

# Analogy, Metaphor, and the New Science

## *Cognitive Science and Early Modern Epistemology*

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Some of the most fruitful insights that cognitive science has provided to literary and cultural critics have been those centered on metaphor and analogy. The work of George Lakoff and Mark Johnson, who argue that all thought and language are fundamentally metaphoric, has altered the traditional literary critical view that metaphor is a feature of specialized literary language.<sup>1</sup> Lakoff and Johnson have shown how conceptual metaphors, extended from the basic kinesthetic and spatial experiences of living in the human body and mapped onto abstract concepts, structure our thought and language in fundamental ways. A number of critics have charted the presence of these conceptual metaphors in literary works, and the literature of early modern England has seemed especially suited for such readings: my book *Shakespeare's Brain* is one example.<sup>2</sup> These readings have, for the most part, focused on literary works by Shakespeare and other authors and not on their larger cultural context.

I believe that cognitive studies of metaphor, analogy, and conceptual change can help us shed light on early modern English literary texts and also on the culture in which they were produced, providing new insights into the epistemological changes that accompanied, and made possible, the "scientific revolution" of the seventeenth century. One of the most important historical narratives about the early modern period in England involves the shift from an essentially medieval "world picture" dominant through the sixteenth century to the incipient modernity of the new science that began its ascendance in the seventeenth century. The "New Science" is largely associated with the discoveries of Nicolaus Copernicus (1473–1543), Galileo Galilei (1564–42), Johannes Kepler (1571–1630), Robert Boyle (1627–91), and Sir Isaac Newton (1642–1727). In the sec-



ond half of the twentieth century, accounts of this epochal change focused on epistemology and intellectual history but have more recently shifted to a preoccupation with the social and political implications of the change.<sup>3</sup> Whatever the emphasis, these accounts share a basic plotline: that by the middle of the seventeenth century, a traditional view of the natural world based on the authority of ancient writers gave way to the rational, empirical, mathematical approach that characterizes modern science. Ideas about astronomy, mechanics, and the composition of matter underwent the most radical transformation, as the old geocentric, deeply hierarchical, and closely interlinked cosmos gave way to a heliocentric and mechanistic one. Analogy (or what E. M. W. Tillyard called “correspondence” and Foucault called, more broadly, “resemblance”) plays a large role in this narrative, since historians of ideas have argued that it functioned as the central structuring mechanism of the old epistemological system but was replaced, in the seventeenth century by, variously, “identity,” “difference,” or “mechanism,” depending on who is telling the story (Tillyard, 83–100). “Resemblance,” in the words of Michel Foucault, “relinquish[ed] its relation with knowledge” and “disappear[ed], in part at least, from the sphere of cognition” (17).

Contemporary cognitive science offers insights into metaphor, analogy, and human thought that have the potential to radically change our view of the early modern scientific revolution.<sup>4</sup> If, as Lakoff and Johnson have argued, all human thought is built up metaphorically from the basic kinesthetic experiences of living in a body, no scientific system could dispense completely with analogy. Analogy didn’t disappear from the realm of cognition in the seventeenth century, as Foucault and others have argued, but became more important, albeit in altered form. An older system of correspondences based on the perception of shared qualities (like heat, cold, and density) gave way to a use of analogy to convey the structural relationships among things that were qualitatively different (like tiny invisible atoms making up what appears to be a solid surface).<sup>5</sup> In addition, cognitive studies of “naïve,” or “intuitive,” science and of the nature of conceptual change allow us to understand how the transition to the new science drove a wedge between scientists and nonscientists that had never existed before. Cognitive science helps us to grasp the implications of the scientific revolution for ordinary (nonscientific) thought and language in

new ways, as everyday experience of the natural world was severed from scientific explanations of it, and ordinary people could no longer trust their experience of the world to reveal the truth about its nature. Finally, a recognition of the difference between qualitative and structural analogies can help us understand the change in poetic language from the sixteenth to the seventeenth centuries, and I’ll use a famous example from John Donne—the “stiffe twin compasses”—to illustrate this change.

