DISCIPLINE & EXPERIENCE

THE MATHEMATICAL WAY IN THE SCIENTIFIC REVOLUTION

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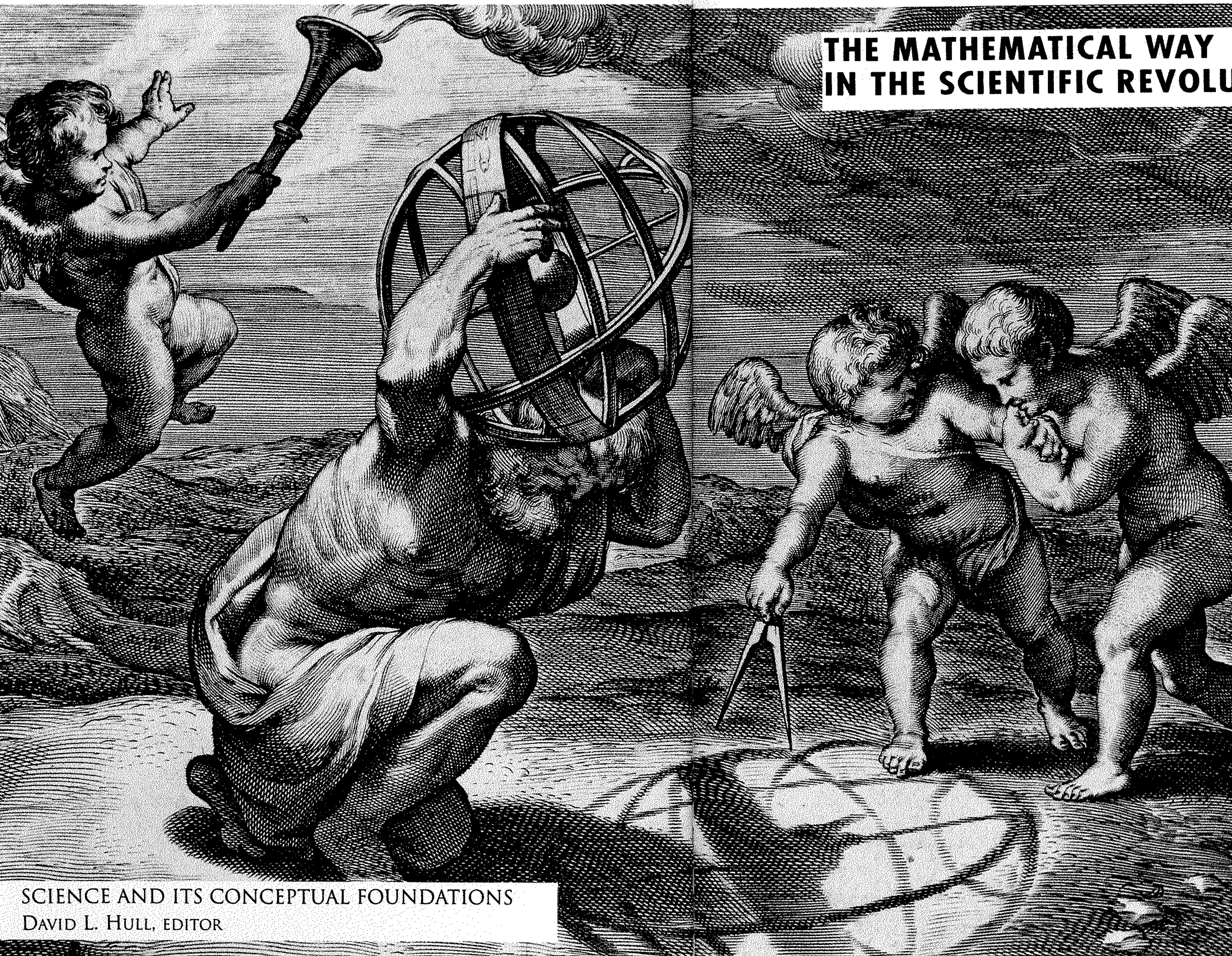

SCIENCE AND ITS CONCEPTUAL FOUNDATIONS
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EXPERIENCE AND JESUIT MATHEMATICAL SCIENCE: THE PRACTICAL IMPORTANCE OF METHODOLOGY

I. Jesuit Mathematical Science and Empirical Principles

Many local contexts of knowledge-making bear witness to the gradual process by which appeal to discrete experiences became culturally dominant in European philosophy of nature. One of the most revealing, however, surrounds the practice of the classical mathematical sciences by members of what was long regarded as a bastion of reaction—the Jesuit order. The shifts in the concept of experience among Jesuit mathematicians impinge directly on the implications of moving from a scholastic to a characteristically early-modern natural philosophical paradigm. They also help to explain how mathematical models of scientific practice became so closely implicated in the new ideology of natural knowledge that had emerged by the end of the seventeenth century. Jesuit mathematicians began to validate the use of singular experiences made using contrived apparatus because the existing practices of their disciplines, besides needing to be defended methodologically against Jesuit critics, restricted the availability of their results. This and the following chapter will track some of the outcomes of this predicament.

Jesuit colleges were among the most important and prestigious of all educational institutions in early-modern Europe. Established throughout Catholic territories from the middle of the sixteenth century onwards as part of the Jesuits' Counter-Reformatory mission, they provided a high level of academic training focused on rational theology, missionary skills, and general cultural excellence aimed at the in-

timidation of Protestants.[1] By the early seventeenth century the mathematical disciplines had come to hold a comparatively prominent place in the courses of study offered by the Jesuits at the larger colleges and in the ideal curriculum enshrined in the 1599 *Ratio studiorum*.[2] The exact pattern varied from college to college, and over time, but the only real constraint appears to have been an insufficient number of competent teachers to go around.[3] Throughout the seventeenth century, Jesuit mathematicians carried out research in their subjects, produced major treatises and wrote textbooks that were widely read.[4] Christopher Clavius, professor of mathematics at the Collegio Romano from 1565 until his death in 1612, was the prime mover in establishing mathematics in the curriculum; his work powerfully shaped the style and attitudes manifest in subsequent Jesuit mathematical writing.[5]

Clavius's textbooks formed the standard introduction to the mathe-

1. See fundamental works by Dainville, *La naissance de l'humanisme moderne* (1940) and *La géographie des humanistes* (1940), as well as the collected articles in Dainville, *L'éducation des Jésuites* (1978); Codina Mir, *Aux sources de la pédagogie des Jésuites* (1968). Snyders, *La pédagogie en France* (1965), provides a useful account of the ethos of these colleges, as does Ducreux, *Le collège des Jésuites de Tulle* (1981). Chartier, Julia, and Compère, *L'éducation en France* (1976) contains useful material on French Jesuit colleges and their structure, as does Brockliss, *French Higher Education* (1987), esp. material in chap. 1.

2. For a general account of Jesuit mathematical education, see, apart from material in Dainville, *L'éducation des Jésuites*, Heilbron, *Electricity in the 17th and 18th Centuries* (1979), pp. 101–114. Cosentino, "Le matematiche nella 'Ratio studiorum'" (1970); idem, "L'insegnamento delle matematiche" (1971). For comprehensive listings and biographical entries of mathematicians in the colleges see Fischer, "Jesuiten Mathematiker in der deutschen Assistenz bis 1773" (1978); idem, "Jesuiten Mathematiker in der französischen und italienischen Assistenz bis 1762, bzw. 1773" (1983); idem, "Die Jesuitenmathematiker des nordostdeutschen Kulturgebietes" (1984). See also Koutná-Karg, "Experientia fuit, mathematicum paucos discipulos habere" (1991). Krayer, *Mathematik im Studienplan der Jesuiten* (1991), pt. I, chap. 2, concludes (p. 41) with the observation that, at least at the institutional level, Clavius's promotion of mathematics in the curriculum had little impact, contrary especially to the impression given by Dainville. The fact remains, however, that mathematics was taught in the Jesuit colleges, using the textbooks of Clavius, and that those Jesuit mathematicians who emerged from such training were imbued, as their writings attest, with the views and values expressed by Clavius. These mathematicians were, furthermore, widely known, and their works influential, in mathematical-scientific circles throughout Europe.

