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## THE ORGANIZATION OF KNOWLEDGE

### Disciplines and Practices

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Carved on the west facade of Chartres cathedral is the most familiar and durable representation of the learned disciplines in the Middle Ages: the seven liberal arts.<sup>1</sup> Along with the allegorical figure of Grammar (who deploys a switch against two sleepy little boys), the six other branches of systematic knowledge appear, accompanied by their founders or main authorities – Geometry with Euclid, for example. Sculpted in the mid-twelfth century, these figures express at once the broad cultural acceptance of this particular picture of how learning was organized and also some of the problems associated with taking such cultural consensus at face value. On the one hand, the cathedral’s school, famous for its academic excellence since the early twelfth century, continued to associate the seven arts with the curriculum for beginning students – first the three verbal disciplines (grammar, rhetoric, and logic) and then the four mathematical disciplines (arithmetic, geometry, astronomy, and music) (Figure 9.1).<sup>2</sup> On the other hand, this template had never entirely fit the shape of scientific enterprises in the early Middle Ages, and, by the time the portal was carved, changes within and beyond the school were making the taxonomy obsolete. The Chartres portal to the contrary notwithstanding, medieval disciplines were not written in stone. Both the fluidity of disciplinary divisions over time and their flexibility at any given moment pose problems for constructing an overview of the borders and compartments of medieval science. By their very nature, however, these uncertainties and variabilities do provide opportunities for understanding

<sup>1</sup> Philippe Verdier, “L’iconographie des arts libéraux dans l’art du moyen âge jusqu’à la fin du quinzième siècle,” in *Arts libéraux et philosophie au moyen âge: Actes du quatrième Congrès International de Philosophie Médiévale, Université de Montréal, Montréal, Canada, 27 août–2 septembre 1967* (Montreal: Institut d’Études Médiévales; Paris: Librairie Philosophique J. Vrin, 1968), pp. 306–55.

<sup>2</sup> On this figure, see John E. Murdoch, *Album of Science: Antiquity and the Middle Ages* (New York: Charles Scribner’s Sons, 1984), fig. 172, p. 191.

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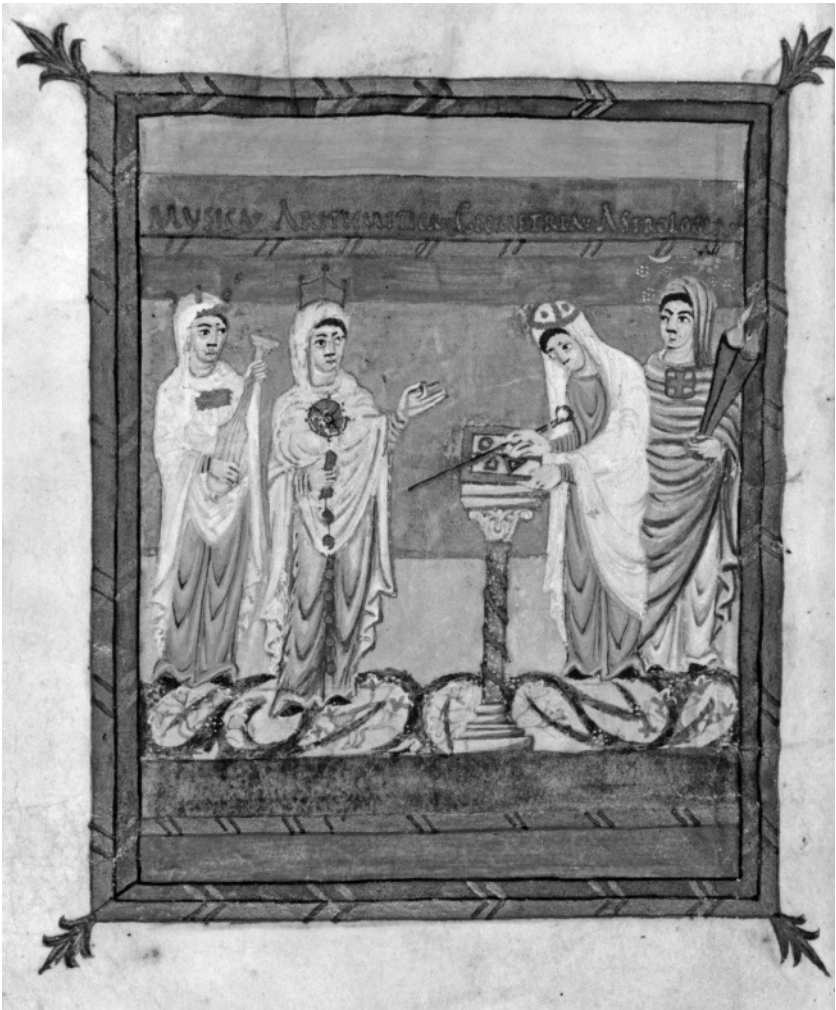


Figure 9.1. Allegorical representations of quadrivial arts with attributes. The quadrivium, or four mathematical arts, appears in a ninth-century copy of a tract on arithmetic, accompanied by identifying objects. From left to right, Music holds a stringed instrument; Arithmetic has a number cord in her right hand and displays a technique of finger-reckoning with her left; Geometry holds a measuring rod, or *radius*, and looks down at a tablet inscribed with geometrical figures; and above Astronomy's head are the stars, Moon, and Sun. Because of differences among authorities, as well as different readings or misreadings of texts or earlier images, such depictions did not follow set formulas. The column in this illustration may reflect Martianus Capella's description of geometry or may be an allusion to the role of geometry in architecture; the torches held by Astronomy have not been explained. By the end of the Middle Ages, new symbols were available: Arithmetic sometimes carries an abacus board, and Astronomy sometimes has an astrolabe or an armillary sphere. By permission of Staatsbibliothek Bamberg, MS HJ.IV.12, fol. 9v.

how the various sciences were both delimited and related, and the extent to which natural science constituted a coherent endeavor in the Middle Ages.

The purpose of this chapter is to investigate the boundaries and relations among medieval disciplines dealing with the natural world. Since medieval intellectuals themselves sought to organize the knowledge they inherited or produced about the natural world, their own views serve as a point of departure. The systems of classification they articulated reflected at once a respect for the programs of their ancient sources, an attentiveness to the problems of coordinating various traditions, and a concern for the ways in which learning could be used. In their prefaces or in the arrangement of their works, medieval authors named, defined, and diagrammed the relationships among the disciplines that embodied what we have come to regard as “science.” Yet, alongside the formal and explicit mapping of knowledge, other lines of organization, often informal and unspoken, emerged. Understanding the taxonomy of the sciences therefore requires placing them in the context of medieval scientific practices; that is, in terms of the ways medieval people acquired, transmitted, and applied ideas about nature.

Given the changes over time and the slippage between theory and practice, the result is not a clear and fixed map of the sciences but rather a set of perspectives from which to approach the question, “What was medieval science?” The first section of the chapter surveys general notions about disciplines and their relations to one another as they were laid out before the twelfth century. For scholars of that period, retaining and transmitting the outlines of received wisdom was often a difficult task. In such an environment, however, scholars were free to try out various strategies and new uses for old knowledge. The second section sketches some of the changes that rendered the older formulations obsolete. Starting in the late eleventh century, new social conditions for learning and the translation of Greek and Arabic texts introduced not only new subject matter but also new methods and even new goals for the sciences. Finally, the third section deals with the ways in which these changes shaped and were shaped by new conditions, especially the organization of learning within the university, between the thirteenth and fifteenth centuries.

#### THE ERA OF THE LIBERAL ARTS: FIFTH TO TWELFTH CENTURIES

The Latin terms *ars*, *disciplina*, and *scientia* all signified elements of *philosophia* and, as such, were manifestations of ordered thought. They were frequently associated with specific definitive texts and with characteristic rules by which they operated – that is, both with what was to be known and what was to be done. When arts, disciplines, and sciences were distinguished from each other, they usually formed a hierarchy of abstraction or

of certainty. For example, the encyclopedist Bishop Isidore of Seville (ca. 560–636) assigned the terms *scientia* and *disciplina* to what was known with certainty. They are about things that cannot be other than they are. Arts, in contrast – including tenets of natural philosophy, such as the belief that the Sun is larger than the Earth – were the domain of mere opinion. Such distinctions were not, however, either fixed or enforced. An author indebted to Isidore reported a variant: Disciplines deal with what can be produced by thought alone, whereas arts, such as architecture, are expressed in material media.<sup>3</sup> And Isidore himself went on to conflate disciplines and arts, saying, “There are seven disciplines of the liberal arts.”<sup>4</sup>

Medieval authors often employed one of these three terms, which will be used interchangeably here, to designate the principal divisions of “philosophy,” as the recognized body of systematic learning was persistently called. But just as the meanings and relations of “sciences” and “arts” varied, so did their membership and order – and indeed the principles upon which they were arranged. Medicine, for example, might be located according to its subject matter (e.g., the maintenance of health), according to the type of study it represented (e.g., a practical art), or according to texts in which its substance was contained (e.g., Galen’s *Art of Medicine*). Furthermore, both architecture and medicine were classified sometimes as mechanical or practical and sometimes as liberal or theoretical arts. Even the familiar names of individual disciplines could be problematic: “*astronomia*” and “*astrologia*” were sometimes synonymous and sometimes quite distinct.

This tangle of terms suffices to illustrate some of the issues involved in concepts about the constellation of knowledge. The structures were not simple; the articulations of them were not formulaic. The utterances of an authority like Isidore or the representations of a source like the cathedral at Chartres were only a part of what was involved, but they convey some of the difficulties of drawing a map of natural knowledge in the early Middle Ages.