In characterizing the analogical system of the Middle Ages and earlier Renaissance, critics have always tended to marvel at its strangeness. Ideas like the correspondences or analogies drawn between the microcosm of the human body and macrocosm of the universe, extending to parallels between the four elements and four humors (blood and air, black bile and earth, yellow bile and fire, phlegm and water), seem far fetched today. Tillyard commented that “much of the doctrine cannot but appear remote and ingenuous to the modern mind, which is quite unmoved by the numerical jugglings and the fantastical equivalences that delighted earlier generations” (84). Critics following Foucault have also tended to view the Renaissance system of analogies as having a primarily regulatory function, working to support the system of hierarchies—the “great chain of being”—that structured the universe. As Jonathan Sawday has put it, “Within this world [of resemblance] the body lay entangled within a web of enclosing patterns of repetition” (23).

It’s worth beginning, then, by remembering why the Aristotelian theories of the natural world that were still dominant in England through the sixteenth century relied so heavily on their own particular version of analogy.<sup>6</sup> They did so because Aristotelian science was, in the words of E. J. Dijksterhuis, “formed by the things we perceive by the senses; all knowledge we can acquire of them ultimately originates in sense-perceptions.” Aristotle “wished to evolve a physical science of qualities, in which material bearers of properties were therefore regarded as explanatory principles” (18). Much ancient science, in other words, read back from observable phenomena to posit the invisible causes of things, constructing an analogical connection between them in which analogy represented a cause or an identity. Aristotelian science constructs its theory of the composition of matter from its sensible qualities and behavior; cold, hot, moist, dry. It constructs its mechanics from observations of the movement of objects in space. It accepts the Ptolemaic universe because



the sun and planets appear to revolve around the earth. These sciences, then, explain what they cannot see or feel by analogy with what they can directly experience; however, what we recognize as analogy (one thing resembles another) they assumed to represent a direct material or causal linkage: if matter appeared to be dry, dryness must be its essential property, so it must therefore be largely composed of "earth." This basis of explanation in analogy was then logically extended to construct theories that linked the causes of all observable phenomena with each other: microcosm must mirror macrocosm because both exhibit the same visible qualities, which must therefore have the same material causes.

The Aristotelian system did a good job of explaining the constants in nature, but it could not easily account for change: if substances are defined by their qualities, and the primary quality of a liquid is its watery nature, why does it change into ice or steam, which have completely different qualities?<sup>7</sup> As Stephen Toulmin and June Goodfield put it, "Any theory of the natural world must have two contrasted features: it must *both* give an account of the unchanging ingredients of things *and* explain how those unchanging ingredients can give rise to the changing flux we perceive" (47). Some rival schools of natural philosophy in the ancient world formulated theories of atomism to better account for change. According to this paradigm, the world is composed of tiny, indivisible particles and the interactions of these particles: the distances between them, their collisions and attraction, cause the changing properties of matter. Water is sometimes liquid and sometimes solid because its atoms can arrange themselves differently under different circumstances.<sup>8</sup> Aristotelian theories of matter, however, won out over atomic theories in classical antiquity and were dominant until the late sixteenth century, when some European thinkers turned once again to an atomic theory of matter as a way to explain change.

Aristotle's account of motion was also firmly based in ordinary observed experience and similarly unable to deal with change. As Steven Shapin suggests, Aristotelians conceived of motion in terms of the observed, qualitative nature of objects: "Bodies naturally moved so as to fulfill their natures, to move toward where it was natural for them to be" (29). Solid objects fall because it is their nature to seek the center of things; fire rises because it is in the nature of fire to seek the heavens. Aristotelian

mechanics held that the weight of an object is a property of the object itself and determines the rate at which it falls. As Nancy Nersessian has argued, this theory fails to explain "how an object continues in its motion after it has been separated from the source of its motion," making it a "subproblem of the problems concerning the nature of change" that was resolved only after Galileo and Newton came up with "an inertial representation of motion" ("Conceptual Change," 167).