3. Heilbron, *Electricity in the 17th and 18th Centuries*, pp. 102–103.

4. Harris, "Transposing the Merton Thesis" (1989), stresses the sheer quantity of Jesuit work in the sciences in the early-modern period, as well as its utilitarian bias.

5. On Clavius's work and career see above all Baldini, "Christoph Clavius" (1983); also Lattis, "Christoph Clavius and the *Sphere* of Sacrobosco" (1989), chap. 1; Knobloch, "Sur la vie et l'œuvre de Christophore Clavius" (1988); idem, "Christoph Clavius—Ein

matical sciences for pupils of the Jesuits such as Descartes.[6] Although he praised the widespread applicability of mathematics to all areas of learning, Clavius restricted his own writings to the more practical aspects of the subject: his work on the Gregorian calendar was very much in keeping with the tenor of his texts on geometry, astronomy, arithmetic, and algebra—the last in its sixteenth-century guise as a department of arithmetic providing analytical computational techniques.[7] Jesuit mathematical teaching, following Clavius, included considerable emphasis on practical matters such as spherical astronomy, geography, surveying, and the concomitant use of mathematical instruments.

Clavius played a seminal role in the formation of a Jesuit tradition of work in the mathematical disciplines running throughout the seventeenth century. His promotion of their intellectual status was of paramount importance because it provided a basis for a treatment of aspects of the natural world that would stand on an equal methodological footing with Aristotelian natural philosophy (physics). The strict disciplinary structure of the Jesuit colleges instantiated a conceptual structure that placed mathematics in a clearly defined position: it was *not* natural philosophy.[8] The arts curriculum of the medieval universities had derived from the late-antique classification of the trivium,

Astronom zwischen Antike und Kopernikus" (1990). Lattis, *Between Copernicus and Galileo* (1994) appeared too late for consideration here.

6. A document written by Clavius for his superiors in about 1579 or 1580, detailing a projected mathematics course with subjects and authors, is reproduced in Baldini, *Legem impone subactis* (1992), pp. 172–175, and also in idem, "La nova del 1604" (1981), on pp. 89–95; see also a similar listing by Clavius of mathematical texts transcribed in Lattis, "Christoph Clavius and the *Sphere* of Sacrobosco," appendix IV.

7. His various works are collected in Clavius, *Opera mathematica* (1611–12). For praise of mathematics' general utility, see, e.g., Clavius, "Geometrica practica," in ibid., vol. 2, "Praefatio," p. 3. On Clavius's calendrical work, see Baldini, "Christoph Clavius"; on his algebra, Knobloch, "Sur la vie et l'œuvre de Christophore Clavius"; Naux, "Le père Christophore Clavius (1537–1612), sa vie et son œuvre" (1983), on pp. 336–338 (although this article is not very reliable or well documented). See also Homann, "Christophorus Clavius and the Renaissance of Euclidean Geometry" (1983). A full listing of Clavius's works may be found in Sommervogel, *Bibliothèque de la Compagnie de Jésus* (1890–1932/1960), vol. 2, cols. 1212–1224. Lattis, "Christoph Clavius and the *Sphere* of Sacrobosco," appendix II, provides a listing of editions of Clavius's commentary on *De sphaera*, while Knobloch, "Christoph Clavius: Ein Namen- und Schriftenverzeichnis" (1990), pp. 136–139, lists the various editions of the works that went to make up the *Opera mathematica*.

8. See, for the official statement in the Jesuits' 1599 *Ratio studiorum* of the disciplinary and conceptual distinction between natural philosophy and mathematics, Salmone, *Ratio studiorum* (1979), p. 66. See also, on these issues of the relationship between mathematics and natural philosophy among the Jesuits, Baldini, *Legem impone subactis*, chap.

comprising the headings grammar, logic, and rhetoric, and the quadrivium, consisting of arithmetic, geometry, astronomy, and music.[9] The Jesuits in effect elevated the quadrivium from its former propaedeutic place as an arts subject to the second or third year of their advanced three-year philosophy course, where it was usually taught alongside either physics or metaphysics (after a year's training in logic.)[10] The precise relationship of mathematics to philosophy had been a matter of contention, however, both before and after the formal incorporation of mathematical studies into the official Jesuit curriculum in the later sixteenth century. It was Clavius who had championed the philosophical standing of mathematics against its detractors when a general college curriculum was being debated in Rome during the 1580s.

The opposition he faced in attempting to ensure a respectable place for mathematics in Jesuit pedagogy emerges vividly, if not disinterestedly, in a policy document that he wrote in the 1580s aimed at taking to task disrespectful teachers of philosophy.[11] There are those, he claims, who tell their pupils such scurrilous things as that "mathematical sciences are not sciences, do not have demonstrations, abstract from being and the good etc." Teachers of mathematics must be accorded proper respect and status, whereas these unfortunate doctrines promulgated by philosophers "are a great hindrance to pupils and of no service to them; especially since teachers can hardly teach them without bringing these sciences into ridicule." Clavius therefore proceeds to make suggestions calculated to promote the image of mathematics, such as ensuring that mathematics teachers attend the regular formal disputations, even participating in them, just as do the philosophers. He also asserted the necessity of mathematics in the study of natural philosophy, mentioning as an example the relevance of mathematical astronomy to cosmology. Furthermore, he claimed that there was "an infinity of examples in Aristotle, Plato and their most illustrious interpreters which can in no way be understood without some knowledge

1, "*Legem impone subactis*. Teologia, filosofia e scienze matematiche nella didattica e nella dottrina della Compagnia di Gesù (1550–1630)."

9. Essays on the quadrivial disciplines in the earlier Middle Ages may be found in Wagner, *The Seven Liberal Arts* (1983). See also Gagné, "Du quadrivium aux scientiae mediae" (1969).

10. See, in addition to references in n. 2, Rochemonteix, *Un collège de Jésuites* (1889), esp. vol. 4, pp. 27, 32.

11. Clavius, "Modus quo disciplinae mathematicae in scholis Societatis possent promoveri," in *Monumenta Paedagogica Societatis Jesu* (1901), pp. 471–474.

of the mathematical sciences."[12] This way of increasing the esteem of philosophers in the colleges for their mathematical colleagues evidently had some appeal: in 1615 Clavius's follower Josephus Blancanus (Giuseppe Biancani) published a 283-page work that proceeds through Aristotle's works in turn picking out passages that admit of mathematical elucidation.[13]

The stakes were considerable: Clavius was not inventing adversaries. Prominent Jesuit natural philosophers denied to mathematics the status of *scientia*, true scientific knowledge (the highest cognitive ideal for methodological Aristotelians). In the sixteenth century a number of Italian philosophers, beginning with Alessandro Piccolomini and including the Jesuit Pereira, had maintained that pure mathematics (geometry and arithmetic) was not a true science in Aristotle's sense because it did not demonstrate its conclusions through causes. They had been followed by the authors of the important Coïmbra commentaries on Aristotle, which were explicitly designed for use in Jesuit colleges. As a rule, teachers of mathematics in Jesuit colleges did not double as teachers of philosophy; if not admitted as an integral part of philosophy, and treated instead as a mere set of calculatory techniques, mathematics, and its practitioners, would suffer accordingly.[14]

An Aristotelian science employed causal demonstrations the ideal unit of which was a syllogism having a middle term that expressed the operative cause (whether efficient, material, formal, or final). This cause should be both necessary and sufficient to account for the effect or property attributed in the conclusion. Any discipline that did not demonstrate its conclusions through causes was, therefore, not scientific; if a geometrical demonstration was just an exposition of logical relations between propositions, it represented an inferior grade of

12. Ibid., pp. 471–472. Nicholas Jardine traces an apparent increase towards the end of the sixteenth century in the perceived relevance of mathematical astronomy for natural philosophy in N. Jardine, *The Birth of History and Philosophy of Science* (1984), p. 246.

13. An exercise suggested by Clavius himself in "Modus," p. 473. Blancanus, *Aristotelis loca mathematica* (1615), is usually bound following another work by Blancanus, *De mathematicarum natura dissertatio;* the works bear identical publication details.