#### THE LIBERAL ARTS AND THEIR SISTERS

Medieval authors did draw such maps, however. Divisions of the sciences have a long and intricate history, borrowing from a variety of traditions and reflecting the dynamics of the intellectual scene.<sup>5</sup> Even before the influence

<sup>3</sup> Hugh of Saint Victor, *The Didascalicon of Hugh of Saint Victor*, trans. Jerome Taylor (New York: Columbia University Press, 1961), bk. II, chap. 1, p. 62.

<sup>4</sup> Isidore of Seville, *Etymologiarum sive originum libri XX*, ed. W. M. Lindsay, 2 vols. (Scriptorum Classicorum Bibliotheca Oxoniensis) (Oxford: Oxford University Press, 1911), vol. 1, bk. II, chap. 2, sec. 2; bk. I, chaps. 1 and 2; see also bk. III, chap. 3, p. 86. All translations are mine unless otherwise noted. See also Boethius, *De trinitate*, in *The Theological Tracts, The Consolation of Philosophy*, ed. E. K. Rand (Loeb Classical Library, 74) (Cambridge, Mass.: Harvard University Press, 1973), pp. 2–31 at Prologue, p. 4.

<sup>5</sup> The basic treatments of the medieval disciplines and their classification are: Richard William Hunt, “The Introduction to the ‘Artes’ in the Twelfth Century,” in *Studia mediaevalia in honorem admodum*

of Arabic science and the wholesale introduction of Aristotle's natural works, some basic elements of what was to be a continuing medieval conversation about disciplines were already present. The most important of these were (1) the seven liberal arts and, sometimes, their stepsisters, the mechanical arts; (2) the distinction between theoretical and practical sciences, with its subdivision of the theoretical into divine, mathematical, and natural sciences; and (3) the schema of physical, logical, and ethical knowledge.

A highly influential work by Martianus Capella (fl. ca. 365–440) enumerated seven liberal arts and offered an introduction to (as well as a personification of) each, including the four “mathematical” arts (later named the “quadrivium”): arithmetic, geometry, astronomy, and music. For early medieval authors, these illuminated nature in various ways. Mathematical relations represented the essence of the created world, the subject of mathematical sciences was quantity separated in thought from the (natural) matter in which it actually inhered, and the quadrivium had functions and uses related to material objects. The particulars of arithmetic, geometry, and astronomy are treated in other chapters of this volume (see North, Chapter 19; Molland, Chapter 21). Against its persistent inclusion by medieval authors, historians of science have generally declined to treat music seriously in this context. Its claim to a place among the mathematical sciences rests on its central concern with intervals and thus with ratios. In addition, through such notions as harmony or proportion, which applied not only to sounds but also to the macrocosm of the heavens and the microcosm of the human body, the discipline of music sometimes incorporated significant natural-philosophical as well as mathematical material.

The other group of arts, the “trivium” – grammar, rhetoric, and logic – bore virtually no formal relation to the pursuit of natural knowledge in its medieval or modern senses. In practice, however, the verbal sciences were relevant in three ways. First, medieval authors used literary skills, represented by grammar and rhetoric, to analyze the natural questions contained in authoritative texts, from the book of Genesis (in which the six days of Creation became a traditional site for discussions of the natural world) to the *Timaeus* of Plato. In addition, literary sources contained valuable wisdom: Virgil's *Georgics* contained agricultural information, and one twelfth-century author referred to Hesiod as a “teacher of natural science.”<sup>6</sup> Finally, although it took on its full prominence only later, the discipline of logic became

*reverendi patris Raymundi Josephi Martin, Ordinis Praedicatorum, S. Theologiae Magistri, LXXum natalem diem agentis* (Bruges: De Tempel, [1948]), pp. 85–112; James A. Weisheipl, “Classification of the Sciences in Medieval Thought,” *Mediaeval Studies*, 27 (1965), 54–90; and James A. Weisheipl, “The Nature, Scope, and Classification of the Sciences,” in *Science in the Middle Ages*, ed. David C. Lindberg (Chicago History of Science and Medicine) (Chicago: University of Chicago Press, 1978), pp. 461–82. See also A. J. Minnis, *The Medieval Theory of Authorship*, 2nd ed. (Philadelphia: University of Pennsylvania Press, 1988), especially chap. 1.

<sup>6</sup> Brian Stock, *Myth and Science in the Twelfth Century* (Princeton, N.J.: Princeton University Press, 1972), pp. 43, 77.

relevant as a subject and as a method, bearing on such questions as how much certainty a science could attain.

Close to but always in the shadow of the liberal arts stood what came to be called the mechanical arts, also often numbered seven, though their exact membership varied.<sup>7</sup> The usual candidates included textiles, arms, commerce, agriculture, hunting, medicine, theater, architecture, and sports. (Later enumerations included navigation, alchemy, and various forms of divination.) They played two roles in the conceptualization of medieval disciplines. The first was negative. In contrast to the liberal arts, the mechanical or “adulterate” arts engaged the body as well as the mind, and their subject was “merely human works.”<sup>8</sup> The superiority of the former was reinforced by the social distinctions between those who work with their hands and those who do not – “the populace and sons of men not free,” in contrast to “free and noble men.”<sup>9</sup> More positively construed, the mechanical arts supplemented the liberal arts, particularly with respect to their engagement with the natural world. This very involvement with objects, which placed them outside the domains of philosophy (they were regularly denied the status of “discipline”), made them potentially useful for expanding the systematic understanding of nature. Some of the links between the mechanical and liberal arts manifested themselves in practices and instrumentation. Thus, a pair of compasses not only regularly accompanies the allegorical figure of Geometry but also appears as an emblem of stonemasons.

#### TRADITIONS OF CLASSIFICATION

Although the notion of the seven liberal arts was the most widely known basis for classifying knowledge, including that concerned with the natural world, it coexisted with other persistent schemata. The existence of alternatives invited scholars to choose, combine, or modify their elements in ways that suited them. The second major framework distinguished between theoretical (or speculative) sciences and practical (or active) sciences. This division was most influentially articulated in the Latin works of Boethius (ca. 480–525), who depicted the Lady Philosophy with the Greek letters theta (for “theory”) and pi (for “practice”) on her garment.<sup>10</sup> The so-called practical sciences, however, concerned not the efforts of artisans but rather the responsibilities of the aristocracy – ethics, household management (“economics”), and politics. Under the influence of Platonism and Christianity, however, the contemplative enjoyed a higher value than the active.

<sup>7</sup> Elspeth Whitney, “Paradise Restored: The Mechanical Arts from Antiquity through the Thirteenth Century,” *Transactions of the American Philosophical Society*, 80, no. 1 (1990), 1–170 at chap. 4.

<sup>8</sup> Hugh of Saint Victor, *Didascalicon*, bk. I, chap. 8, p. 55.

<sup>9</sup> *Ibid.*, bk. II, chap. 20, p. 75.

<sup>10</sup> Boethius, *De consolazione philosophiae*, in Rand, *The Theological Tracts, The Consolation of Philosophy*, pp. 130–435 at bk. I, *prosa* 1, ll. 18–19, p. 132.



The three constituents of “theory” likewise formed a value hierarchy: Theology was concerned with a subject that existed independently of matter; mathematics with the formal relations abstracted from their material subjects (e.g., dimensions abstracted from the land they measured); and *physica* (that is, natural philosophy) with the properties of material objects. Just as association with manual labor devalued the dignity of the mechanical arts vis-à-vis the liberal arts, so association with matter placed mathematical and natural sciences in descending order below theology. Such a ranking, which, according to Boethius, corresponded to different ways of knowing,<sup>11</sup> suited a Christian sensibility that emphasized the triumph of immaterial spirit over material flesh. It was not, however, static. In the intellectual as in the spiritual realm, the mundane could be a stepping stone to higher levels, thus lending dignity to natural and mathematical sciences.

The third and less influential arrangement of the disciplines derived from an ancient Stoic tradition and was passed on by Isidore of Seville. It distinguished ethics (that is, the active sciences of the second scheme), *physica* (including the quadrivium), and logic (including the trivium).<sup>12</sup> Whereas Boethius had separated the mathematical disciplines from natural philosophy, here mathematics is part of it. Indeed, this arrangement sometimes also included in the category of *physica* the more practical arts of astrology, mechanics (meaning certain kinds of craft production), and medicine.<sup>13</sup> Although it, too, found expression within monastic schools, this taxonomy was less hierarchical than the previous one and less closely associated with a program of spiritual ascent. In these respects, it placed a higher and more independent value on at least some natural and verbal sciences.

Throughout the early Middle Ages and beyond, tensions among the various schemata, along with the variety of traditions that nourished them, gave rise to a fluid and eclectic outlook on the divisions and relations of scientific disciplines. The work of individual scholars often represented compromises among the various options. For example, the abbess Herrad of Landsberg (ca. 1130–1195) represented Philosophy as a queen encircled by figures of the seven liberal arts, wearing a crown with figures of ethics, logic, and physics.<sup>14</sup>

Such reworkings have contributed to the perception that “nobody knew what to make of ‘philosophy’ or ‘science,’” and scholars have suggested

<sup>11</sup> Boethius, *De trinitate*, chap. 2, p. 8.

<sup>12</sup> Weisheipl, “Classification of the Sciences in Medieval Thought,” pp. 63–4.

<sup>13</sup> Manuel C. Díaz y Díaz, “Les arts libéraux d’après les écrivains espagnols et insulaires aux VII<sup>e</sup> et VIII<sup>e</sup> siècles,” in *Arts libéraux et philosophie au moyen âge*, pp. 37–46; Murdoch, *Album of Science*, fig. 29, p. 40; Hrabanus Maurus, *De universo*, in *Opera Omnia*, ed. Martin Mabillon, (Patrologia Latina, 111) (Paris: J.-P. Migne, 1864), vol. 5, cols. 9–614 at bk. II, chap. 1, col. 113.

