomy *does* provide a space in which disciplines might make the defining and use of more replicable and somewhat standardized). While interesting and appropriate research can be drawn by locating and labeling visual ambiguities only, rich and valuable understandings about the communication of visual elements further emerge by establishing how they function *rhetorically* within larger communicative scopes. The rhetorical contexts are much harder to quantify, of course, but that does not make them any less valuable.

Rhetorical analysis of the ratios also? provides a close “reading” of visual elements. It provides a means by which we may evaluate large quantities of images across media or several visual ambiguities within one particular representation. Journet evaluated several terms and metaphors within two separate documents written by Hamilton. Researchers investigating visual representations of science may similarly wish to look at several visual ambiguity types within one image or representation, such as Barker's "Osteoporosis." Or, they may wish to evaluate one visual ambiguity type in several different related visual representations (like a series of images published in different venues). Either way, a Tetradic Analysis of visual ambiguity using ratios exposes communicative influence found across visual texts. The Tetradic ratios do not, however, glean particular insight into how individuals idiosyncratically react to visual elements. Perhaps for more quantitative measures, if a researcher (who is interested how visual communication distorts or alters the materiality of science) wants to know how the duotone affects the way in which a viewer actually perceives osteoporosis after viewing a representation, initial questions to the viewer, in a sampling-surveying research design, would focus around each domain, dimension, and type (which would be *Technological-Cognitive-Modality* in our example). The researcher would be reliant upon the definition of each domain, dimension, and type as it is accepted in his or her discipline to generate questions. Sample questions to research participants, then, might look something like this:

1) After viewing the image, what color would you imagine a "live" case of osteoporosis in a human bone to look like? (*Note that the researcher, with this question, looks for cognitive interpretation of the 'color' of the image, drawing the question from the technological domain and cognitive dimension, as outlined in Chapter 4*.)
2) After viewing the image, how large would you imagine are the gaps, or holes, in the bone in a typical case of osteoporosis? (*Note that the researcher, with this*

question, looks for cognitive interpretation of the 'magnitude' of the image, drawing the question from the technological domain and cognitive dimension.)

3) From your perspective, what is emphasized most in the image? (*Note that here, the researcher uses the term 'emphasis' from the definition of 'modality'*.)

Research in the social sciences (as opposed, perhaps, to the natural sciences) is reliant upon, in many ways, ambiguous research designs. This is not a derogatory statement. What often separates the "hard sciences" from those of the "soft" is perceived in levels of quantifiability. The former is perceived as knowable science through replicable, strict, and accurate measures—something a researcher can attach a numerical value to; the latter is perceived as knowable science as well, but only through the nuanced lenses of human emotion and idiosyncrasy. The hard sciences are not typically faced with research questions that deal with a high level of human interpretation. Much of what we learn about human experience (whether it be about how a person views himself as being victimized, his attitude toward products, or his perceived level of fear, and so forth) is through questioning. And, in an arguably qualitative, ambiguous process for measurement, those being researched often provide interpretable, adjustable responses. Even standardized Likert scales provide respondents opportunity for multiple potential responses. As Floyd J. Flower noted of social science research:

> There is an almost limitless body of desirable and useful information that can be gathered only by asking people questions. In some cases, that is because we want to know facts that are difficult to observe systematically…. We also are often

> interested in measuring phenomena that only individuals themselves can perceive: what people think or know, or what they feel. (1)

For those who wish to attempt the quantifying of visual ambiguity's epistemic influence, perhaps one of the most feasible research designs using a taxonomy of visual ambiguity is sampling and surveying. To recognize the frequency and effect of representations in a genre of scientific communication (such as scientific photographs in popular trade magazines like *Scientific American* or *American Scientist*, for example), a pool of scientific representations might be collected and evaluated based on viewer interpretation. If a researcher wanted to investigate the role and influence of *Technological-Cognitive-Modality* ambiguities in this genre of scientific communication, he or she might begin with the definition of "modality" outlined in the taxonomy, tweak or refine it depending on the scope of the research and the scientific field which he or she represents, and proceed to determine frequencies, characteristics, and locations in which this type is found. Furthermore, this researcher may then survey participants viewing representations that exhibit this type of ambiguity. Of course, from there, the scientific communication researcher can further establish relationships and confidence limits that might eventually lead to statistically correlated results (depending on the type of visual ambiguity).

Some of the types of ambiguity outlined in the taxonomy, after all, will likely struggle to ever be effectively researched quantitatively—that is, correlations between some types of visual ambiguity (particularly those in the affective domain) and viewer meaning-making may never be correlated to a behavior or response with clear and strong confidence limits. This is clear from the ongoing research about emotions and user experience design where great controversy is arising over whether or not aesthetic and emotive qualities of design such as “beauty” can be codified (Norman; Tractinsky; Hassenzahl; Kim; Shedroff). With these difficulties in mind, quantitative research of visual ambiguities, then, might often be reduced to establishing definitional properties of types and recognizing when and where these ambiguities are most present. However, much can be gleaned from qualitatively exploring types of ambiguity less clearly quantified. What a heuristic and taxonomy under the guise of visual ambiguity does is provide researchers a framework under which a more holistic understanding of how affective design elements work in tandem with cognitive design elements to influence meaning-making.