14. See Galluzzi, "Il 'Platonismo' del tardo Cinquecento" (1973); see also Wallace, *Galileo and His Sources* (1984), p. 136, for further references to work by G. C. Giacobbe, to which may be added Carugo, "Giuseppe Moleto" (1983). Giacobbe, *Alle radici della rivoluzione scientifica rinascimentale* (1981) presents texts and analysis focused on Catena, with a dominant theme of the replacement, starting in the sixteenth century, of a "dialectical logic" by the "mathematical logic" relating to singular phenomena that comes to characterize (in Giacobbe's view) modern science. See also De Pace, *Le matematiche e il mondo* (1993), esp. chap. 1 on Piccolomini and Pereira. N. Jardine, "Epistemology of the Sciences" (1988), esp. pp. 693–697, provides a valuable guide to these matters.

knowledge.[15] As a consequence, mathematics could not be a proper part of philosophy. Mathematical objects (numbers or geometrical figures) were not real things; they existed only in the intellect. Therefore—so the objection ran—mathematical objects could not have essences: that is, mathematical definitions were not *essential* definitions of real objects from which the characteristic properties of those objects could be deduced.[16]

Clavius's approach to maintaining mathematics as a part of philosophy amounted to little more than an argument from authority. He adopted the conventional classification of subject matters found in Aristotle and stemming from Plato, a classification frequently used in the Latin West since the early Middle Ages.

> Because the mathematical disciplines discuss things that are considered apart from any sensible matter—although they are themselves immersed in matter—it is evident that they hold a place intermediate between metaphysics and natural science, if we consider their subject, as is rightly shown by Proclus. For the subject of metaphysics is separated from all matter, both in the thing and in reason; the subject of physics is in truth conjoined to sensible matter, both in the thing and in reason; whence, since the subject of the mathematical disciplines is considered free from all matter—although it [i.e., matter] is found in the thing itself—clearly it is established intermediate between the other two.[17]

This classification therefore placed mathematics as an integral part of philosophy, no less than physics or metaphysics. Thus, following the same tack, Blancanus could reply to denials of mathematics' philosophical status by saying that "among Aristotle and all the peripatetics

15. Those who denied scientificity to mathematics usually attributed the widely acknowledged certainty of mathematical demonstration to the nature of its subject matter, not to its methodological structure.

16. See references in n. 14.

17. Clavius, "In disciplinas mathematicas prolegomena," in *Opera mathematica*, vol. 1, p. 5: "Quoniam disciplinae Mathematicae de rebus agunt, quae absque ulla materia sensibili considerantur, quamvis reipsa materiae sint immersae; perspicuum est, eas medium inter Metaphysicum, & naturalem scientiam obtinere locum, si subiectum earum consideremus, ut recte à Proclo probatur, Metaphysices etenim subiectum ab omni est materia seiunctum, & re, & ratione: Physices vero subiectum & re, & ratione materiae sensibili est coniunctum: Unde cum subiectum Mathematicarum disciplinarum extra omnem materiam consideretur, quamvis re ipsa in ea reperiatur, liquido constat hoc medium esse inter alia duo." The career of this classification is examined in Weisheipl, "Classification of the Sciences" (1965); idem, "The Nature, Scope and Classification of the Sciences" (1978). On Clavius's arguments, see also Crombie, "Mathematics and Platonism in the Sixteenth-Century Italian Universities" (1977); see also Carugo and Crombie, "The Jesuits and Galileo's Ideas of Science and of Nature" (1983).

nothing occurs more frequently than that there are three parts of philosophy: physics, mathematics, and metaphysics."[18] Indeed, Clavius used the same scheme, on Ptolemy's authority, as a way of suggesting, not just the equality, but the preeminence of mathematics: "For he says that natural philosophy and metaphysics, if we consider their mode of demonstrating, are rather to be called conjectures than sciences, on account of the multitude and discrepancy of opinions."[19]

In his policy document of the 1580s Clavius had tried a similar ploy: mathematical knowledge was not only indispensable for the philosopher, but might be seen as the highest of all intellectual pursuits: "Since therefore the mathematical disciplines in fact require, delight in, and honor truth—so that they not only admit nothing that is false, but indeed also nothing that arises only with probability, and finally, they admit nothing that they do not confirm and strengthen by the most certain demonstrations—there can be no doubt that they must be conceded the first place among all the other sciences."[20] He regarded astronomy as the noblest of all, since it fulfilled Aristotle's criteria of excellence better than any other: it used the most certain demonstrations (those of geometry), while dealing with the most noble subject, the heavens.[21] Clavius was careful to choose criteria of assessment that would elevate his own field at the expense of natural philosophy.

Clavius handled the crucial objection that the mathematical disciplines were not scientific in a similar fashion, by sidestepping it. He chose to appeal to the authority of Aristotle rather than present any positive arguments of his own, relying on the explicit inclusion of the

18. Blancanus, *De mathematicarum natura dissertatio*, p.27: "apud Arist. & omnes peripateticos nihil frequentius occurrat, quam tres esse philosophiae partes, Physicam, Mathematicam, & Metaphysicam."

19. Clavius, "In sphaeram Ioannis de Sacro Bosco commentarius," in *Opera mathematica*, vol. 3, p. 4: "Ait enim philolophiam *[sic]* naturalem & Metaphysicam, si modum demonstrandi illarum spectemus, appellandas potius esse coniecturas, quàm scientias, propter multitudinem, & discrepantiam opinionum." Cf. Ptolemy, *Almagest* I.1; see the English translation by Toomer, *Ptolemy's Almagest* (1984), p. 36. De Pace, *Le matematiche e il mondo*, chap. 4, sect. 5, discusses the use of Ptolemy's arguments in favor of mathematics by Jacopo Mazzoni (and also Galileo); see also Drake, "Ptolemy, Galileo, and Scientific Method" (1978).

20. Clavius, "In disciplinas mathematicas prolegomena," in *Opera mathematica*, vol. 1, p. 5: "Cum igitur disciplinae Mathematicae veritatem adeo expetant, adament, excolantque, ut non solum nihil, quod sit falsum, verum etiam nihil, quod tantum probabile existat, nihil denique admittant, quod certissimis demonstrationibus non confirment, corroborentque, dubium esse non potest, quin eis primus locus inter alias scientias omnes sit concedendus."

21. Clavius, "In sphaeram Ioannis de Sacro Bosco commentarius," in *Opera mathematica*, vol. 3, p. 3.

mathematical disciplines within the domain of Aristotle's general model of an ideal science. According to Aristotle, sciences should be founded on their own unique, proper principles, which provided the major premises for deductive, syllogistic demonstration. Subject matters were therefore strictly segregated to their appropriate sciences, a logical necessity expressed in the methodological rule of homogeneity. Homogeneity required that the principles of a science concern the same genus as its objects, so as to ensure the possibility of a deductive link between them. But disciplines such as astronomy and music clearly violated this rule because they drew on the results of pure mathematics (divided into arithmetic and geometry) so as to apply them to something else, namely celestial motions and sounds. Accordingly, Aristotle made a special accommodation for such subjects by classifying them as sciences *subordinate* to higher disciplines.[22] They were later represented in the quadrivium by astronomy and music (these two standing for a host of others, such as geography and mechanics), and came to be known variously as "subordinate," "middle," or "mixed" sciences.[23] Aristotle's was in some ways an ad hoc solution to the classificatory problem, and it provoked later scholastic discussions, particularly among the Jesuits, on whether demonstrations in a subject such as optics yielded true scientific knowledge if the presupposed theorems of geometry were not proved at the same time.[24] The approach served Clavius's purpose perfectly well, however, because the very attempt to fit the applied disciplines into a general model for a science made clear Aristotle's acceptance of the scientific status of all the mathematical disciplines.[25]

22. See, for valuable discussions, McKirahan, "Aristotle's Subordinate Sciences" (1978); Lennox, "Aristotle, Galileo, and 'Mixed Sciences'" (1986); see also McKirahan, *Principles and Proofs* (1992). Two central sources are Aristotle, *Posterior Analytics* I.7; Aristotle, *Metaphysics* XIII.3 (esp. 1078a14–17).

23. Jesuit discussions include Clavius, "In disciplinas mathematicas prolegomena," pp. 3–4; Blancanus, *De mathematicarum natura dissertatio*, pp. 29–31. See for a useful discussion Laird, "The *Scientiae mediae*" (1983), esp. chap. 8 on Zabarella. Not all "subordinate sciences" were mathematical.