<sup>14</sup> Herrad of Hohenbourg, *Hortus deliciarum*, reconstructed with commentary by Rosalie Green, Michael Evans, Christine Bischoff, and Michael Curschmann with T. Julian Brown and Kenneth (Levy Studies of the Warburg Institute, 36), 2 vols. (London: The Warburg Institute; Leiden: Brill, 1979), vol. 2, pl. 18. The manuscript was destroyed in the Franco-Prussian War of 1870. On this figure, see Murdoch, *Album of Science*, fig. 31, p. 41.

that *physica* remained a virtually empty category until the assimilation of Aristotle's natural works starting in the twelfth century.<sup>15</sup> In one sense, this is true, in that unlike the liberal arts, each of which was regularly linked to a basic text (Porphyry on logic, Boethius on music, and so forth), natural philosophy had no standard introductory authority. But this perspective ignores not only the extent to which other kinds of texts – Genesis and Plato's *Timaeus* – provided textual grist for the natural-philosophical mill but also the extent to which subject matter was imported from a variety of other categories. Latin authors not only arranged and rearranged but also added to the list of disciplines, a process that further illustrates the malleable and living nature of medieval classifications. In the ninth century, an encyclopedic work by Hrabanus Maurus (ca. 780–856) full of information about natural philosophy included under the heading of *physica* not only arithmetic, geometry, astronomy, and music but also such “practical” or “mechanical” arts as astrology, medicine, and mechanics.<sup>16</sup> This realignment reflects a process by which information and ideas migrated across putative boundaries.

Especially in an environment in which authoritative texts were scarce, scholars often appealed to learning in one domain to illuminate another. Medicine in particular was a resource for those seeking to explore the principles of nature. Isidore of Seville had likened medicine to philosophy itself because it drew upon all of the liberal arts.<sup>17</sup> In the course of the early Middle Ages, standard medical texts mentioned the constituents of both the body and the environment; *materia medica* spoke of plants, animals, and stones; and tracts on obstetrics touched on principles of reproduction as well as practical advice. The intellectual cross-fertilization suggested by the permutations of classification is confirmed by material evidence. For example, book owners bound medical, mathematical, and natural-philosophical texts together in the same manuscript books.

The absence of specialization enhanced these processes. The Venerable Bede (672–735) wrote on geographical subjects in addition to mathematical disciplines. Practitioners of medicine might be socially distinguishable, but its content was accessible to others. After giving a stranger some advice on his health, for example, Gerbert of Aurillac (945–1003) offered this disclaimer: “Do not ask me to discuss what is the province of physicians, especially because I have always avoided the practice of medicine even though I have

<sup>15</sup> Weisheipl, “Nature, Scope, and Classification of the Sciences,” p. 472. See also Weisheipl, “Classification of the Sciences in Medieval Thought,” p. 62; and Whitney, *Paradise Restored*, p. 59 and n. 8.

<sup>16</sup> Hrabanus Maurus, *De universo*, bk. V, chap. 1, col. 413. See Díaz y Díaz, “Les arts libéraux d’après les écrivains espagnols et insulaires,” p. 41, nn. 17 and 43; Murdoch, *Album of Science*, fig. 29, p. 40; Whitney, *Paradise Restored*.

<sup>17</sup> Isidore of Seville, *Etymologie*, bk. IV, chap. 13; cf. Bruce S. Eastwood, “The Place of Medicine in a Hierarchy of Natural Knowledge: The Illustration in Lyon Palais des Arts, ms. 22, f. 1r, from the Eleventh Century,” *Sudhoffs Archiv*, 66, no. 1 (1982), 20–37.



striven for a knowledge of it.”<sup>18</sup> Taken together, this diverse body of evidence bears witness to the gradual formation of a loosely associated body of knowledge about the constituents, causes, and arrangements of the natural world rather than the scholarly void that has been suggested.

#### CULTURAL FUNCTIONS OF DISCIPLINARY IDEALS

Both the attempts to define and arrange specific disciplines and the conditions that moved or eroded boundaries manifested themselves in the various uses to which medieval authors put the sciences. During the early Middle Ages, even the reiteration of fixed names and definitions could serve a variety of cultural, religious, and political functions. For example, in her drama about the conversion of a prostitute, the abbess Hrotswitha of Gandersheim (ca. 935–1000) has the saintly Paphnutius name the quadrivial arts and define the discipline of music as he explains to his students the harmony of the elements in the human body.<sup>19</sup> Both for Hrotswitha, whose own familiarity with the liberal arts was extensive, and for her protagonist, the preservation of learned traditions was a significant project in itself. Similarly, something as simple as a shared terminology facilitated more complex scholarly exchanges, as when Gerbert, the future Pope Sylvester II, sought help from correspondents across Europe in acquiring old and new works on *astrologia*.<sup>20</sup>

Such cultural reproduction played a role in social and political developments, such as the construction of the Carolingian Empire and the evolution of clerical power. The prominence of the seven arts in the early Middle Ages is as much a product of a political agenda as it is a reflection of the intellectual projects and practices of the time. Charlemagne’s biographer Einhard emphasized that he had his sons and daughters educated in the liberal arts (of which the ruler’s own favorite was astronomy).<sup>21</sup> A classicizing curriculum, like a classicizing biography, suited Carolingian claims to be successors to the Roman Caesars and protectors of the Roman Church. Alcuin of York (ca. 735–804), master of Charlemagne’s palace school and Bede’s intellectual heir, was thus advancing a broad cultural and political program, as well as following his own scholarly trajectory, when he gave the subjects of the quadrivium a respectable (though not a prominent) place in the curriculum.

<sup>18</sup> Gerbert of Aurillac, *The Letters of Gerbert with His Papal Privileges as Sylvester II*, trans. Harriet Pratt Lattin (Records of Civilization, Sources and Studies) (New York: Columbia University Press, 1961), no. 159, p. 187; cf. no. 178, pp. 207–8.

<sup>19</sup> Hrotswitha von Gandersheim, “Conversio Thaidis meretricis” [or “Pafnutius”] 2.5 in *Opera*, ed. H. Homeyer (Paderborn: Ferdinand Schöningh, 1970), pp. 328–49, scene 1, lines 4–22.

<sup>20</sup> Gerbert of Aurillac, *Letters of Gerbert*, no. 15, pp. 54–5; cf. no. 138, pp. 168–9.

<sup>21</sup> Einhard, *Vita Karoli Magni: The Life of Charlemagne*, ed. and trans. Evelyn Scherabon Firchow and Edwin H. Zeydel (Miami: University of Miami Press, 1972), chap. 19, pp. 78–9 and chap. 25, pp. 92–3.

Hrotswitha of Gandersheim illustrates how command of the terminology and substance of scientific disciplines conveyed and even constituted clerical superiority over the laity. In her allegorical Latin drama on the martyrdom of virgins named Faith, Hope, and Charity, one of their persecutors inquires about the girls' ages. Their mother, Wisdom, asks, "Does it please you, my daughters, that I should exhaust this fool with an arithmetic disputation?" and she proceeds to overwhelm him with a long and learned exposition on numbers, derived from Boethius.<sup>22</sup> Although the classical disciplines are not as powerful as the Christian virtues, the allegorical figure Wisdom and the abbess Hrotswitha wield the two sets of weapons in close coordination, appropriating and thereby according dignity to the arts. As the cases of Hrotswitha and Alcuin (a Benedictine monk) suggest, the naming and arrangement of the disciplines belonged first and foremost in the early Middle Ages to monastic environments that played a central role in the transmission and validation of the disciplines.

#### BEYOND DISCIPLINARY IDEALS

The political and cultural uses of the scientific disciplines depended in part on their clarity, stability, and links with recognized authority. To that extent, they were conservative – in tension with the dynamics by which the definitions and materials of individual disciplines and natural knowledge more generally were shifting and expanding. Gerbert expressed an awareness of precisely this problem as he sought to enhance the texts and practices available to a student of arithmetic by laying out rules for the use of an abacus – a tool of practical calculation: "Do not let any half-educated philosopher think that [these rules] are contrary to any of the arts or to philosophy."<sup>23</sup> The "half-educated" purists did not prevail. An eleventh-century tract on geometry incorporated not only passages from Euclid but also discussions of the abacus, land measurement, map making, and land tenure.<sup>24</sup>

The practices discussed so far, even those relating to calculation and cartography, were textual in nature. They involved the transmission and elaboration of written traditions, whether associated with an ideal curriculum or with more immediate and mundane matters. As Gerbert's apparently contested interest in the abacus suggests, we have evidence of nontextual practices inscribed in sources ranging from the geometrical artifacts of stonemasons to records of the heuristic methods used in schools. A monastic teacher of the twelfth century took his pupils out in front of the church in the middle of the night, extending his arm and using his fingers to show them how to

<sup>22</sup> Hrotswitha von Gandersheim, "Passio sanctarum virginum Fidei Spei et Karitatis" [or] "Sapientia," 2.6 in *Opera*, pp. 181–99, scene 3, secs. 8–22 on pp. 184–7.

<sup>23</sup> Gerbert of Aurillac, *Letters of Gerbert*, no. 7, p. 45; see also pp. 46–7, n. 5.