Several researchers have suggested that the "naïve," or "intuitive," theories of motion that people develop based on their ordinary, kinesthetic experience of the world are very similar to Aristotelian and medieval theories of motion and sharply at odds with Newtonian mechanics.<sup>9</sup> John Clement has argued that the "motion implies a force" theory of mechanics that Galileo (as a precursor of Newton) was at pains to discredit is still widely held today and that it is probably "rooted in everyday perceptual-motor experiences like pushing and pulling objects"; as such, he suggests it belongs to our set of "deeply seated mental models in the form of physical intuitions that can be very compelling and resilient" (337). Michael McClosky's research has shown that even students who have completed a college-level physics course can still retain naïve concepts of motion at odds with the Newtonian mechanics taught in both high school and college courses (305–7).<sup>10</sup> Allan Harrison and David Treagust have similarly shown that intuitive theories of matter also make it difficult for students to understand atomic theory. These perceptually grounded mental models are clearly similar to the "conceptual metaphors" that George Lakoff and Mark Johnson see as structuring human thought and language. It isn't surprising, then, that several of Lakoff and Johnson's primary metaphors (through which sensorimotor experience is mapped onto subjective experience) are based in intuitive mechanics: "change is motion," "actions are self-propelled motions," "causes are physical forces" (*Philosophy*, 47, 52–53). To the extent that the new science of the seventeenth-century contradicted basic sensorimotor experience, it opened up a gap between nonscientists and nature that has never been closed.

Historians of science have realized, of course, that "the new philosophy assaulted common sense at a mundane as well as a cosmic level."<sup>11</sup> John Donne's famous lines have long been cited as providing evidence of this disturbance:



And new philosophy calls all in doubt,  
 The Element of fire is quite put out;  
 The sun is lost, and th'earth, and no mans wit  
 Can well direct him where to looke for it.  
 And freely men confesse that this world's spent,  
 When in the Planets and the Firmament  
 They seeke so many new; they see that this  
 Is crumbled out againe to his Atomies.

("THE FIRST ANNIVERSARY," ll. 205-13)

However, Lakoff and Johnson's insights about the centrality of concrete bodily experience to all human thought raise the stakes: if new theories explaining the structure of the cosmos, matter, and motion were at odds with ordinary embodied experience of these phenomena, then the scientific revolution marked an unprecedented separation between the very bases of cognition and the specialized technologies of scientific thought.<sup>12</sup> There have been many historical explanations for the origins of the feelings of isolation and fragmentation that characterize modernity, but I believe we can add to them this moment when our understanding of the world became counterintuitive.

Recognizing these deep-seated cognitive implications of the scientific revolution can provide insight into literary works from this period that are preoccupied with change, the insubstantiality of the material world, and the ramification of concepts like the void for human understanding of the nature of things: Shakespeare's *King Lear* comes to mind.<sup>13</sup> More generally, the widening gap between everyday observation of the world and scientific explanations of its workings made metaphor and analogy important in new ways, which also impacted literary language. If the causes of natural phenomena are no longer directly linked to their visible or sensible qualities, those causes can only be conceptualized by analogy with phenomena that can be seen or felt.

In some cases, of course, technology allowed scientists to see things that other people couldn't see, thus providing direct empirical evidence for new theories. However, it was not always easy for scientists to convince other people that what was seen through a telescope, for example, was an accurate reflection of reality. Elizabeth Spiller describes Galileo's attempts

to persuade resistant observers to trust that his descriptions of what he had observed through a telescope reflected what was actually present in the heavens, even though they couldn't see any of it with the naked eye (101-2). Galileo provided an opportunity for doubters to look through his telescope at distant lettering on the Lateran Palace, so what they saw could be tested against a closer view. However, some of those observers refused to accept that the telescope was just as accurate in its view of the moon as it was of the palace. Galileo was essentially asserting an analogy between the verifiable telescopic view that could be seen on earth and what could be seen (but not verified by the naked eye) in the sky.<sup>14</sup>

The gap between everyday experience and scientific theory was even greater in the case of evolving theories of matter. There were no instruments available in the seventeenth century that could make atoms visible, and, in fact, experimental proof of the existence of atoms that provided information about their actual structure would not become available until the nineteenth century. The particulate theory of matter advocated by Robert Boyle and others sought to explain the observable qualities of matter as produced by the motion, size, and interconnections of the atoms (corpuscles, or particles) that constituted it.<sup>15</sup> Seventeenth-century atomic theory could better account for change than could Aristotelian theories of matter; for instance, the transformation of water into ice or steam made sense when explained as an alteration in the distance and nature of the bonds between atoms. But, as Shapin has suggested, "most practitioners [in seventeenth-century England] accepted that the corpuscular world was, and probably would forever remain, inaccessible to human vision . . . their physical truth could never be *proved* by sensory means" (50). The behavior of atoms could only be conceptualized by analogy with "visible and tangible phenomena" (50).