24. See Wallace, *Galileo and His Sources*, p. 134.

25. I refer to the "mixed" mathematical disciplines as "applied" in a somewhat loose, but not altogether misleading, sense: Daston, *Classical Probability in the Enlightenment* (1988), esp. pp. 53–56, maintains that in the eighteenth century mixed mathematics had a character that dwarfed in importance and stature so-called pure mathematics, and that it was not a simple matter of "applying" prepackaged pure mathematics to concrete objects. However that may be, the Aristotelian conceptualization still dominant in the seventeenth century emphasized the subordination of mixed to pure mathematics, and seems clearly different from Daston's portrayal of probability as a mixed mathematical discipline in the following century.

Clavius could therefore present mathematics as genuinely scientific without engaging the tricky question of causes. He said of the mathematical disciplines that "they alone preserve the way and procedure of a science. For they always proceed from particular foreknown principles to the conclusions to be demonstrated, which is the proper duty and office of a doctrine or discipline, as Aristotle, *Posterior Analytics* I, also testifies."[26] He thus kept the issue on a purely methodological plane. In 1615, however, Blancanus tackled the question of causes directly, in a text entitled *De mathematicarum natura dissertatio*. Employing the standard Aristotelian classification of causes into material, efficient, formal, and final, he argued that demonstrations in geometry utilized formal and material causes, since geometry specified both the essences of geometrical objects and their "matter," quantity.[27] Blancanus even made the argument that geometrical optics could provide final causes in the study of the physiology of the eye, in that it explained why the eye needs to be more or less spherical.[28] Blancanus's lengthy apology for mathematics seems to have become well known in the seventeenth century; it was, for example, drawn upon heavily in a similar discussion by another Jesuit, Hugo Sempilius (Hugh Sempill), as part of his own treatise on the mathematical disciplines.[29]

The extent to which Blancanus himself simply followed a path already trodden by Jesuit mathematicians, however, appears clearly in the introductory material to a master of arts dissertation defended by a student of the Jesuit astronomer and optician Christopher Scheiner at Ingolstadt in 1614. The opening section is headed: "De praestantia, necessitate et utilitate mathematicae," and consists largely of lengthy quotation from Possevino on the value of mathematics for understanding Plato and Aristotle and its use in a number of practical arts. The flavor is exactly that found in Clavius's and Blancanus's writings on the subject; Clavius's own "De utilitate Astronomiae" from his commentary on *De sphaera* is dutifully acknowledged.[30] There follows material on the scientific status of mathematics and the proper objects of its various branches: "Mathematics demonstrates its conclusions scientifically, by axioms, definitions, postulates, and suppositions; whence it is clear that it is truly called a science."[31] A pamphlet of mathematical propositions intended for an academic festival at the French Jesuit college of Pont-à-Mousson in 1622 stressed the same familiar points about the "nature of mathematics," affirming the mathematical disciplines as sciences.[32]

Such discussions by Blancanus and other Jesuit mathematicians of the period served to reinforce Clavius's Aristotelian description of the logical structure of the mathematical disciplines, and they highlight the importance that the Jesuit mathematical tradition stemming from Clavius attached to maintaining the scientific status of mathematical knowledge. It is important to stress that the issue went beyond the mere making of a few apologetic remarks at the beginning of a treatise before proceeding to the real content. The usual, and most effective approach was to carry on as if the mathematical discipline in question were obviously and unproblematically a science. The Euclidean theorem form provided a structure already conformable to the ideal of scientific demonstration because it had been Aristotle's own model for

26. Clavius, "In disciplinas mathematicas prolegomena," p. 3: ". . . solae modum rationemque scientiae retineant. Procedunt enim, semper ex praecognitis quibusdam principijs ad conclusiones demonstrandas, quod proprium est munus, atque officium doctrinae sive disciplinae, ut & Aristoteles I.posteriorum testatur." Clavius had commenced this passage by showing that the etymological derivation of "mathematics" linked it to the meanings of "discipline" or "doctrine." He refers to the question of causes, but only in passing, in "Modus," p. 473.

27. Blancanus, *De mathematicarum natura dissertatio*, pp. 7–10. A convenient summary of his discussion may be found in Wallace, *Galileo and His Sources*, pp. 142–143.

28. Blancanus, *De mathematicarum natura dissertatio*, p. 30; pp. 29–31 are on the "middle sciences" in general, presented with the observation that they of course give causal demonstrations, and citing Aristotle to support this characterization. On the shape of the eye, cf. Cabeo, *In quatuor libros Meteorologicorum Aristotelis commentaria* (1646), Lib. III, p. 186 col. 2.

29. Sempilius, *De mathematicis disciplinis libri duodecim* (1635). See Lib. I, pp. 1–20, on the nobility of the mathematical sciences; Lib. II covers another standard topic familiar from Clavius, "De utilitate scientiarum Mathematicarum," pp. 21–53. For more extended accounts of Blancanus's arguments, see Galluzzi, "Il 'Platonismo' del tardo Cinquecento," esp. pp. 56–65; Giacobbe, "Epigone nel Seicento della 'Quaestio de certitudine mathematicarum': Giuseppe Biancani" (1976); Wallace, *Galileo and His Sources*, pp. 141–144. For additional material on Blancanus, see Baldini, *Legem impone subactis*, passim and chap. 6, a new version of idem, "Additamenta Galilaeana: I" (1984); and Sommervogel, *Bibliothèque de la Compagnie de Jésus*, s.v. "Biancani." Isaac Barrow mentions Blancanus's discussion in his *Mathematical Lectures* (although not approvingly on the specific point at issue): Barrow, *The Mathematical Works* (1860/1973), p. 84.

30. Scheiner, *Disquisitiones mathematicae* (1614), pp. 6–11. This text was evidently written by Scheiner for the student to defend—a common practice in this period. Scheiner sent a copy to Galileo in 1615: Galileo, *Opere*, 12:137–138. Its ninety pages of text include such items as nine diagrams of the positions of Jupiter's satellites at various times in 1612, 1613, and 1614 (p. 79). For the attribution (certain from internal evidence), see Sommervogel, *Bibliothèque de la Compagnie de Jésus*, vol. 7, p. 737 col. 1.

31. Scheiner, *Disquisitiones mathematicae*, pp. 12–15, quote on p. 14: "Mathematica conclusiones suas demonstrat scientificè, per Axiomata, per definitiones, postulata & suppositiones. Unde patet ipsam verè dictam scientiam esse."

32. *Selectae propositiones* (1622), p. 1.

a science.[33] Its mere employment therefore went a long way towards bestowing upon its subject matter the mantle of "science." The difficulties lay in persuading the subject matter to fit the formal structure.

The certainty and necessity of the conclusions in an Aristotelian scientific demonstration were rooted in the premises: it was easy to construct a formally valid syllogism, but hard to invent premises with the right properties. Clavius outlined the problem, for which Aristotle's *Posterior Analytics* was the locus classicus, in the "Prolegomena" to his edition of Euclid:

> While every doctrine, and every discipline, is produced from preexisting knowledge, as Aristotle says, and demonstrates its conclusions from particular assumed and conceded principles, yet no science, according to the opinion of Aristotle and other philosophers, demonstrates its own principles; the mathematical disciplines certainly will have their principles, from which, posited and conceded, they confirm their problems and theorems.[34]

But if a science could not confirm its own principles, how were those principles, on which the certainty of the science depended, to be established?

The ideal was to have principles, or premises, that were *evident* and therefore immediately conceded by all. In the case of geometry, Euclid's "common opinions"—what Aristotle called "axioms"—represent the concept precisely: statements such as "the whole is greater than its proper part," or "if equals are subtracted from equals, the remainders are equal."[35] From a practical standpoint, empirical principles concerning the natural world could be made evident in a similar way, just as (for Aristotle) geometrical axioms themselves ultimately

33. Lloyd, *Magic, Reason and Experience* (1979), chap. 2, discusses these matters at length. Giacobbe, *Alle radici della rivoluzione scientifica rinascimentale*, pp. 22–23, notes Aristotle's incorporation of mathematical argument into his scientific methodology while characterizing it as ineffective because fundamentally illustrative. The same could, of course, be said of Aristotle's presentation as a whole in the *Posterior Analytics;* the text is not intended as an instrument of research.