<sup>24</sup> John E. Murdoch, "Euclid," in *Dictionary of Scientific Biography*, IV, cols. 437–459 at cols. 443a–b.

observe the course of the stars.<sup>25</sup> Gerbert himself illustrates the comfortable coexistence of textual and manual practices. He was famous for the swiftness with which he could do calculations using an abacus, and he described to a student how to construct and use a tube for astronomical observations.<sup>26</sup>

Determination of the date of Easter generated both active and contemplative science.<sup>27</sup> It was a source of perennial concern (as well as sectarian discord) and required the use of astronomical data and mathematical calculations. The problem being solved was essentially liturgical in that its purpose was to answer not a question about nature but rather one about ritual observance seen through the lens of natural phenomena. Thus the fixing of Easter bore a limited relationship to quadrivial and natural-philosophical disciplines as formally defined. Nevertheless, just as artists depicted both stonemasons and the allegorical figure of Geometry with a compass, so copyists and librarians perceived some link when they copied and bound these texts on calendrical calculation along with a variety of materials treating quadrivial and natural-philosophical subjects.<sup>28</sup> The abacus and the astrolabe may often have been instruments more of intellectual fascination than of practical application, but they were understood and even used to illustrate principles and perform specific operations.

## CULTURAL CONFLUENCES AND TRANSFORMATIONS OF THE ARTS: TWELFTH CENTURY

The existence of a variety of tools adds complexity to our picture of early-medieval practices, suggesting not only a manual but probably also an oral dimension to the pursuit and transmission of natural knowledge – from eclipse prediction to surgery, from numerology to divination. Yet the most powerful scientific instrument in the Middle Ages remained the book. And within the book, though illustrations and diagrams played a variety of important roles, written words did the lion's share of the work. The period from the late eleventh to the early thirteenth centuries witnessed a proliferation of text-based analytical and argumentative techniques. These accompanied the formation of the universities, which dominated the intellectual scene in the thirteenth and fourteenth centuries. The enrichment of the substance, methods, and taxonomies of the sciences during this transition in the Latin West depended on two closely related processes: the selection, translation, adaptation, and incorporation of Greek and Arabic learning; and the expansion

<sup>25</sup> Philippe Delhaye, "L'organisation scolaire au XII<sup>e</sup> siècle," *Traditio*, 5 (1947), 211–68 at p. 252, n. 82.

<sup>26</sup> Gerbert of Aurillac, *Letters of Gerbert*, letter of Richier quoted at no. 7, p. 46, n. 1; no. 2, pp. 36–9.

<sup>27</sup> Stephen C. McCluskey, *Astronomies and Cultures in Early Medieval Europe* (Cambridge: Cambridge University Press, 1997), especially chap. 5.

<sup>28</sup> Delhaye, "L'organisation scolaire au XII<sup>e</sup> siècle."

of literary and philosophical activity associated with the “Renaissance of the Twelfth Century.”

### CONVERGING TRADITIONS

European access to Greek, Arabic, and Hebrew learning was concentrated in southern Italy and Spain – two multicultural crossroads of Mediterranean societies. Constantine the African (fl. 1065–85), for example, a converted Muslim who became a monk at Monte Cassino, both carried Arabic medical books from North Africa to Italy and rendered them intelligible to a Latin audience. Consolidating a huge body of learning from the Aegean, West Asia, and North Africa, Arabic works by philosophers and physicians especially fostered the adoption of Aristotle’s ideas and methods and provided interpretations of the Aristotelian natural world. With respect to practices, Latins learned about specific instruments, such as the astrolabe and the zero, and an array of ways to treat and order texts – from structures for medical formularies to modes of philosophical commentary. With respect to the organization of knowledge, Europeans confronted a number of serious challenges that opened new areas of inquiry and revived old ones. Arabic authors not only proposed their own versions of how disciplines were constituted and arranged but also made massive, highly developed substantive contributions to subjects that had commanded little or no place in older Latin systems. Areas such as optics or alchemy, hardly discussed in early Latin schemata for dividing the sciences, became impossible to ignore. Natural science had become more important, while the substance of its diverse parts had become richer and even harder to map.

In ways that varied with local conditions, many twelfth-century scholars not only welcomed but actively pursued the lush profusion of possibilities contained in newly available texts. In some areas of Southern Europe, for example, medicine was the intellectual seed around which natural questions crystallized. At Salerno and Monte Cassino in the late eleventh century, and later in northern Italy and southern France, it reshaped Latin inquiries into the natural world. First, medicine as received from Greek and Arabic sources offered explicit models for the relation between theory and practice in the arts. Second, as medical writers sought to elaborate and strengthen the theoretical foundations of their knowledge, they directly addressed the form and content of natural philosophy. In doing so, authors like Constantine the African not only shaped medicine but also conveyed to natural philosophy a flood of material that was to be put to many uses.<sup>29</sup> The theory of the four elements, for example, which finds no specific place in the older taxonomies of natural knowledge, occupied a pivotal position between the

<sup>29</sup> Paul Oskar Kristeller, “The School of Salerno: Its Development and Its Contribution to the History of Learning,” *Bulletin of the History of Medicine*, 17 (1945), 138–94.

constitution of the world in general and the physiological principles of medical science. Along with the body of knowledge, textual and pedagogical practices developed. Prominent among them were loosely organized series of short queries that came to be known as “Salernitan Questions.”<sup>30</sup> These bear the marks of a method in which rote learning was coupled with medical apprenticeship. As they were disseminated, the questions acquired written answers, which in turn became more elaborate, not only incorporating more natural-philosophical material but also making room for the seeds of debate. For example, one such text summarizes Hrabanus Maurus’s explanation for the deadly look of the basilisk, then states that it is *not* the creature’s look but rather its ability to poison the air that makes it dangerous.<sup>31</sup>

By the late twelfth century, such Salernitan Questions flourished in the very different cultural climate of the Île-de-France, Normandy, and England, where natural philosophy had previously drawn much of its content and its methods from literary studies. Indeed, northern learning about the natural world owed more to the practices associated with the trivium, especially grammar and rhetoric, than to those associated with the quadrivium. In particular, the glosses produced at Chartres and elsewhere, not only on Plato’s cosmogonical myth, the *Timaeus*, but also on the works of Macrobius (fl. early fifth century) and Martianus Capella, brought to the intellectual stage such powerful concepts as prime matter and the four elements. Scholars in this environment applied a variety of textual techniques to topics such as the emergence and differentiation of the cosmos. William of Conches (ca. 1100–1154), for example, after writing a formally conventional gloss on the *Timaeus*, produced a work that combined aspects of Plato’s account of nature with Salernitan material. Whereas some of William’s contemporaries mustered the quadrivial and natural-philosophical material to serve literary purposes, he struggled to define, give shape to, and legitimize the discipline of natural philosophy (*physica*) as “the true understanding of what exists and is seen and of what exists and is not seen.”<sup>32</sup> And whereas William drew upon the Northern academic culture of grammar and rhetoric, others, most notably Peter Abelard (1079–1142), advanced the third member of the trivium, logic.

The variety of academic practices (question-and-answer and textual explication, mythological poetry and practical prose) and the diversity of interests (medical and cosmological, natural-philosophical and metaphysical) formed

<sup>30</sup> Brian Lawn, *The Salernitan Questions: An Introduction to the History of Medieval and Renaissance Problem Literature* (Oxford: Clarendon Press, 1963).

<sup>31</sup> Brian Lawn, *The Prose Salernitan Questions Edited from a Bodleian Manuscript (Auct. F.3.10): An Anonymous Collection Dealing with Science and Medicine Written by an Englishman c. 1200 with an Appendix of Ten Related Collections*, ed. Brian Lawn (Auctores Britannici Medii Aevi, 5) (London: for the British Academy by Oxford University Press, 1979), B.105, p. 49 and P.7, p. 209.

<sup>32</sup> William of Conches, *Philosophia*, ed. Gregor Maurach (Studia, 16) (Pretoria: University of South Africa, 1980), bk. I, chap. 1, sec. 4, p. 18. See Stock, *Myth and Science in the Twelfth Century*, especially pp. 173–83; and Helen Rodnité Lemay, “Guillaume de Conches’ Division of Philosophy in the *Accessus ad Macrobius*,” *Medievalia*, 1 (1977), 115–29.

one axis of the twelfth-century legacy; the wholesale importation of texts formed the other. These changes in turn produced new challenges and opportunities for European intellectuals seeking to order knowledge and organize education.

#### A NEW CANON OF THE ARTS

One of the earliest and most influential Latin treatises to reflect the changing intellectual climate was *On the Division of Philosophy* by Dominicus Gundissalinus. Active in Toledo (Spain) in the late twelfth century, he had participated in the translation efforts that brought so much previously unavailable scholarship into the West. His classification of the sciences reflects lasting reorientations in Western thinking about the scientific disciplines: (1) direct indebtedness to Arabic ideas about the arrangement of systematic knowledge; (2) adjustment to the introduction of massive new material and even new sciences; and (3) involvement of classification in fundamental questions about the order of nature and the path to secure knowledge.

Gundissalinus's work drew heavily upon a treatise of al-Fārābī (ca. 873–950), which he had translated into Latin, not only with respect to the enumeration of specific branches of learning but also with respect to the nature and order of the world that natural science sought to describe. Several of Gundissalinus's moves were far from revolutionary, as the improvisations of the early Middle Ages attest. He expanded mathematics beyond the traditional quadrivium (arithmetic, music, geometry, and astronomy) to include the science of weights (statics) and the science of engines (i.e., using natural bodies and mathematical principles to some end).<sup>33</sup> These last two were among the areas virtually unexplored by earlier Latin authors and amply developed within the Arabic tradition. In addition, though on a much more modest scale, he offered subdivisions of *physica* or, as he called it, “natural science”: medicine, omens, necromancy, magical images, agriculture, navigation, optics (“mirrors”), and alchemy. The strong presence of sciences of divination and control is an indication of the powerful influence of new intellectual appetites and materials.