Nancy Nersessian has argued that the conceptual change from Aristotelian to Newtonian theories of motion similarly produced a greater role for structural analogy. Newtonian mechanics exists "only in mental models. For example, a Newtonian object is a point mass moving in an idealized Euclidean space" and has to be imagined by analogy with actual objects in real space ("Conceptual Change," 178). After Newton, motion was no longer conceived of as a property of objects but rather as a relation. As a result, there was a concomitant shift "from a concrete to an



abstract representation" of movement in space (178). Like Dedre Gentner, Nersessian emphasizes the important role of analogy in facilitating these abstract structural representations.

As many critics have noticed, the seventeenth century saw the increasing prominence of a new analogy for the workings of nature, that of a clockwork mechanism.<sup>16</sup> The mechanistic model of the universe was a necessary component of atomic theory, since the invisible movements and meshings of atoms could be imagined as working like the gears of a tiny machine to produce the visible properties of matter.<sup>17</sup> More importantly, the mechanistic analogy had a heuristic advantage over the previously dominant analogy that linked microcosm and macrocosm through their visible qualities, because the salient features of a mechanism are structural: attention is focused on ways in which the parts fit together and affect each other. A mechanistic atomic theory of matter thus enabled a crucial change in the role of analogy in scientific thought, a change identified by cognitive scientists as basic to conceptual change in modern science.

Qualitative analogy, however, still maintained an important role in the formulation and dissemination of scientific knowledge. Many writers and scientists continued to rely on qualitative analogies well into the seventeenth century, and many used both old and newer forms of analogy almost indiscriminately. Cognitive psychologists like Dedre Gentner and Michael Jeziorski have established the continuing role of what they call structural analogy in contemporary science, in teaching (where electricity, for instance, is explained by analogy with flowing water), and in discovery itself, as in Ernest Rutherford's ability to conceptualize the structure of a hydrogen atom by analogy with the structure of the solar system. In these instances, the analogy does not posit a qualitative or causal relationship (electricity isn't thought to look or feel like water or to be materially the same) but rather maps a system of relationships from a visible domain to an invisible one (the relationship between pressure and rate of flow makes water and electricity behave in similar ways).

Gentner and Jeziorski have argued that the seventeenth century marked a shift in the kind of analogy operative in scientific knowledge. They contrast with modern analogy as it appears in the writings of sixteenth-century alchemists, who took the Aristotelian system of correspondences to an extreme, equating analogy with identity, ascribing causal powers to

analogy, and holding that even symbols did not just stand for their referents but were identical to them in essence (467). The alchemical symbol for gold, for example, was a circle, because both the circle and gold were considered to be perfect: the perfection of the symbol was thought to reflect in essence the perfection of its referent.

Writers like Robert Boyle and Johannes Kepler, on the other hand, evince what Gentner and Jeziorski call modern attitudes toward scientific analogy. Boyle, for instance, in his treatise *Of the Great Effects of Even Languid and Unheeded Local Motion* (1590), argued for an atomic theory of matter against "men [who] undervalue the motions of bodies too small to be visible or sensible." Because such small particles cannot be seen, they can only be understood through analogy with what is visible; on the other hand, Boyle breaks with tradition by asserting that the visible surface of matter doesn't directly reveal its composition of particles. He seeks to explain the nature of the particles by analogy with ants moving a large pile of their eggs and with the action of wind in trees. These analogies do not depend on essential similarity (he doesn't argue that the particles actually resemble ants), but, in the words of Gentner and Jeziorski, instead invoke "common relational systems" (462). Boyle can envision the way that invisibly small particles can cause large-scale effects by imagining the ability of ants to move a huge pile of eggs: the analogy reflects the structural relation of an accretion of small, individual actions. Kepler, similarly, advocates use of analogies in geometry, where, again, in the words of Gentner and Jeziorski, "the analogy is useful in virtue of its ability to capture common causal relations" (474) and not an essential identity.