34. Clavius, "In disciplinas mathematicas prolegomena," p. 9: "Cum omnis doctrina, omnisque disciplina ex praeexistente gignatur cognitione, ut auctor est Aristoteles, atque ex assumptis, & concessis quibusdam principijs suas demonstret conclusiones; Nulla autem scientia ex eiusdem Aristotelis, aliorumque Philosophorum sententia sua principia demonstret; habebunt utique & Mathematicae disciplinae sua principia, ex quibus positis, & concessis sua problemata ac theoremata confirment." This passage also serves to place the mixed mathematical sciences on a par with all other sciences, despite their assumption of results from other disciplines, by stressing that *all* principles in *all* sciences are ultimately just conceded.

35. See Lloyd, *Magic, Reason and Experience*, esp. p. 111.

derived from the senses: they would be evident if everyone agreed on their truth and judged argument to be unnecessary in the establishment of that agreement. Experiential statements, therefore, could not play a role in scientific discourse unless they were universal; if they were not, they could never be evident. Formal universality did not in itself establish an experience as "evident," of course; the experience had to express, and derive from, the perennial lessons of the senses.[36]

The classical mixed mathematical sciences appealed to just such empirical principles. The basic empirical premise of the mathematical science of optics, for example, held that light rays (or visual rays) travel in straight lines in homogeneous media. This counted as evident because everyone knew, from common experience, that you can't see around corners.[37] The foundational catoptrical works of Euclid and Ptolemy represent attempts at developing a complete science on such a basis: they present the principle that asserts equality of the angles of incidence and reflection so as to make it appear a necessary corollary of everyday visual experience.[38] The geometrically elaborated axioms of Archimedes' mechanical works were also chosen for their immediate acceptability by all reasonable people: Postulate 1 of *On the Equilibrium of Planes* states that "equal weights at equal distances [from the fulcrum] are in equilibrium, and equal weights at unequal distances are not in equilibrium but incline towards the weight which is at the greater distance."[39]

The one glaring scientific deficiency of such principles was that they fell short of the strict Aristotelian ideal by lacking any obvious *necessity*. This, however, seems to have been ignored by the Jesuit mathematical apologists, no doubt because it could not in its own terms be remedied. Necessity could accrue to empirical statements in physics, on

36. A celebrated example is Aristotle's observation that bees appear to reproduce parthenogenetically: Aristotle held his opinion to be open to correction by subsequent experience. Aristotle, *History of Animals* IX.42.

37. The object was to employ principles that were *per se nota*, that is, that were known without recourse to anything else. On the rectilinear propagation of light in antiquity see Lindberg, *Theories of Vision* (1976), pp. 12, 220 n. 79. For an interesting discussion of this principle that shows how much is taken for granted in seeing it as "self-evident," see Toulmin, *The Philosophy of Science* (1953), pp. 17–30.

38. Schramm, "Steps Towards the Idea of Function" (1965), pp. 71–73; note also, however, the difference between Euclid and Ptolemy—Ptolemy is more conscientious about establishing his foundational suppositions. See also Omar, *Ibn al-Haytham's "Optics"* (1977), chap. 1, esp. pp. 17–36.

39. Archimedes, "On the Equilibrium of Planes," Book I, in Heath, *The Works of Archimedes* (1953), p. 189. Archimedes' use of "postulate" is slightly odd in relation to the usual uses of that term as discussed by Proclus; on this point see Dijksterhuis, *Archimedes* (1987), chap. 9, esp. pp. 296–298.

the other hand, owing to the alleged possibility of grasping essences: propositions such as "man is a rational animal," once established, were necessarily true by definition. Actually establishing them was another matter, one that fueled the sixteenth-century methodological discussions concerning the demonstrative regress; the mathematicians kept clear of such niceties.[40]

Mathematical scientists in the early seventeenth century, then, looked to these Aristotelian and other classical sources as their disciplinary models. Jesuits, and those touched by the Jesuit approach, were particularly prone to see these issues through Aristotelian methodological spectacles. Galileo's empirical work on falling bodies, for example, was aimed at finding principles for his "new science of motion" that would imitate the Archimedean model of a mathematical science by commanding immediate assent: it was not aimed at uncovering recondite facts accessible only through elaborate experimental procedures. Galileo saw the construction of a mathematical science of nature in terms of classical mixed mathematics as defined by Aristotle.[41] His attempts to render evident the principles of the "new science of motion" illustrate very neatly the scholastic-Aristotelian concept of experience reflected in the traditional mathematical sciences. To be fully adequate, empirical premises needed to command assent because they were evident, not because particular events were adduced in their support. This was not experimental science in its modern acceptation.

"Experience" in scholastic natural philosophy and mathematics, therefore, in keeping with these criteria for scientific knowledge, typically took the form of universal statements because singular statements, statements of particular events, are not evident and indubitable, but rely on fallible historical reports. The Aristotelian model of a science adopted by the Jesuits took scientific knowledge to be fundamentally public: scientific demonstration invoked necessary connections between terms formulated in principles that commanded universal assent. Singular experiences were not public, but known only to a privileged few; consequently, they were not suitable elements of scientific discussion. Franciscus Aguilonius expressed clearly the Aristotelian perspective of the Jesuits in his 1613 treatise on optics:

> For a single [sensory] act does not greatly aid in the establishment of sciences and the settlement of common notions, since error can exist which lies hidden for a single act. But if [the act] is repeated time and again, it strengthens the judgment of truth until finally [that judgment] passes into common assent; whence afterwards [the resulting common notions] are put together, through reasoning, as the first principles of a science.[42]

40. On the demonstrative regress, see chapter 1, section IV, above.

41. This last point is made strongly by Machamer, "Galileo and the Causes" (1978). See chapter 5, below, for a more extended examination of Galileo on these questions.

Aguilonius's remarks clearly appeal to Aristotle's definition of "experience" in the *Posterior Analytics:* "from perception there comes memory . . . and from memory (when it occurs often in connection with the same thing), experience; for memories that are many in number form a single experience."[43] For Aguilonius, then, multiple repetition is essential to creating a proper scientific experience. It guarantees avoidance of accidental deception by the senses or the unfortunate choice of an atypical instance, and ensures a reliable statement of how nature behaves "always or for the most part," as Aristotle put it.[44] The result is experience adequate for the establishment of the empirical "common notions" that form the basis of a science.

The conception that Aguilonius here presents can, perhaps, best be explicated by a contrast with the modern hypothetico-deductive view of scientific procedure. Some version of the latter, whether confirmationist or falsificationist, would place experience, at least as regards its formal justificatory role, at the *end* of a logical structure of deduction from an initial hypothesis: the hypothesis yields conclusions regarding observable behavior in the world, and experiment or observation then steps in to confirm or falsify these predictions—and hence, in a logically mediated way, to confirm or falsify the original hypothesis itself.[45] A methodological Aristotelian, however, approached these issues in a quite different fashion. Since the point of Aristotelian scientific demonstration was to derive conclusions deductively from premises that were already accepted as certain—as with those of Euclidean geometry—there was no question of testing the conclusions against experience. The proper role for experience was to ground the assertions contained in the original premises, as Aguilonius assumed. Once they had been established, so too, from an empirical standpoint, had the conclusions potentially deducible from them.

42. Aguilonius, *Opticorum libri sex* (1613), pp. 215–216: "Non enim ad scientiarum primordia, communiumque notionum constitutionem, unicus actus magnopere iuvat; siquidem error huic subesse potest, qui lateat, at saepè ac saepiùs repetitus iudicium veritatis corroborat, quousque tandem in communem assensum transeat. unde *[sic]* posteà velut ex primis principiis scientiae per ratiocinationem colliguntur."

43. Aristotle, *Posterior Analytics* II.19, trans. Jonathan Barnes in Aristotle, *The Complete Works* (1984); see chapter 1, section III, above.

44. Aristotle, *Metaphysics* VI.2.

45. Classic expositions of variants of this picture are Nagel, *The Structure of Science* (1961); Popper, *The Logic of Scientific Discovery* (1959).