Beginnings of deeper structural changes also appear in Gundissalinus, among them the organization of the sciences around Aristotelian texts. His eight-part division of natural philosophy bypasses his own list of subdivisions just mentioned and sets up a sequence of subjects ranging from the study of bodies in general through the more particular properties of minerals, plants, and animals. He names a text newly available in Latin as an element in his characterization of each subdivision of science.<sup>34</sup> Although

<sup>33</sup> Dominicus Gundissalinus, *De divisione philosophiae*, ed. Ludwig Baur, *Beiträge zur Geschichte der Philosophie des Mittelalters*, 4, fasc. 2–3 (Münster: Aschendorff, 1903), pp. 122–3.

<sup>34</sup> *Ibid.*, pp. 19–27.



the specific texts did not all remain the same, this was the way in which natural philosophy came to be structured in European universities.

In some respects, the way Gundissalinus presents the relations among the sciences reflects ideas about pedagogical process – one must learn grammar before turning to more complicated subjects – but this sequence also mirrors his ideas about the ranking of objects of knowledge and the ways in which they are known. In Gundissalinus's day, long-familiar sources ranging from Plato to Augustine, and new works by Arabic authors like al-Fārābī and Ibn Sīnā (Avicenna; 930–1037), lent a strong Platonic color to Latin philosophy, one aspect of which was the conceptualization of a hierarchy of substances and thus of the academic subjects treating them. Physics studies the general principles of change without reference to any particular bodies; cosmology studies change of place in otherwise changeless bodies; generation and corruption studies the changes of bodies coming to be and passing away; and the lowest subjects are concerned with the specific properties and operations of particular bodies in the elemental world. This ladder of value resonates with some of the older classifications, such as Boethius's view that theology is more exalted than mathematics and that mathematics is higher than natural philosophy.<sup>35</sup> At the same time, it seems to undermine the status Gundissalinus lent to medicine, alchemy, and other arts concerned with the material and the particular rather than the formal and the general.<sup>36</sup>

Gundissalinus's attempts to sort out the subjects, relations, and values of knowledge about nature, like those of earlier medieval authors, bespeak the variety, flexibility, and mobility of the disciplines and reflect an active intellectual scene. Furthermore, older textual practices, from the examination of etymologies to the preparation of compilations, continued to play a role in scientific learning. By the early thirteenth century, however, much had changed in the substance, methods, and conditions of the sciences. The work done by Isidore of Seville or Hrotswitha of Gandersheim simply to name, define, and iterate the fundamentals of the disciplines was no longer called for in a world in which thousands of students traveled from one European city to another to hear masters lecture, call out questions at disputations, and purchase and annotate books.

## THE ERA OF THE FACULTIES OF ARTS: THIRTEENTH TO FOURTEENTH CENTURIES

The works of Aristotle, whose titles became metonymic for many disciplines in the later Middle Ages, had displaced (though not entirely erased) the

<sup>35</sup> Weisheipl, "Classification of the Sciences in Medieval Thought," pp. 68–81.

<sup>36</sup> George Ovitt, Jr., *The Restoration of Perfection: Labor and Technology in Medieval Culture* (New Brunswick, N.J.: Rutgers University Press, 1986), pp. 107–36.

liberal arts as critical landmarks on the map of learning. More technical, specialized, and advanced, they never took on the iconographic status of their predecessors – arithmetic with her number cord or astronomy with her quadrant. Some general classificatory principles, however, persisted. Writers continued to distinguish in principle between “sciences” and “arts.” According to Thomas Aquinas (ca. 1225–1274), the former (e.g., metaphysics and physics) involve “only knowledge,” whereas the latter (e.g., logic, which constructs syllogisms, and astronomy, which calculates planetary positions) “involve not only knowledge but also a work that is directly a product of reason itself” or, in the case of nonliberal arts (e.g., medicine and alchemy), “involve some bodily activity.”<sup>37</sup> As in the earlier period, however, these distinctions were not widely enforced in the language or institutions of the late Middle Ages; thus students in the “arts” faculties of universities attended lectures on both physics and logic.

The world in which knowledge about nature was shaped and transmitted had also changed considerably by the early thirteenth century. The growth of towns, for example, had created demand for higher levels of practical knowledge in such areas as calculation and medicine, and new forms of political administration had created demand for training not only in law but also in astrology. With support from civil or ecclesiastical authorities (or both), universities took shape. Through the formulation of curricula, the support of advanced investigation, and the position of natural sciences within the larger institutional structure, they provided both opportunities and constraints for defining and pursuing scientific disciplines.

#### ARTS AND METHODS

Questions about curriculum and pedagogy, challenges associated with the profusion of disciplines, and debates contained in the works of newly available authorities all contributed to a sense of urgency about the methods of the sciences. Did each have its own rules of investigation, forms of argumentation, and degree of certainty? Boethius’s assertion that divine, mathematical, and natural sciences were known differently<sup>38</sup> no longer sufficed for thirteenth- and fourteenth-century scholars interested in the distinction between “natural philosophy” and “mathematics.” The latter had once meant the quadrivium, but mathematical developments in the Islamic world not only revolutionized old categories, such as arithmetic, but also introduced new ones. In particular, the distinction between mathematical and natural

<sup>37</sup> Thomas Aquinas, *The Division and Methods of the Sciences: Questions V and VI of His Commentary on the De Trinitate of Boethius*, trans. Armand Maurer, 3rd ed. (Toronto: Pontifical Institute of Mediaeval Studies, 1963), q. 5, art. 1, p. 12.

<sup>38</sup> Boethius, *De trinitate*, chap. 2, p. 8.

knowledge, unsettled even in the early Middle Ages (see Figure 9.2), receded with the incorporation of what came to be called “middle sciences.” Optics, the science of weights, and astronomy (the last of these once housed in the quadrivium) dealt with specific properties of natural objects but employed mathematical representations and demonstrations. Some of the issues raised by these changes were formal: Do the middle sciences actually constitute a subcategory of mathematics?<sup>39</sup> Others were epistemological: What degree of certitude can astrology or medicine attain?<sup>40</sup>

Theoretical debates on the relation of subject to method took a number of forms. From one perspective, the crux of the matter was what kind of demonstration each group of sciences could muster. The conviction that geometry (as represented by Euclid) could produce airtight proofs and hence incontrovertible explanations enjoyed wide acceptance, as did the complementary view that natural philosophy, insofar as it dealt with material objects and was thus burdened by the attendant contingencies, could not aspire to give a complete and certain account. Disagreement nevertheless abounded. For some scholars, such as Albertus Magnus (ca. 1200–1280), the physical world, in which form and matter were actually inseparable, posed questions to which mathematical methods could offer only partial solutions because they treated just a small number of properties abstracted from the actual natural body. For others, such as Roger Bacon (ca. 1219–ca. 1292), natural objects could not be properly understood without mathematics.<sup>41</sup>

Such disagreements illustrate the extent to which classification of the sciences had become implicated in debates about the nature of scientific thought itself. Yet when scholars were working on specific problems, the theoretical divisions often blurred. Albertus Magnus, for example, was committed in general to clarifying the independence of natural philosophy and mathematics. When discussing the generation of a surface by the motion of a line, however, he saw number not only as located in the mind of the mathematician but also as inhering materially in numbered things.<sup>42</sup> Conversely, Roger Bacon articulated a strong theoretical program for the subordination

<sup>39</sup> Murdoch, *Album of Science*, fig. 32, p. 44.

<sup>40</sup> Edward Grant, “Nicole Oresme on Certitude in Science and Pseudo-Science,” in *Nicolas Oresme: Tradition et innovation chez un intellectuel du XIV<sup>e</sup> siècle*, ed. P. Souffrin and A. Ph. Segonds (Science et Humanisme) (Paris: Les Belles Lettres, 1988), pp. 31–43; and Michael R. McVaugh, “The Nature and Limits of Medical Certitude at Early Fourteenth-Century Montpellier,” *Osiris*, 2nd ser., 6 (1990), 62–84.

<sup>41</sup> Weisheipl, “Classification of the Sciences in Medieval Thought,” pp. 72–89; David C. Lindberg, *Roger Bacon and the Origins of Perspectiva in the Middle Ages: A Critical Edition and English Translation of Bacon’s “Perspectiva”* (Oxford: Clarendon Press, 1996), Introduction, pp. xxxvii–xlvii; and David C. Lindberg, “On the Applicability of Mathematics to Nature: Roger Bacon and His Predecessors,” *British Journal for the History of Science*, 15 (1982), 3–25.

<sup>42</sup> A. G. Molland, “Mathematics in the Thought of Albertus Magnus,” in *Albertus Magnus and the Sciences: Commemorative Essays 1980*, ed. James A. Weisheipl (Texts and Studies, 49) (Toronto: Pontifical Institute of Mediaeval Studies, 1980), pp. 462–78 at pp. 475–6.