The epistemological shift that accompanied the rise of the new sciences in the seventeenth century, then, did not bring to an end the use of analogy for scientific thought but rather gave rise to a change in the nature and uses of analogy in that context. This change, in turn, sheds light on what has traditionally been called the "metaphysical imagery" used by seventeenth-century writers such as John Donne. Perhaps the most common example of a metaphysical image is that of the "stiffe twin compasses" found in Donne's poem "A Valediction: Forbidding Mourning," where the speaker, attempting to reassure his lover about an impending separation, argues that even though their bodies will be apart, their souls will be



connected like the feet of a compass. Critics like Marjorie Hope Nicolson tended to read early seventeenth-century poetic imagery as manifestations of the old analogical system. She reads Donne's famous "twin compasses," perhaps the archetypal metaphysical image, as a manifestation of the old analogy of "the circle of perfection": "More completely than in any other symbol in the universe, the Great Geometer had shown the intricate relationship of the three worlds in the repetition of the Circle of Perfection" (47). W. A. Murray drew a connection between Donne's "gold to airy thinness beat" and the compasses through the alchemical symbol for gold, a circle with a dot in the center, which Gentner and Jeziorski consider to be a prime example of the older version of qualitative analogy. Donne's compasses, in this reading, liken the love between the two to the perfect circles of gold and of the cosmos.

I think the image of the compasses makes more sense as an example of the newer style of structural analogy identified by Gentner and Jeziorski in the writings of seventeenth-century scientists like Boyle. Samuel Johnson famously derided these images consisting of "the most heterogeneous ideas . . . yoked by violence together," and his emphasis on the unlikeness of the two terms of the analogy seems prescient of Gentner's research (218).<sup>18</sup> Its quality of yoking together two unlike things (the souls of lovers and a mathematical instrument) is a function of the fact that it doesn't posit an essential similarity between the two terms but instead indicates only a structural relationship between two joined yet divided poles. The relationship of this image to the concept of circular perfection is therefore more complex than Murray realized.

As various critics have argued in different ways, the poem is in part about the relationship between body and soul, or, to rephrase this, between the sensible and the invisible. The speaker begins by likening his separation from his beloved to the separation of soul from body after death. However, he uses the analogy of the death of a virtuous man to argue that the process of separation is, or should be, itself invisible. He suggests that the process of making the invisible visible through analogy is problematic when he cautions that they should "melt, and make no noise,/No teare-floods, nor sigh-tempests move" (ll. 5–6) that would reflect their unseen inner feelings outwardly, the notion of outwardness here being hyperbolically linked to the larger scale of the macrocosm. The speaker refers to the traditional links between microcosm and mac-

rocosm in a gently humorous way to suggest that the unseen should not always be made visible.

He then offers two different accounts of the relationship between his soul and his lover's, and each is represented by a different analogy. If their souls are united into one, they are like beaten gold. If they possess two separate but connected souls, they are like stiff twin compasses. By choosing two such different analogies, Donne highlights the fact that the analogies are not qualitative (because the gold and the compass are themselves so different) but instead structural (each represents a different relationship between the two souls). The differing materiality of the gold and the compasses is crucial here: although both have traditionally been associated with circular perfection, the emphasis in the poem is on the material process of creating the circle that represents it.

Jess Edwards has shown how early modern mathematics and geometry in particular were situated "in a vacillation *between* the ideal and the material." He traces forward from Neoplatonism a tradition in which mathematical figures such as the circle are merely "analogic props," "worldly analogies for existential primacy" (45). He argues that medieval and early modern mathematical thinkers, as we have seen, began to conflate analogy with reality, and to consider "triangle, circles, and so on . . . not just as metaphors for, or images of, the material inhabited by the ideal, but also as a third realm of being, and a stepping stone between the temporal and the absolute" (46). The mathematician Thomas Harriott, for instance, speculated that geometrical points were identical with the indivisible particles of atomic theory, a hypothesis that proved an obstacle to his progress in geometry. John Dee, in his preface to a 1570 edition of Euclid's *Elements of Geometry*, articulates the view that "thinges Mathematicall" represent a "third being" between the natural and the supernatural because they "are thinges immaterial and neverthesse, by material thinges hable to be somewhat signified." He contrasts "pure geometrie," which can allow men to be "holpen and conducted to conceive, discourse, and conclude of thinges intellectual, spirituall, eternall," with practical geometry, which is derived from true geometry and is "the Arte of Measuring Sensible magnitudes . . . by due applying of cumpasse, Rule, Squire, Yarde, Ell, Perch, Pole, Line, Gaging rod, (or such like instrumente)." The instruments of practical geometry are the means by which the invisible and immaterial forms of geometric truth take on visible,



material reality. They are, that is, the means of constructing an analogy, which Dee's language reflects when he begins instructions for the practical use of geometry by physicians with "first describe a circle: whose diameter let be an inch."