Jesuit philosophers required that a science fulfill a scholastic-Aristotelian conception of experience.[46] The insistence of the Jesuit mathematical school upon the scientific status of their own disciplines therefore obliged them to use only evident and manifestly universal empirical propositions. However, elements of the mathematical sciences themselves as they had been practiced since antiquity demanded that special accommodations be made in the strict Aristotelian framework.

II. Astronomy, Optics, and Expertise

The peculiarities of observational data in astronomy did not intrude themselves into considerations of the scientific role of experience so long as astronomy was regarded as a specialized mathematical discipline concerned with models for the computation of tables.[47] However, by emphasizing that mathematics was a part of philosophy, and by going so far as to promote astronomy itself to the position of a preeminent science, Clavius drew direct attention to its methodological form.

Mathematical, positional astronomy provided potential anomalies for an orthodox scholastic-Aristotelian view of the place of experience in a science. To accord with the formal model of a science, the empirical premises used in astronomical demonstrations would have to take the form of universal statements about how things are or behave in the heavens. In practice, however, astronomy employed data that consisted of discrete observations made at particular times and places with the aid of instruments. Thus astronomical phenomena were clearly not all known through common experience; they were not all, in that sense, *evident*. Precession of the equinoxes, for example, was a phenomenon that could only be constructed from discrete data collected over long periods of time.

Clavius, in keeping with his tendency to avoid head-on confrontations with methodological questions, left the matter alone; his use of

46. The ways in which Jesuit philosophers discharged their adherence to Thomism is discussed in Feldhay, "Knowledge and Salvation in Jesuit Culture" (1987).

47. Robert S. Westman has drawn attention to the importance of the disciplinary division between astronomy and natural philosophy in the sixteenth century. See especially Westman, "The Melanchthon Circle" (1975); idem, "The Astronomer's Role in the Sixteenth Century" (1980). See also the important essay by N. Jardine, "The Status of Astronomy," chap. 7 of his *The Birth of History and Philosophy of Science.* Paul Oskar Kristeller made some extremely prescient remarks on this matter in an essay originally published in 1950, "Humanism and Scholasticism in the Italian Renaissance" (1961), on pp. 118–119.

the word "experience" when discussing astronomy, however, while retaining the usual scholastic sense, hints at the complications in its function created by the role of singular experiences in astronomical practice. Regarding questions to do with the rotation of the heavens and precession, for example, Clavius concludes: "Wherefore faith is to be had in the experiences of astronomers, until something else is brought forward to the contrary by which it be demonstrated that what is propounded by astronomers concerning the motion of the stars from the west towards the east above the poles of the zodiac is not true."[48] The "experiences of astronomers" refers to their general accumulated experience in this matter rather than to a body of discrete observations, but the acknowledged possibility that "something else" could be "brought forward to the contrary" admits the practical dependence of astronomical doctrine on such observations. As with the problem of causality in mathematical demonstrations, a more explicit analysis of the role of experience in astronomy was left to Blancanus, in his *Sphaera mundi* of 1620.[49]

Sphaera mundi is an introduction to the elements of astronomy and cosmography that covers much the same ground as Clavius's commentary on *De sphaera.* Blancanus justified this apparent duplication in part by pointing out that the final edition of Clavius's work still failed to take into account the new telescopic discoveries.[50] His regard for the importance of telescopic observations indicates how the special features of astronomical practice could intrude into questions of scientific methodology: telescopic observations were produced by the use of special instrumentation not readily available to all. These "experiences" could certainly be expressed as universal statements—"Venus displays phases"; "the moon's surface appears rough"—but they lacked "evidentness" precisely because only telescopic observers were privy to them. There was thus a sense in which, for everyone else, they

48. Clavius, "In sphaeram Ioannis de Sacro Bosco commentarius," in *Opera mathematica,* vol. 3, p. 33: "Quare experientiis Astronomorum fides habenda est, donec in contrarium aliud quid afferatur, quo demonstretur, vera non esse, quae de motu stellarum ab occasu in ortum super polos Zodiaci traduntur ab Astronomis."

49. Blancanus, *Sphaera mundi* (1620).

50. Ibid., "Praefatio," 2d p.; cf. Clavius, "In sphaeram Ioannis de Sacro Bosco commentarius," in *Opera mathematica,* vol. 3, p. 75. For discussion of the meaning and reception of Clavius's remarks, see Lattis, "Christoph Clavius and the *Sphere* of Sacrobosco," pp. 282–285, 307–317. Clavius's remarks quickly became a standard point of reference: apart from the material in Lattis see, e.g., Scheiner, *Disquisitiones mathematicae,* pp. 50–51, quoting Clavius on the new demands that Galileo's discoveries have put on astronomers to save the phenomena.

stood *outside* the ordinary course of nature: this may be what Clavius had in mind when he called them "monsters."[51]

The key terms in the medieval and early-modern astronomical lexicon were *phaenomenon* and *observatio*, each corresponding to a Greek prototype found classically in Ptolemy's *Almagest*.[52] Ptolemy's usage was fairly straightforward: a phenomenon was any kind of appearance in the heavens, whether the path of a planet or an eclipse of the moon, and an observation was an act whereby a phenomenon became known through the senses.[53] Neither Ptolemy nor his successors had any methodological difficulties with this terminology, because they did not concern themselves with defending the scientific status of astronomical experience along Aristotelian lines. Since Blancanus did, however, his methodological orientation resulted in the presentation of a refined version of the two central Ptolemaic terms.

Following elementary material on the celestial sphere, *Sphaera mundi* gets under way with a section called "Sphaerae materialis et mundanae simul explicatio."[54] The section's opening chapter is headed "Suppositiones." This was a technical term that designated those things that, although not in themselves obvious (as were, in their different ways, definitions and axioms), needed to be accepted prior to the construction of a science. In the case of a subordinate science like astronomy, the results of the pure mathematical sciences on which it relied counted as *suppositiones* because, although they were demonstrable, they were not proved within the subordinate science itself. The Latin term *suppositio* was the equivalent of the Greek *hypothesis*, which was in turn Aristotle's word for the category found in Euclid as postulates.[55] Blancanus explains the suppositions used in astronomy:

51. See chapter 1, section II, above.

52. Pedersen, "Astronomy" (1978), is a general survey of medieval astronomy; the secondary literature in general tends to concentrate on either planetary models and tables or on instruments rather than on the interactions between instruments, data, and the process of modeling.

53. See, e.g., his usage in *Almagest* I.3, 4 (Toomer, *Ptolemy's Almagest*, pp. 38, 40). Cf. Joachim Jung's use of the same Greek term to designate "observation" in extra-astronomical contexts: above, chapter 1, n. 5.

54. Blancanus, *Sphaera mundi*, pp. 15 ff.

55. See on this Wallace, *Galileo and His Sources*, pp. 112–113, and, more fully, idem, *Galileo's Logic of Discovery and Proof* (1992), pp. 139–150. On postulates see Lloyd, *Reason, Magic and Experience*, chap. 2, and above, chapter 1. Blancanus seems to use *suppositio* somewhat less strictly than Paulus Vallius (Valla) in the material examined by Wallace. Baliani, *De motu naturali* (1646), p. 9, labels those principles underpinning his science of motion that are known through experience "suppositions," thereby distinguishing them from other "petitions" which, he says, serve construction, but are easy to do and understand and therefore require no explicit consideration. Cf. on suppositions Aristotle, *Posterior Analytics* I.10.

> Besides those things supposed by astronomy that it has received from outside, both from geometry and from arithmetic (as has been said in the apparatus at the beginning), it also supposes other principles and, so to speak, foundations intrinsic and proper to it, which are indeed of two kinds, for astronomers call some "Phenomena," or "Appearances," because they appear and are manifest to all, even the vulgar, such as: the rising and setting of the stars, moon, and sun; that all stars move from the east to the west; that the sun moves lower in winter and higher in summer; that the sun does not always ascend from the same place on the horizon; and many other things of that kind which we suppose as very well known to all.[56]

Blancanus, then, unlike Ptolemy, defines "phenomena" not simply as appearances in the heavens, but as appearances that are known generally—they are evident, a part of common experience. That is what one should expect of the empirical suppositions of a true science; that is how they are justified. Blancanus then designates his second kind of internal principle in astronomy using the other central Ptolemaic term, "τηρήσεις, that is, 'Observations'." These are "particular concepts, provided by experiments, which do not become known to all as appearances do, but only to those who apply themselves zealously to the science of the stars with diligent work and with instruments skillfully designed for the purpose."[57] This privileged knowledge includes such things as the apparent diameters of the sun and moon, and the retrogradations and speeds of the planets.[58] Blancanus's terminological distinction thus expresses a distinction in cognitive status: phenomena are evident, while observations are recondite, because while phenomena are more or less given in ordinary experience, only expert astronomers, using their special instruments, are privy to observations.