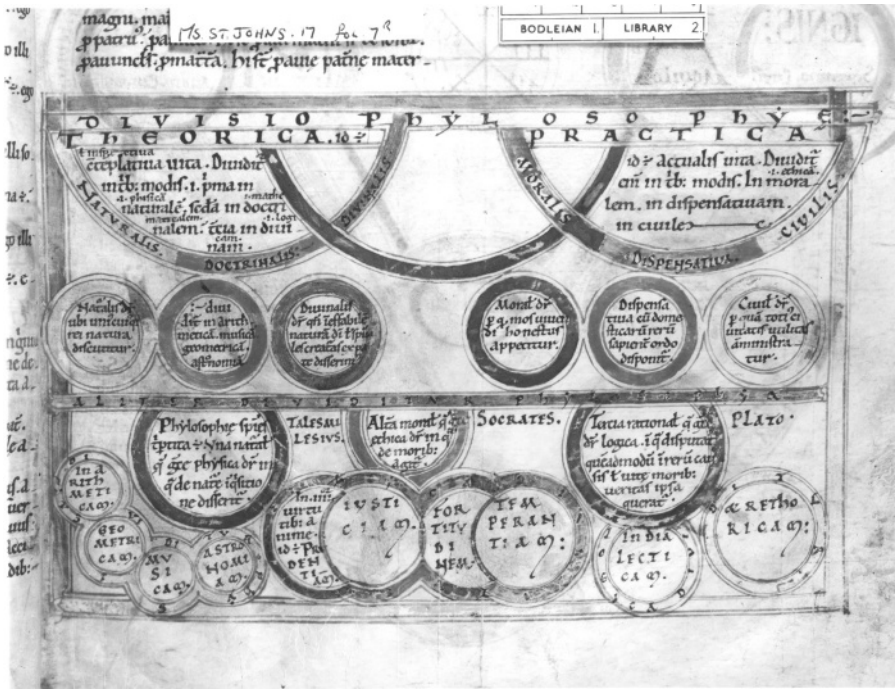


Figure 9.2. Combined divisions of philosophy. This twelfth-century diagram illustrates the mix-and-match character of medieval maps of scientific knowledge. The top half divides philosophy into theory and practice, with the former (on the left) constituted of (from left to right) natural, mathematical, and divine sciences. The circle of the mathematical sciences contains the quadrivium from the liberal arts: arithmetic, music, geometry, and astronomy. The bottom half starts with a three-part division (articulated by Augustine and attributed to Plato): natural, moral, and rational sciences (left to right). To the right of each of these almost-circles, a scribe has carried on the tradition of associating disciplines with their founders, inserting the names of Thales of Miletus, Socrates, and Plato, respectively. Little circles containing the members of the quadrivium are here clustered around natural science, or *physica*, rather than belonging to a separate mathematical division as in the top half. On the right, rational science is flanked by circles for dialectic (logic) and rhetoric. Six of the seven liberal arts are thus represented, with grammar, the most elementary, omitted. Reproduced with the permission of the President and Scholars of St. John's College, Oxford, MS 17, fol. 7r.

of natural philosophy to mathematics, but his accounts of specific phenomena sometimes contained elements that were not reducible to mathematics. Thus his treatment of refraction, while deeply mathematized, depended nevertheless upon his understanding of the physical properties of light and upon a metaphysical principle of uniformity.<sup>43</sup>

<sup>43</sup> Lindberg, *Roger Bacon and the Origins of Perspectiva in the Middle Ages*, Introduction, pp. 1–1ii.

Debates about the relation between mathematics and natural philosophy were among the most heated in the late Middle Ages. Their urgency was enhanced by the tension between the qualitative cosmology of Aristotle and the quantitative astronomy of Ptolemy, and by the mathematization of more and more fields, from pharmacology to the study of local motion.<sup>44</sup> Even within the Aristotelian tradition, which had traditionally bypassed the middle sciences, classification involved ideas about the order and value of the entities studied and about the methods proper to each or common to all disciplines.

Indeed, the Aristotelian perspective on what constituted appropriate and secure demonstration was at the heart of one of the most striking disciplinary rearrangements of the period: the elevation of logic as the most important preparation for the study of philosophy, as the source of critical methods for the pursuit of systematic knowledge, and even as a subject for advanced research in its own right. The privileged position of logic had earlier precedents, but it acquired new meaning and force through the availability of the full body of Aristotle's logical writings. The curricula of universities, as well as the declarations of natural philosophers and learned physicians, testify to this reconceptualization of the starting point for higher learning. As Thomas Aquinas said, citing first Aristotle and then Ibn Rushd (Averroes; 1126–1198), “We must investigate the method of scientific thinking before the sciences themselves. And . . . before all sciences a person should learn logic, which teaches the method of all the sciences; and the trivium concerns logic.”<sup>45</sup> Logic precedes natural philosophy not because its subject matter is more exalted but because it offers tools necessary for the pursuit of the other sciences.

Collections of texts and university curricula embodied the methodological principle that logic comes before the sciences, but at the same time they subscribed to two other ways of ordering knowledge: the principle that higher beings have precedence (and power) over lower beings and the principle that one should move from the general to the particular. The placement of Aristotle's *On the Heavens* before his *Generation and Corruption* reflects the first of these, for the celestial subject matter is more exalted than the earthly. But the placement of *On Vegetables* before *On Animals* reflects the second, for plants are not superior to animals. Rather they embody the defining fundamentals of life – nutrition, growth, and reproduction.

The priority of logic and the high value placed on what was general did not preclude either a role for sense experience or attention to the particulars of nature. From the early Middle Ages onward, there is evidence of

<sup>44</sup> Murdoch, *Album of Science*, especially pts. 2, 3, and 6; Michael R. McVaugh, “The Development of Medieval Pharmaceutical Theory,” in *Aphorismi de gradibus*, vol. 2 of *Arnaldi de Villanova opera medica omnia*, ed. Luis García-Ballester et al. (Seminarium Historiae Medicae Granatensis) (Granada: n.p., 1975), pp. 1–136.

<sup>45</sup> Aquinas, *Division and Methods of the Sciences*, q. 5, art. 1, p. 11.

the purposeful examination of natural phenomena. With a simple tube that sheltered the eye from ambient light, the curious could focus their attention on a star or a planet; with a complex astrolabe, keyed to the local latitude, the trained observer could make measurements and calculations relating to the same object. In Latin and Hebrew compilations of herbal remedies, terse expressions of approval follow some recipes – but not all – with phrases like, “This has been tested.” Occasionally observations are singular – reports of specific events or conditions at a particular place and time. Some astronomical data, including those incorporated into “nativities,” or horoscopes, are of this kind, as are autopsy reports, which proliferate in the late Middle Ages. However, first-person accounts were not necessarily based on singular experiences. In late-medieval Italy, compilations of clinical reports by prominent physicians became a genre of scientific literature, and it is likely that some of the cases recorded were encapsulations of medical theory or more general clinical experience. Nevertheless, the existence of such works is evidence that experience had a certain status in the profession, as was the fact that medical students at the University of Paris received bedside training as well as lectures. Particular disciplines, such as astronomy, were more oriented than others toward seeking and using data directly related to the questions addressed.

Most often, the observations invoked in natural philosophy are of a general character, even if they may have been built on personal and perhaps hands-on experience. Albertus Magnus, for example, in his explanation of the phenomena of growth, makes use of the fact that lower creatures are able to regenerate more of their bodily parts than higher creatures.<sup>46</sup> Furthermore, most works with significant empirical content blended material from ancient authorities, contemporary informants, and personal experience, as was the case with the book on hunting with birds compiled by the Holy Roman Emperor Frederick II (1195–1250). Occasionally, however, the context and wording of an appeal to experience strongly suggest a specific observation or series of observations deliberately and personally undertaken. Such is the case when Roger Bacon gives detailed instructions for constructing and using an apparatus to demonstrate the phenomenon of double vision.<sup>47</sup>

Observation served a number of functions. Reports of anomalous occurrences, especially those regarded as “marvels,” excited wonder and gave rise to reflections about what could and what could not be brought within the fold of natural sciences.<sup>48</sup> On the other end of the spectrum, everyday

<sup>46</sup> Albertus Magnus, *De generatione et corruptione*, in *Opera omnia*, ed. August Borgnet (Paris: Louis Vivès, 1890), vol. 4, bk. 1, tract 3, chap. 8, pp. 383–4.

<sup>47</sup> Roger Bacon, “Perspectiva,” in Lindberg, *Roger Bacon and the Origins of Perspectiva in the Middle Ages*, pt. 2, distinction 2, chap. 2, pp. 182–7 and lxi–lxii.

<sup>48</sup> Bert Hansen, *Nicole Oresme and the Wonders of Nature: A Study of His “De mirabilium”* (Toronto: Pontifical Institute of Mediaeval Studies, 1985); and Lorraine Daston and Katharine Park, *Wonders and the Order of Nature, 1150–1750* (New York: Zone Books, 1998).



experiences – whether directly relevant or in the form of analogies – often served heuristic and persuasive purposes. Observations were frequently made and called upon to confirm or illustrate preexisting knowledge. This was the case with the practice of human dissection when it first became integrated into university curricula. Although conservatively framed, such practices sometimes slid from illustration to clarification to revision to critique, as occurred in the field of anatomy. In addition, experience often occupied a place within the structure of an argument. For example, the size of a human body increases either because material is added to it or because its original material gets rarified; but we see that a man's flesh is denser, not rarer, than a boy's; therefore growth occurs by the addition of material.<sup>49</sup> Although the practice was not common, more specialized observations could be similarly invoked to confirm or rule out a theory or to choose among competing premises. To establish that refracted rays of light are involved in vision, Bacon offers the evidence of a thin straw held close to the face against a distant background. The straw does not block our perception of the background, which it would if only direct rays were involved.<sup>50</sup> The invocations of experience are too varied to constitute a single scientific method, but the profusion of observations and attentiveness to the particulars of nature attest to the seriousness with which scholars approached the phenomena that their disciplines undertook to record and explain.

In spite of the diverse roles played by experience, the differences among these Aristotelian hierarchies, and the disagreements about the role of mathematics, late-medieval sciences achieved a certain coherence when it came to scholarly practices.<sup>51</sup> As in the earlier Middle Ages, these were, first and foremost, textual. Now, however, the new bodies of knowledge, the lessons from Greek, Arabic, and Hebrew scholarship, and especially the development of the universities contributed to the creation of far more varied and technically sophisticated ways of dealing with the corpus of authoritative texts and generating a corpus of modern texts. Some modes of university teaching and research, such as the explication of an authority's literal meaning, were indebted to older habits of exegesis. Others, such as the public debate of disputed questions (often in a raucous environment), were unique to the new conditions. Masters had to be able to take and defend positions on a variety of topics: philosophers on whether the Earth is always at rest in the middle

<sup>49</sup> Albert of Saxony, *Questiones de generatione et corruptione*, in *Questiones et decisiones physicales* (Paris: Iodocus Badius and Conradus Resch, 1518), bk. I, question 9, fol. 135ra.