CHAPTER SIX

AMBIGUOUS CONCLUSIONS

> "Science is the attempt to make the chaotic diversity of our sense-experience correspond to a logically uniform system of thought."
>
> -Albert Einstein, *Out of my Later Years*

Back to Reality: Ambiguity in Objective Science

So where does an ambiguous taxonomy and an ambiguous heuristic lead us? To ambiguous conclusions, of course. The evaluative model set forth for analyzing how visual representations affect interpretation of scientific phenomena clearly does not follow traditional scientific method. In fact, the recurrence and seemingly omnipresence of ambiguity in the taxonomy and Tetradic Model of visual ambiguity presented may instill pejorative reactions in those seeking clear scientific results. After all, doesn't such an ambiguous process assume that we may never fully grasp the nature of the phenomenon we observe, nor how visuals affect meaning-making in viewers? And if this is the case, doesn't that contradict the largely embraced logic that the value of science is that it codifies an objective reality? Or that the value of critical heuristics is that they provide a measure of order to a subjective realm of experience? Or, even more damning to science, doesn't this assume that the ubiquitous presence of ambiguity in scientific communication subverts science itself, and suggests that no scientific discovery can ever clearly represent reality (this was, of course, the fear of early empiricists like Sprat)? It may seem, particularly to scientists, that the premise behind an entire work on ambiguity in science is built out of a deceptive (and perhaps irrational) syllogism: science must be communicated to be understood; communication is inescapably ambiguous; thus, science is inescapably ambiguous. At its extreme, such a premise might seem to imply that an objective reality cannot be understood at all and, hence, perhaps exist.

To these very valid concerns, I hope my response is adequate: no. Ambiguity does not have to kill science, nor epistemologically throw scientific communication into chaos; at least it should not be intended to. One may certainly take the philosophical arguments to the extreme, but that would undermine the more practical value of a Tetradic Model of Visual Ambiguity might provide the scientific community. For one of the values of a tetradic analysis of visual ambiguity is that it raises important ethical questions about how science is represented visually and how such knowledge, even if ambiguous, improves visual literacy. Stepping back (or away) from the Cartesian fears that empiricism cannot discover truth, we might rather look to ambiguity from a much more practical perspective where we hope to discover *more about* how truth is represented.

Despite much of the literature and philosophies that circumnavigate topics like reality, truth, and objectivity, the pursuit of delineating a deeply philosophical perspective on ambiguity's role in these ideologies was never the intention of this work (we can leave that discussion to the philosophers of science). Rather, ambiguity as it pertains to science has been explored in these chapters within strictly communicative realms for the purposes of rethinking and strengthening scientific visual literacy. Besides, the ubiquity of communicative ambiguity is not necessarily a new discussion, and it has not ruined science. Really, a discussion about visual ambiguity in scientific representation should not be all that alarming to scientists, who have long recognized—as Francis Bacon did—that words, whether we like it or not, will always, somehow "[obstruct] the understanding" (XLIII). As scientific communication itself continues to evolve into a more mature discipline, much is already being embraced in regards to the non-specificity (ambiguity) of communicative practices. Penrose and Katz, in their textbook *Writing in the Sciences*, for example, repeatedly point to how rhetoric, social systems, values, technologies, and argumentation—all of which contribute to ambiguous communication—are a normal part of shaping science. This dissertation has merely sought to expand this understanding, though with a particular insight into the specific challenges of working with *visual* ambiguity.

The scope of this dissertation, then, is being played with in its title: *Ambiguous Science and the Visual Representation of the Real*. The aim has been to more thoroughly recognize how communicating the real world is affected by ambiguous representation. Science itself doesn't necessarily have to be ambiguous for the communication of it to be. "The real" in the title is the objective scientific phenomena that representations seek to mimic but fail to, with precision, mimetically do so. "Ambiguous science" represents the signified interpretations that "the real" becomes after being mediated by visual representations. In essence, the purview of this dissertation has been to explore methods for improving our understanding of visual communication in the sciences through the lens of ambiguity. What has been discovered is that visual ambiguity in scientific communication should not be viewed as a hindrance to science. Ambiguity, after all, has been shown to function as a space in which meaning is constructed. Without it, productive insights and revelations about scientific phenomena may be blockaded. The multiplicities of meanings within visual representations of science necessarily spark curiosities—they teach, inform, and raise awareness. Anomalies (that Kuhn suggests open doors into new paradigmatic understandings) could not happen without such ambiguities. "What handier…resource," Burke asks, "could a rhetorician want than an ambiguity whereby he can say 'The state of affairs is substantially such-and-such,' instead of having to say 'The state of affairs *is* and/or *is not* such-and-such?" (52).