Blancanus's account of "observations" derives from Ptolemy's de-

56. Blancanus, *Sphaera mundi*, p. 15: "Praeter illa, quae extrinsecus accepta tam ex Geometria, quam ex Arithmetica, ut initio apparatus dictum est, supponit Astronomia; adhuc alia intrinseca, & sibi propria Principia, ac veluti fundamenta supponit, quae quidem duplicis sunt generis, alia enim appellant Astronomi Phaenomena, seu Apparentias, eò quod omnibus etiam vulgò appareant, ac manifesta sint, uti sunt; stellas, Lunam, & solem oriri, ac occidere: omnia sydera moveri ab Oriente in Occidentem: solem hyeme humilius incedere, aestate vero altius: non semper solem ex eodem horizontis loco ascendere: & alia id genus complura supponimus ceu cunctis notissima."

57. Ibid., pp. 15–16: "sunt autem cognitiones quaedam ab experimentis comparatae, quae non omnibus, uti apparentiae, innotescunt, sed ijs tantummodo, qui diligenti opera, atque instrumentis ad id artificiosè elaboratis, in stellarum scientiam naviter incumbunt."

58. Ibid., p. 16.

scription of his procedures in the *Almagest*.[59] Ptolemy used "observation" to refer to the gathering of discrete items of astronomical data rather than to the knowledge manufactured from them. Nonetheless, Ptolemy's account of the production, or construction, of a piece of astronomical knowledge from various sets of data accords exactly with Blancanus's description of the nature of an "observation": Ptolemy described how he had confirmed Hipparchus's belief that the stars within the zodiac maintain their positions relative to those outside it, thus showing precession to be common to all the stars. Hipparchus had formed his conclusion by comparing his positional data with those of earlier astronomers; Ptolemy then compared his own data with Hipparchus's in a similar fashion.[60]

The difference between "phenomena" and "observations" according to Blancanus is not one between universal and discrete experiences: both are experiences expressed as universal statements. An "observation," however, is a universal experience that has been explicitly constructed, using appropriate computational techniques, from discrete experiences, themselves the product of deliberate instrumental manipulation. "Phenomena," by contrast, are universal experiences that do not need to be explicitly constructed, and which therefore fit most closely the Aristotelian definition of an experience. Blancanus's treatment of "observations" as a distinct class of astronomical suppositions addressed the requirements of a genuine science: the privileged experiences of expert practitioners, they created severe difficulties for any attempt to fit astronomy to the Aristotelian model of a science, and therefore required special handling. For anyone not so wedded to an Aristotelian approach, astronomy could appear in a quite different light, as Tycho Brahe exemplifies.

For Tycho, astronomy was not an Aristotelian science. Instead, it was akin to the secret art of alchemy. Like alchemy, its knowledge was private, acquired through personal experience and endeavor. Astronomy/astrology on the one hand and alchemy on the other formed a common pursuit; the astrological linkages between planetary influences and the generation of metals and other minerals on the earth led Tycho to refer to alchemy as "terrestrial astronomy."[61] In 1598, prior to his move to Prague, he wrote regarding projected new astronomical

59. See Sabra, "The Astronomical Origin of Ibn al-Haytham's Concept of Experiment" (1971). The passage is Ptolemy, *Almagest* VII.1 (Toomer, *Ptolemy's Almagest*, pp. 321–322).

60. Sabra, "The Astronomical Origin of Ibn al-Haytham's Concept of Experiment," p. 134. On Ptolemy's use of observational data see also Lloyd, *Magic, Reason and Experience*, pp. 183–200.

61. See, e.g., Tycho Brahe, *Opera Omnia* (1972), V, p. 118; VI, p. 145; VII, p. 238.

instruments: "I shall hardly publish anything about these and similar matters that I have invented recently . . . nor about those that I shall invent in future. . . . But to distinguished and princely persons . . . shall I be willing to reveal and explain these matters when convinced of their gracious benevolence, but even then only on condition that they will not give them away."[62] Tycho's perception of his work as private was tempered only by his need for patronage. That astronomical practice lent itself so readily to such a view of knowledge indicates starkly the problems faced by Blancanus.

Jesuit work in others of the mixed mathematical sciences shows a similar concern with establishing and elucidating their methodological structure. Geometrical optics was at least as well established a discipline as astronomy, with a tradition that incorporated the texts of Euclid, Ptolemy, and Alhazen (Ibn al-Haytham). Together with Witelo's contributions in the thirteenth century, Alhazen's remained the major work on the subject at least until Kepler's *Ad Vitellionem paralipomena* of 1604.[63] In the second decade of the seventeenth century there appeared two optical works by Jesuits: the *Opticorum libri sex* of Franciscus Aguilonius in 1613 and Christopher Scheiner's *Oculus* in 1619.[64] Both involve the deliberate creation of instrumentally contrived experiences, something that had been a part of optical science since antiquity and was particularly prominent in Alhazen. Whereas in astronomical treatises the relationship between positional data and derived universal knowledge-statements could be characterized, as it was by Ptolemy, in terms of the comparison of data, optical practice placed a greater emphasis on the particular experiences themselves. Ptolemy's measurement of refraction bears an apparent similarity to astronomical measurements, but it is not typical of his usual approach to optics; furthermore, the data given appear to have been generated with the aid of a computational paradigm of second differences rather than by the bald measuring technique described by Ptolemy.[65] A. I. Sabra and S. B. Omar have each argued that it was Alhazen, not Ptolemy, who first incorporated the deliberate construction of empirical fact into op-

62. Ibid., V, p. 101, trans. adapted from Raeder, Stromgren, and Stromgren, *Tycho Brahe's Description of his Instruments* (1964), p. 101. See Christianson, "Tycho Brahe's German Treatise on the Comet of 1577" (1979); and especially Webster, *From Paracelsus to Newton* (1982), pp. 29–30; Hannaway, "Laboratory Design and the Aims of Science" (1986).

63. Lindberg, *Theories of Vision*, provides a thorough survey.

64. Aguilonius, *Opticorum libri sex;* Scheiner, *Oculus* (1619). Ziggelaar, *François de Aguilòn* (1983), part II, chaps. 1 and 2, examines the *Opticorum libri*. Further references on Scheiner may be found in Baldini, *Legem impone subactis*, p. 115 n. 107.

65. Smith, "Ptolemy's Search for a Law of Refraction" (1982).

tics and explicit optical methodology. As with astronomical data, Alhazen's optical experiences were constructed using special apparatus and were often quantitative.[66]

Alhazen did not employ the standard Arabic translation of the peripatetic (and Galenic) word *empeiria*, "experience." Instead, he used an Arabic astronomical term, one corresponding to Ptolemy's expression for a test or proof involving the comparison of distinct sets of data, akin to the example of Hipparchus and precession. This term, in its various forms, was rendered into Latin as *experimentum* or *experimentatio, experimentare*, and *experimentator*.[67] Alhazen's use of a word distinguished in meaning from the usual "experience" appears to have been deliberate. Sabra maintains that Alhazen's astronomical term retains the technical specificity of Ptolemy's concept of "test by comparison," and that he therefore intended just that notion.[68] Omar disagrees with Sabra, arguing that Alhazen meant "experiment" in the sense of a means of generating, not merely testing, hypotheses; in his support, Omar cites the way in which Alhazen's treatise develops its ideas in tandem with its described "experiments."[69] This interpretation seems doubtful, however: the presentation of material in a systematic treatise need bear little relation to any methodological "logic of discovery," and in any case such a procedure by Alhazen would be egregiously out of keeping with premodern ideals of science.