The fact that Donne focuses on the compasses in the act of describing a circle rather than on the circle itself is thus highly significant. Rather than depicting the invisible circle of perfection, Donne shows the mechanical and imperfect *process* of representing it. John Freccero, in a 1963 essay on this poem, calls attention to a passage from one of Donne's sermons where he contrasts human life with eternal life: "This life is a Circle, made with a Compasse, that passes from point to point; That life is a Circle stamped with a print, endlesse, and perfect Circle as soon as it begins" (339). Freccero argues that Donne's circle in the poem "traces the emblem" of a union of body and soul "that cannot be perfect while it remains disembodied" (339). I would shift emphasis slightly to suggest that Donne's focus is on the process of creating an analogical relationship between visible and invisible, material and immaterial. In a poem about the incommensurability of the visible and invisible, Donne's speaker scorns human lovers whose experience of the insensible consists of analogy with physical qualities—"things which elemented it" (l. 16). In this poem, the speaker wittily applauds the disjunction between experiential reality and an invisible spiritual reality that lies beyond it. The soul cannot be understood as being qualitatively like the body but only as sharing a structural relation with it. The compasses are shown in the act of drawing a circle, and it is this process rather than the circle itself that conveys the structural relation.

Donne, of course, does sometimes rely on the older system of analogy, but I think his most striking "metaphysical" images participate in the new epistemology that I have been describing. Understanding analogy in science and literature from both cognitive and historical perspectives gives us a finer instrument for seeing how those images work. If we replace a dichotomy between resemblance and difference with a subtler understanding of the ways analogy yields both, we can better read the traces of earlier structures of thought wherever we find them.



22. Oberhuber, 12.

23. Thanks to Orley Marron for calling this to my attention.

#### Chapter Four: *Analogy, Metaphor, and the New Science*

1. Lakoff and Johnson, *Metaphors*; Lakoff, *Women*; Lakoff and Johnson, *Philosophy*.

2. See essays by Crane, Sweetser, Freeman, Turner, Bradshaw, and Brandt in Bradshaw, Bishop, and Turner. See also Freeman, "Catch[ing] the Nearest Way"; Freeman, "'According to My Bond'"; Freeman, "'The Rack Dislimns'"; and Hogan and Pandit, introduction. For a critique of cognitive approaches to metaphor, see Anderson.

3. Historians of science call these traditions "intellectualist" and "contextualist." Work on this transition has been undertaken both by historians of science and by literary and cultural critics. See Shapin's useful bibliographic essay in *Scientific Revolution* for an account of central work in the history of science. For the purposes of this essay, the most useful historical works in the epistemological tradition have been Koyré, Dijksterhuis, Kuhn, *Structure*, and Toulmin and Goodfield. The most important work taking a social approach is Shapin and Schaeffer. Work on the history of ideas by literary and cultural critics includes Tillyard and Nicholson. For literary/cultural studies focused on the social implications of the new science, see Sawday and Paster. Recent work like that of Turner, *English Renaissance Stage*, and Spiller consider both epistemological and social aspects of the transition.

4. On metaphor, see Lakoff and Johnson, *Metaphors*, and especially Lakoff, *Women*, and Lakoff and Johnson, *Philosophy*. For a cognitive analysis of the role of analogy in scientific thought, see Gentner and Gentner; Gentner and Jeziorski; Nersessian, "Conceptual Change"; and Thagard and Toombs.

5. See Gentner and Jeziorski, who characterize the change as a shift from "metaphor" to "analogy."

6. By "Aristotelian," I mean the theories of nature based in the writings of Aristotle and his medieval commentators, which represented "an intellectual synthesis of several traditions—scientific ideas drawn from Aristotle, medical ideas from Galen, and theological doctrines handed down from the Christian fathers" (Toulmin and Goodfield, 139). Platonic ideas were sometimes included in this mix to the extent that they could be reconciled with the basically Aristotelian system.

7. Aristotle explained these transmutations as a product of "forms" or "modifiable, rather than . . . enduring[,] characteristics of base matter." However, this

theory of forms was "occult," or hidden, and therefore not very satisfactory as an explanation. See Kuhn, "Robert Boyle," 223.