<sup>50</sup> Bacon, "Perspectiva," bk. III, distinction 2, chap. 1, pp. 293 and lxiv–lxv.

<sup>51</sup> John E. Murdoch, "From Social to Intellectual Factors: An Aspect of the Unitary Character of Late Medieval Learning," in *The Cultural Context of Medieval Learning: Proceedings of the First International Colloquium on Philosophy, Science, and Theology in the Middle Ages, September 1973*, ed. John E. Murdoch and Edith D. Sylla (Boston Studies in the Philosophy of Science, 26; Synthèse Library, 76) (Dordrecht: Reidel, 1975), pp. 271–348; and Jole Agrimi and Chiara Crisciani, *Edocera Medicos: Medicina scolastica nei secoli XIII–XV* (Istituto Italiano per gli Studi Filosofici, Hippocratica Civitas, 2) (Naples: Guerini, 1988).

of the heavens or whether it can be moved, physicians on whether men or women experience greater pleasure in sexual intercourse, and so forth. In an intricate structure, a master preparing responses had to present arguments for and against each proposition, raise objections to the arguments, and provide responses to the objections, as well as muster the relevant evidence from authoritative texts. Many such practices were widespread, deployed not only in a variety of disciplinary areas, from mathematics to meteorology, but also in all parts of Europe at institutions that differed in other respects.

#### USES OF THE ARTS

University students encountered these patterns of scholarly inquiry in the faculty of arts, where all began their education with Aristotelian logic and natural philosophy. Although in the early Middle Ages scientific ideas and practices had fulfilled a number of social functions, from the calculation of Easter to the enhancement of cultural prestige, in the changing demographic, economic, and political scene of the late Middle Ages people with scientific knowledge became more common and more prominent. Some went on to advanced degrees in theology, medicine or law (civil or canon); others moved more quickly into opportunities available to this literate elite.

As the new class of university-trained men pursued a variety of newly developing careers, not only in the professions but also in the management of secular and ecclesiastical government, the old distinctions between theory and practice underwent radical revisions. Boethius had distinguished theory (theology, mathematics, and natural philosophy) from practice (ethics, economics, and politics); encyclopedists had valued the liberal arts above the mechanical arts because the latter had involved the use of the hands. Now texts converged with social conditions to produce a growing respect for action in the world, including the mechanical arts.<sup>52</sup> Under the influence of Arabic traditions, Westerners began to take seriously the idea that each art had a theoretical and a practical part.<sup>53</sup> More important, those same traditions had been the source of significant bodies of “practical” learning in such areas as mathematical calculation, observational astronomy, magic, and medicine. Signs of this shift appear in specific institutional changes. For example, what had originally distinguished the university-trained physician from other medical practitioners was his mastery of classic Latin texts. By the end of the Middle Ages, however, surgery – the most manual branch of medicine – had acquired a place within the university curriculum itself. Manuscripts of astronomical tables abounded in the libraries of princes as

<sup>52</sup> Pamela O. Long, “Power, Patronage, and the Authorship of *Arts*: From Mechanical Know-How to Mechanical Knowledge in the Last Scribal Age,” *Isis*, 88 (1997), 1–41; and Whitney, *Paradise Restored*, pp. 129–49.

<sup>53</sup> Hunt, “Introduction to the ‘Artes’ in the Twelfth Century,” pp. 98–105.

well as those of schools, and enough horoscopes survive to indicate that they were not there just for show. A passing reference to “alchemists’ books” in a letter from Christine de Pisan (fl. 1399–1429) to a member of the French court suggests that people were ready to put these texts to use: “Some read and understand them one way and others completely differently. . . . And on this basis they open and prepare ovens and alembics and crucibles, and they blow hard for a little sublimation or congelation.”<sup>54</sup>

The mushrooming of the middle sciences, the enrichment of the applied dimensions of theoretical sciences, the articulation of institutions dedicated to the development and transmission of learning, and the multiplication of social functions for scientific knowledge all contributed to a situation in which the most advanced study in many fields was highly technical. These changes, too, are reflected in late-medieval divisions of the sciences. According to a diagram in one fifteenth-century manuscript, for example, mathematics has eleven distinct parts, some of which are parts of parts of parts.<sup>55</sup> The intricacies of such divisions and subdivisions reflect a real situation in which not only the specificity but also the sophistication of advanced scientific work is inscribed. Few students or even masters in the faculties of arts or medicine actually read Ptolemy’s *Almagest*. Likewise, in other fields, works of comparable complexity (if not always of comparable stature) were accessible to only the most advanced scholars. This situation gave rise to a degree of specialization and thus a hardening of disciplinary lines. The commentators on Ibn Sīnā’s *Canon of Medicine* typically did not expound theories of the rainbow. Gerbert, who in the tenth century had access to a very modest collection of texts, had busied himself producing textbooks and instruments for teaching rhetoric, astronomy, and music, and enjoyed a reputation for his astonishing calculational abilities. By contrast, Albertus Magnus, the “Universal Doctor” of the thirteenth century, had available a vastly larger library but produced little to suggest proficiency in the mathematical sciences.<sup>56</sup> At the same time, as Arabic arithmetic techniques, growing academic interest in mathematics, and flourishing urban commerce all converged, new systems of calculation joined, if they did not entirely displace, Gerbert’s counting method. By the thirteenth century, for example, scholars in Paris did what were recognized as Arabic “algorithms,” dealing

<sup>54</sup> Christine de Pisan, “A maistre Pierre Col, Secretaire du roy nostre sire,” in *Christine de Pisan, Jean Gerson, Jean de Montreuil, Gontier Col, and Pierre Col, Le débat sur le Roman de la rose*, ed. Eric Hicks (Bibliothèque du XV<sup>e</sup> Siècle, 43) (Paris: Honoré Champion, 1977), no. 4, pp. 115–50 at p. 126.

<sup>55</sup> On this figure, see Murdoch, *Album of Science*, fig. 32, p. 42.

<sup>56</sup> M. J. E. Tummers, “The Commentary of Albert on Euclid’s Elements of Geometry,” in Weisheipl, *Albertus Magnus and the Sciences*, pp. 479–99; and Molland, “Mathematics in the Thought of Albertus Magnus.” Compare David C. Lindberg, “Roger Bacon and the Origins of Perspectiva in the West,” in *Mathematics and Its Applications to Science and Natural Philosophy in the Middle Ages: Essays in Honor of Marshall Clagett*, ed. Edward Grant and John E. Murdoch (Cambridge: Cambridge University Press, 1987), pp. 249–68 at pp. 256–7.

with remainders and carrying by writing and erasing digits in sand on a table, whereas their predecessors had used tokens marked with numerals on a board laid out as an abacus.<sup>57</sup>

Although much of what medieval scholars *did* when they applied or enacted their knowledge is inaccessible to us, some evidence points to lively economic, social, and even mechanical activities. The construction of clocks called upon both mathematical knowledge and mechanical know-how.<sup>58</sup> The horoscopes and other forms of astrological counsel offered for a fee by university mathematicians of fifteenth-century Vienna represented at once expert calculations and useful products.<sup>59</sup> Similarly, the *consilia*, or case histories, written down by physicians constituted not only texts for instruction but also representations (if not always transparent) of their careers as medical practitioners.<sup>60</sup>

#### THE ARTS AND THE BODY OF MEDIEVAL SCIENCE

Although late-medieval classification schemes were mainly concerned with the internal structure of systematic learning – with the functions and relations of its parts – they also served to delineate what constituted the body of legitimate knowledge as a whole. Whether explicitly or implicitly, the taxonomies marked off what might (or had to) be excluded from consideration. The same diagram that so intricately parsed mathematics also divided astronomy into two parts: the study of heavenly motions and the study of their effects. The second of these is bluntly divided into “prohibited” (with no further elaboration as to the subjects and texts implicated) and “not prohibited” (see Figure 9.3).

Medieval authors did not always agree about which inquiries were licit, but wherever the line was drawn, some ways of knowing and dealing with nature were left outside of a boundary that thus defined the proper domains of natural science in general. Distinctions between permitted and prohibited, or proper and improper, were not limited to astrology. Medical treatises, for example, reflect controversies about what aspects of sexual experience a physician ought properly to consider.<sup>61</sup> Much of the excluded material

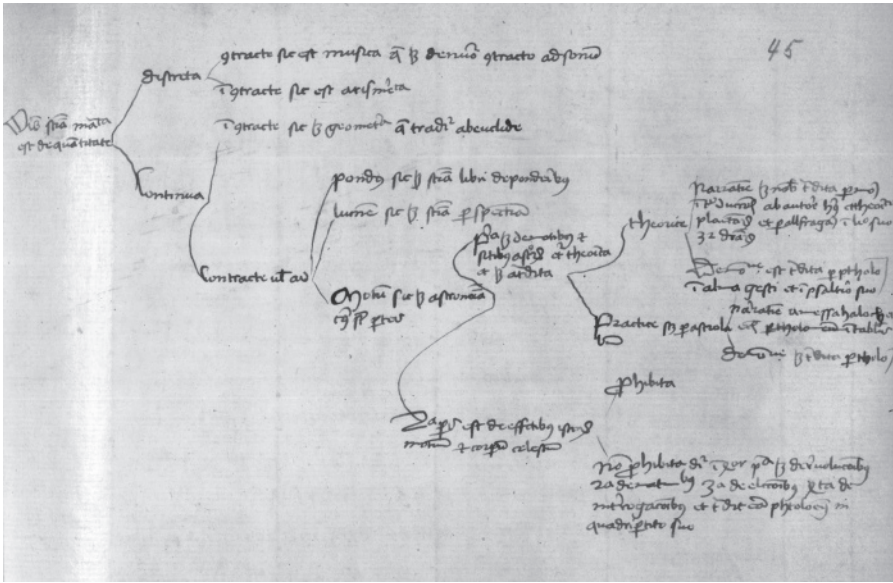
<sup>57</sup> Guy Beaujouan, “L’enseignement de l’arithmétique élémentaire à l’université de Paris aux XIII<sup>e</sup> et XIV<sup>e</sup> siècles: De l’abaque à l’algorithme,” in *Homenaje a Millás-Vallcrosa*, 2 vols. (Barcelona: Consejo Superior de Investigaciones Científicas, 1954), vol. 1, pp. 93–124 at pp. 94–6.