Such a question also might make us ponder: how does visual communication epistemologically provide "substance" to scientific phenomena? Much like Kenneth Burke's textual antinomies of definitions, visual elements within representations garner substance through "antinomies" of *representation*. After all, the more an image might be said to concurrently represent (even if there is ostensibly only one subject being represented), the more there may be to learn from the image, and thus the more we might learn about the science behind it. Visual ambiguities qualify the meanings of visual elements, such that the communicator's awareness of the complexity of the representation's relationship with the scientific object, increases. Visual ambiguities give power not only to the scientist who seeks to visually represent phenomenon, but also to the communicator *and* the viewer because of the increased awareness about what is portrayed in the visual representation

Limitations and Future Research

Investigating ambiguity as an integral part to scientific communication, however, does not come without its limitations. Harnessing our understanding of ambiguity's influence in science, after all, is not made easy by simply producing a taxonomy and rhetorical tetrad. The Taxonomy and Tetradic Model that I developed is a heuristic, aimed to provide, like most other taxonomies, a somewhat tangible resource for improving discourse—and thus literacy—in the visual communication of science. Regardless of how we might try to frame ambiguity in scientific communication, however, we will never be able to fully control it. Application of a taxonomy and rhetorical model of visual ambiguity, really, is not near as important as the proposition made in Chapter 1: that we first and foremost *embrace* visual ambiguity as a real and important part of scientific communication discourse. The Tetradic Model of Visual Ambiguity provides us with a language to talk about ambiguity, but its applicability, in many ways, stops there. The taxonomy may expose us to communicative elements that had evaded us, or that we ignored, but it cannot show us how to remove their ambiguity.

As I have shown, the eradication of ambiguity is not possible. Nor is it necessary or even desirable. Altering or "removing" a type of visual ambiguity will only create other types, after all. It may be said, then, that this taxonomy of visual ambiguity simply becomes a tool for perpetually reassigning types of visual ambiguity. Simply put, it does not solve *anything*. Fixed solutions are rare in science, if they exist at all. In science, there are ideas, paradigms, and discoveries; but there are also always new variables, new ambiguities, to keep moving science along, and keep it from stagnating.

The proposed Tetradic Model of Visual Ambiguity is but one perspective for looking at visual representations of science. It draws from a (albeit carefully selected) hodgepodge of scholarship within and without the sciences. Its potential relies on specific disciplines' willingness to adapt and modify the ambiguously definitional boundaries—drawing from their own carefully selected scholarship—in which domains, dimensions, and types are described. Awareness of the ambiguities present in representations has a powerful ability to shape the way disciplines understand their scientific practice, particularly those communicative. Visual ambiguities are not necessarily just design mistakes or confusions, but rather they are spaces in which the abstractness and vagueness of science can be made clear. Paradoxically, then, visual ambiguities epistemologically *become* a discipline's understanding of what is real. But to adequately improve the discourse and literate awareness of ambiguities in a particular discipline, a far more thorough establishment of the domains, dimensions, and types would need to be established. The tetradic analysis of visual ambiguity outlined in Chapter 4 was a non discipline-specific, abbreviated example of what might function as a proposed model, but by no means a definitive one.

But perhaps one of the most conspicuous limitations of the Tetradic Model of visual ambiguity for investigating visual representations of science is the cumbersome nature of its application. In Chapter 5, the taxonomy and Tetrad were applied to only *one* visual element (the duotone) in Barker's "Osteoporosis" image. One can imagine the difficulty of analyzing an image where hundreds of visual elements may be surfaced in a single representation and applied to potential scores of types of visual ambiguity in varying dimensions and domains. Furthermore, my analysis in Chapter 5 addressed only one image. Far more would have to undergo a similar Tetradic Analysis before any generalizations could be made.

It seems, then, that if we are to take seriously visual ambiguity as an important part of the scientific communication discourse, we must more thoroughly develop heuristics in which it can practically and easily be applied and researched across a wide swath of visual representations from all scientific disciplines. At the very least, we will need to be patient as disciplines work to develop their own taxonomies of visual ambiguity and highlight the kinds of visual investigations they wish to pursue.

In conclusion, I wish to evoke an old axiom credited to the German dramatist Gotthold Lessing (but made famous by Albert Einstein in a 1946 edition of *Science Illustrated* [Einstein 99]): “The search for truth is more precious than its possession.” Visual representations of science, so long as they are influenced by visual ambiguities, may seemingly communicate an ambiguous science. But the great power and wonder of this is that ambiguous science, through the visual representation of the real, will always allow us to reshape and rethink scientific possibilities. Ambiguity, then, at its core, is a truly valuable aspect of human inquiry because it encourages exploration and the “search for truth” even if we never come to possess it. In an era of ubiquitous visualization, exploration into visual ambiguities may provide a new and important perspective into how scientific communication shapes science itself. The way in which scientific communicators familiarize themselves with it, become aware of it, and appreciate its effects, after all, has potential to shape the way they understand and represent their own fields of inquiry. Preservation and appropriate application of visual ambiguity may, then, have increasingly important functions in the way we make ethical decisions about representing scientific phenomena. A Tetradic Model of visual ambiguity is not necessarily the only or best solution. But it might move us toward a strengthened visual literacy in a world that is quickly embracing the value of and seeking insight into the complexity of visual communication.

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