8. Thagard and Toombs, 247, note that according to the ancient atomic theories of Leucippus, Democritus, Epicurus, and Lucretius, "atoms are in constant motion and come in a great variety of shapes, which account for the different characteristics of different compound bodies. . . . Things that are hard and firm, such as diamonds and iron, are composed of atoms that are more hooked together than the atoms of soft substances like liquids."

9. See Champagne, Klopfer, and Anderson for the similarities between intuitive physics and Aristotelian theory. See also McCloskey, 318, who argues that naïve theories are medieval and not specifically Aristotelian, and Clement, 325–29, for "qualitative arguments" used by Galileo to counter the deeply entrenched theories of medieval mechanics.

10. This research was based on a study of thirteen students at the Johns Hopkins University.

11. Shapin, 28.

12. There were, of course, philosophical and religious traditions preceding this historical moment that helped people accept the fact that the ultimate nature of reality is not directly perceivable and the ultimate causes of experience in the world are not directly perceivable either. Platonic philosophy, for instance, offers the theory that worldly experience is just an imperfect reflection of a truer reality. Various traditions of skepticism suggest that our inability to achieve certainty about the causes of natural phenomena should not be a cause for anxiety or concern. Various traditions of religious mysticism emphasize the mysterious and unknowable nature of God. My argument here is that in early modern Europe, the Aristotelian tradition was the accepted means of understanding natural phenomena, and that when its basis in direct perception of the world was questioned, a rupture resulted that, for some thinkers, could not be resolved by existing philosophical or religious explanations. They sought a materialist set of explanations, and that impulse led to the new science of the seventeenth century.

13. See Crane, "Physics."

14. Latour, 78–79, similarly argues that the relationship between the evidence produced in a laboratory and the "real world" of nature is representational: "We have taken science for a realist painting, imagining that made an exact copy of the world. The sciences do something else entirely—paintings too, for that matter. Through successive stages they link us to an aligned, transformed, constructed world."

15. Shapin, 49.

16. See Dijksterhuis.



17. Nersessian, "Kuhn," 178–211, discusses possible connections between Kuhn's theories about paradigm shifts and cognitive work on conceptual change.

18. Johnson's sense that these images involve "a combination of dissimilar images, or discovery of occult resemblances in things apparently unlike," allies him with Nicholson, however, on whose account far-fetched resemblances is a property of the old world picture, which posited "occult" forces to explain changes it could not otherwise account for.

### *Chapter Five: Lying Bodies of the Enlightenment*

1. See Herman, "Narrative Theory" (chap. 7 of this volume); Scarry, *Dreaming by the Book*; Starr, "Multisensory Imagery" (chap. 13 of this volume); Crane, *Shakespeare's Brain* and "'Fair Is Foul'"; Hart, "Embodied Literature"; Easterlin, "Cognitive Ecocriticism"; Hogan, *Empire and Poetic Voice*; and Aldama, "Race."

2. For a discussion, see Alan Richardson, "Studies," 12–14.

3. For a detailed discussion, see Zunshine, "Theory of Mind and Fictions of Embodied Transparency."

4. Borenstein and Ruppin, 229.

5. Rizzolatti, Fogassi, and Gallese, 662.

6. See also Goldman for a detailed discussion of relationship between mirror neurons and theory of mind, and Ramachandran, *Brief Tour*, for a discussion of anosognosia (38) and autism (119) as possibly associated with damage in the system of mirror neurons.

7. Nussbaum, 96.

8. See Spolsky, *Word vs. Image*, and Stafford, "Romantic Systematics."

9. Warner, xii.

10. Bear in mind, too, that, as Gabrielle Starr observes, "even if we, as savvy readers and critics are on guard against fallacies of sincerity, we do well to note that being taken in—or at least along—by expectation and illusion is part of the pleasure of art, and the strategy of artists" (*Lyric Generations*, 219n14).

11. "There is subversion, no end of subversion, only not for us" (65).

12. Quoted in West, 13.

13. Quoted in Wasserman, 265.

14. As Porter Abbott suggests, the eighteenth-century cultural discourse on youth as a state of transparency was complemented by the discourse of "innocence"—frequently associated with but not limited to youthful protagonists. We can trace, he maintains, "the cultural need to maintain the idea of innocence as by definition incapable of distrusting appearances. Such innocence is meant to be part of Squire Allworthy's nature, and Tom's, and consequently keeps them from