<sup>58</sup> Richard of Wallingford, *Tractatus horologii astronomici*, in *Richard of Wallingford*, ed. and trans. John D. North, 3 vols. (Oxford: Clarendon Press, 1976), vol. 1, pp. 441–523; vol. 2, pp. 309–60; vol. 3, pp. 63–74.

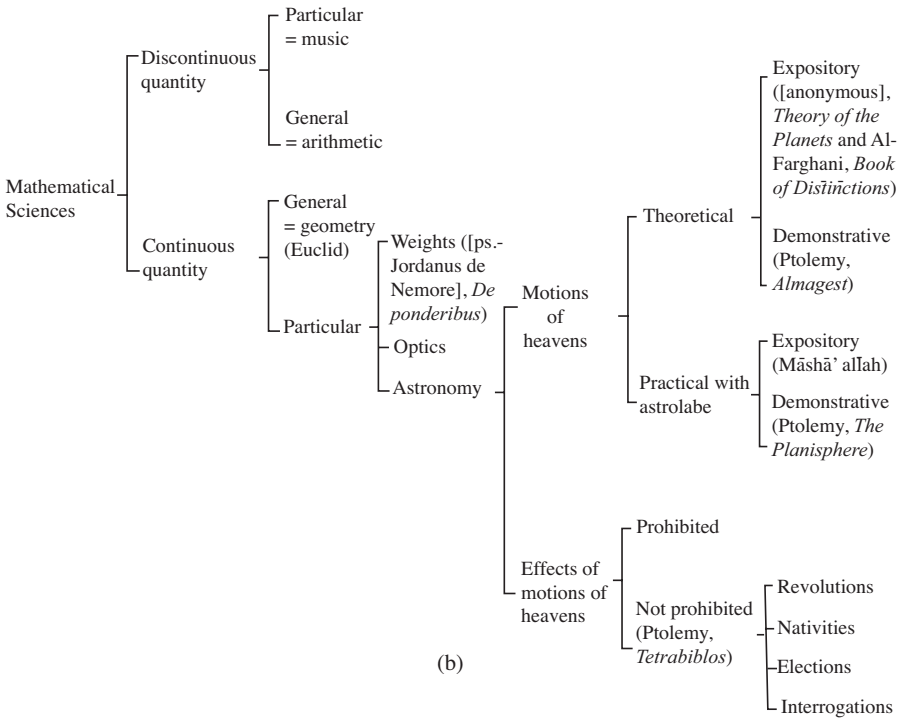
<sup>59</sup> Michael H. Shank, “Academic Consulting in Fifteenth-Century Vienna: The Case of Astrology,” in *Texts and Contexts in Ancient and Medieval Science: Studies on the Occasion of John E. Murdoch’s Seventieth Birthday*, ed. Edith Sylla and Michael McVaugh (Leiden: Brill, 1997), pp. 245–70.

<sup>60</sup> Jole Agrimi and Chiara Crisciani, *Les consilia médicaux*, trans. Caroline Viola (Typologie des Sources du Moyen Âge Occidental, 69) (Turnhout: Brepols, 1994).

<sup>61</sup> Joan Cadden, “Medieval Scientific and Medical Views of Sexuality: Questions of Propriety,” *Medievalia et Humanistica*, n.s. 14 (1986), 157–71.



(a)



(b)

Figure 9.3. Division of the mathematical sciences, fifteenth century. This schema of the parts of mathematics could only have been drawn in the late Middle Ages, when texts for and branches of inquiry devoted to subjects such as optics and weights had become established. The diagram indicates that certain unspecified areas of astrology are prohibited; the licit portion includes horoscopes (“nativities”). By permission of Basel, Öffentliche Bibliothek der Universität, MS F.II.8, fol. 45r.

was what opponents labeled “divination” or “sorcery,” from the casting of lots to the manipulation of images to achieve specific results. Many of the works associated with these arts were (or were purported to be) from Arabic, Hebrew, “Chaldean,” or other exotic traditions, making them both more interesting and more suspect. Curricular statutes and learned arguments, as well as rhetorical attacks, acted to contain the pursuit of such sciences, but they were by no means successfully suppressed or even marginalized. Their survival was due not only to the wealth of texts but also to their perceived utility. In the early thirteenth century, the Holy Roman Emperor received a commentary on a work supposedly written by Aristotle for Alexander the Great. It included material on judging a person’s character from physical traits – physiognomy, “the science of which should really be kept secret, because of its great effectiveness. It contains secrets of the art of nature that meet the need of every astrologer. . . . [A]mong other things of which you should be mindful is the science of good and evil.”<sup>62</sup> An array of evidence attests to diverse, flourishing, learned, and occasionally highly technical activity in precisely the domains targeted, such as geomancy and chiromancy, suggesting the futility of medieval (and modern) attempts to exclude these subjects from the canon of medieval natural knowledge.<sup>63</sup>

In addition to such hotly contested lines of demarcation, other signs point to the ambiguous relationships of individual sciences to the central body of scientific knowledge. This situation was intensified by the newness of some subjects and texts for scholars in the Latin West. For example, works on physiognomy, of which there was hardly a trace in the early Middle Ages, were sometimes enshrined with the Aristotelian natural corpus and adorned with learned commentaries, sometimes copied into manuscripts containing medical or magical texts, and sometimes reproduced in the company of religious and moral writings. The boundaries of exclusion and inclusion, whether indefinite (as in the case of physiognomy) or contested (as in the case of certain branches of astrology), thus manifested the same sorts of flexibility and fluidity as the internal lines dividing the constituent parts of natural knowledge from each other.

## CONCLUSION

Divisions and classifications (whether explicit or implicit) reflected, embodied, or activated, but did not determine, the ways in which knowledge about nature was received, created, shaped, and transmitted. Even in the earlier part of the period, alternative models and cheerful syncretism left authors

<sup>62</sup> Michael Scot, *De secretis secretorum*, cited in Charles H. Lohr, “Medieval Latin Aristotle Commentaries, Authors: Johannes de Kanthi-Myngodus,” *Traditio*, 27 (1871), 251–351 at p. 349, no. 1.

<sup>63</sup> The greatest mass of evidence is contained in Lynn Thorndike, *A History of Magic and Experimental Science*, 8 vols. (New York: Columbia University Press, 1923–1958).



much freedom to rearrange the components of the intellectual map to suit their purposes. The dyad of theory and practice and the triad of theology, mathematics, and natural philosophy both intersected with the seven liberal arts. Later, pluralism and outright conflict prevented the hegemony of any particular system. For example, scholars categorized questions about the motions of the heavenly bodies differently, depending upon whether they arose from Aristotle's *On the Heavens* or texts on mathematical astronomy. More important, at no time did the most favored taxonomies encompass all of the activities that medieval scholars themselves called "sciences" and that they associated with the objects and operations of the created world. In the early Middle Ages, the theory of the four elements did not occupy a secure position; in the later Middle Ages, the proper place of physiognomy was unclear. For these reasons, not only the internal organization but also the external boundaries of natural knowledge were flexible and fluid, contested and contextual, in the Middle Ages.

Changing material, institutional, and intellectual conditions, from urbanization to the accessibility of Arabic science, added a chronological dimension to this variability. After the twelfth century, the number of areas of investigation that were candidates for the denomination "science" had multiplied dramatically, as had the kinds of issues that denomination raised. Not only did new subjects, such as alchemy, challenge the boundaries of the natural and mathematical sciences and new texts, such as the *Optics* of Ibn al-Haytham, test the capacities of individuals and even curricula to reach the most advanced levels in all fields, but new questions concerning the foundations of knowledge about the world, such as the role of mathematics, demanded increased attention to how sciences were conducted. In this intellectual and social environment, the stabilizing and conservative functions of dividing and classifying the sciences characteristic of the early Middle Ages gave way to more dynamic functions, such as creating institutional space for competing bodies of knowledge and providing a medium for debates about substances and methods.

No matter how differently scholars construed and used the arrangements of the various fields of natural knowledge before and after the changes centered on the twelfth century, notions of disciplinary distinctions and order played certain continuing roles throughout the Middle Ages. First, they provided a vocabulary with which to express successive attempts to organize not just concepts but also books, curricula, and activities. Second, they highlighted, even as they circumscribed, certain persistent distinctions that precluded a simple, static, and unified science of nature – divisions between mathematics and natural philosophy, for example, or between theory and practice. Systems of classification thus brought order to a diverse set of activities and helped to create a foundation and a map for a wider range of knowledge and practices. At the same time, because

of the many purposes they served, because of the variety of traditions and outlooks they encompassed, and because they were neither complete nor consistent with each other, their lacunas, tensions, and fissures constituted an aspect of the productive, open-ended environment in which medieval science thrived.