In fact, Alhazen's contrived experiences (called *experimenta* in the Latin translation) seldom correspond even to the astronomical usage to which Sabra etymologically traces them. Alhazen usually employs such an experience in order to show something to be the case, not to test a hypothesis or to derive sets of data for comparison. When discussing refraction between air and water (to choose a typical example), Alhazen provides, not a report of an attempted test of his claims, but instructions to the reader on how to experience the behavior he describes: "let him take a straight-sided vessel, such as a copper urn, or an earthenware jar, or something similar. . . ." Alhazen concludes by saying, "In this way, therefore, the passage of light through a body of water will be experienced."[70] The sense clearly indicates that the

66. Sabra, "The Astronomical Origin of Ibn al-Haytham's Concept of Experiment"; Omar, *Ibn al-Haytham's "Optics"*; see also Sabra, *The Optics of Ibn al-Haytham* (1989).

67. Sabra, "Astronomical Origin," esp. p. 133, referring to Risnerus, *Opticae thesaurus* (1572).

68. Sabra, "The Astronomical Origin of Ibn al-Haytham's Concept of Experiment," pp. 134–135.

69. Omar, *Ibn al-Haytham's "Optics,"* chap. 3, esp. p. 68.

70. Risnerus, *Opticae thesaurus*, pp. 233, 235: "Cum ergo experimentator voluerit experiri transitum luminis in aqua per hoc instrumentum: accipiet vas rectarum orarum, ut cadum cupreum, aut ollam figulinam, aut consimile . . ."; "Hac ergo via experi-

translation "experienced" rather than "tested" or "tried" is appropriate here: Alhazen has given a recipe allowing his reader to see what Alhazen himself already knows, not a protocol to provide the reader with an opportunity of checking his claims. The same point holds throughout. In introducing some theorems in catoptrics (to take another example at random), Alhazen remarks, "What we have said will be evident in spherical mirrors polished on the outside"—there is no sense of contingency about his assertions; he simply provides information about how things always happen.[71]

Although Alhazen used a special technical term, apparently drawn from astronomy, to designate an active production or construction of phenomena, he did not worry about the problems of casting optics as an Aristotelian science.[72] Methodologically, he saw himself within a properly optical tradition stemming from Euclid, who is his main source of references on such matters.[73] For Alhazen, contrived experiences were techniques; they did not constitute a cognitive category. Both Aguilonius and Scheiner, by contrast, wanted to establish optics as a science fulfilling Aristotelian canons: we have already quoted Aguilonius on the place of repeated trials in establishing empirical principles. However, Aguilonius gave no sign of seeing problems in the use of specially constructed experiences in scientific demonstration, despite his acknowledgment that, in his optical work, "I consider things intentionally altered by me," in addition to those provided by occasion.[74] Scheiner, the Ingolstadt astronomer and optician who became embroiled in a dispute with Galileo over sunspots,[75] was much more concerned with the implications of such an admission.

Scheiner begins his preface to the *Oculus* by categorizing optics in standard Aristotelian fashion, taking for granted its subordination to geometry.

mentabitur transitus lucis per corpus aquae." This was, of course, the version known to early seventeenth-century optical writers such as Kepler or the Jesuits.

71. Ibid., p. 126: "In speculis sphaericis extrà politis patebit quod diximus."

72. Smith, "Alhazen's Debt to Ptolemy's Optics" (1990), argues that Alhazen's characteristic mixing of mathematical, physical, and physiological concerns is no radical departure from the approach adopted by Ptolemy's *Optics*.

73. See, e.g., material in Risnerus, *Opticae thesaurus*, pp. 30–32. Rashed, "Optique géometrique et doctrine optique chez Ibn al Haytham" (1970), notes that Alhazen uses traditional optical terminology even while departing from Euclidean-Ptolemaic conceptions of the nature of optics.

74. Aguilonius, *Opticorum libri sex*, preface "Lectoris," 9th p.: "Consulto igitur consilio à me mutata res." Aguilonius often seems to follow Alhazen's view of optics, as in his stress on vision as an aspect of cognition—compare, e.g., ibid., preface "Lectoris," 1st p., and Book III *passim*, with Alhazen, book II, chap. 1, in Risnerus, *Opticae thesaurus*.

75. See chapter 4, below.

> Optics, truly and properly called a science,[76] has much distinct from, and much in common with, physics. Common are the object and the things foreknown. For both, as much physicists as opticians, are concerned with visible things and the organ of sight; however, in different ways. For geometry, as the Philosopher declares, 1.2. Phys.t.20. [*Physics* II.2], considers the physical line, but not insofar as it is [the physical line] of the physicist: optics, however, indeed considers the mathematical line, but not insofar as it is physical. They both [optics and physics] investigate the truth of the same thing, therefore, but in different ways.[77]

Both physics and optics, Scheiner continues, deal with those things which enter the senses:

> of which some, which come about naturally and are evident to everyone, and require only the attention of the sedulous investigator, are called "Phenomena" or appearances: others, which either do not occur or do not become evident without the industry of special empirics, are called "Experiences."[78]

Scheiner's dichotomy for optics matches Blancanus's for astronomy, with the slight difference that what Blancanus calls "observations" Scheiner calls "experiences." Scheiner's "experiences" need to be constructed by "special empirics," just as Blancanus's "observations" required the specialized work of astronomers. Since they would be couched in the form of universal statements (if only as conditionals), these optical "experiences" resemble Aristotle's general concept of "experience" sufficiently to allow Scheiner to invoke Aristotle's authority. Thus his description of the contents of Book I, Part II of the *Oculus* reads: "In the second part we bring forward experiences produced for the purpose, so that from them we might establish truth and rebut

76. Here a marginal reference to "Arist.I.Post.Text.30 & passim", as well as references to Pereira (an ironic choice), Villalpandus, and Blancanus's *De mathematicarum natura dissertatio.*

77. Scheiner, *Oculus,* "Praefatio," 1st p.: "Optice vera [reading as *Optica vere*] & proprie dicta scientia, multa seiuncta, multa cum Physicâ communia habet. Communia sunt obiectum & praecognita. Utrique enim tam Physici quam Optici circa visibilia, & organum visus versantur; modo tamen diverso. Geometria enim, teste Philosopho, 1.2. Phys.t.20. de Physica linea considerat, sed non quatenus est Physici: Perspectiva autem mathematicam quidem lineam, sed non quatenus Physica est. Veritatem ergo eiusdem rei ambo, sed viis diversis investigant."

78. Ibid.: "quorum alia quae ita contingunt ut naturâ fiant omnibusque obvia sint, solamque seduli speculatoris animadversionem requirant, Phaenomena, sive appariti-ones: alia quae absque peculiari Empyrici industriâ aut non fiunt aut non patescunt; Experientiae vocantur."

errors. For one true experience, the Philosopher [i.e., Aristotle] declares, is worth more than a thousand deceitful subtleties of underhand reasons."[79]

Not only were Scheiner's "experiences" such that without the "industry of special empirics" they would fail to become evident; without it they might not occur at all. Indeed, Scheiner planned in his treatise to "bring forward experiences produced for the purpose" to establish his arguments, a point he elaborates upon in part II of book I, entitled "Experientiae variae" (regarding the operation of the eye).

> This other part of the first book is occupied with putting forward and explaining various recondite and well-tried experiments, most diligently investigated with singular industry, tenacious labor, and much exertion, and faithfully brought into the light from the hidden treasury of nature, so that from these as it were foreknown, undoubted [starting points], it may be permitted finally to reach into the true throne of the visual power without obscurities.[80]

Like Aguilonius, Scheiner is concerned with establishing "undoubted" principles as premises for scientific demonstration. In that connection, he speaks of putting forward recondite *experimenta,* not *experientiae,* and the distinction is a functional one embodied in the structure of the presentation. Thus the subsequent text commences with chapter I, "Experientia Prima. Pupillae variatio."[81] This chapter contains three sections, each headed "Experimentum" and consisting of a set of instructions whereby an aspect of the variation in size of the pupil can be evinced. Most of the other chapters in this part of *Oculus* are also labeled as *experientiae;* they deal with a number of matters apart from pupil size, such as the effect of different degrees of illumination on the apparent size of objects. Only the first chapter is broken down into sections explicitly labeled *experimentum,* but the other chapters that bear the heading *experientia* follow the same form, being composed of so-called *experimenta* similar in nature to those of Alhazen (Scheiner is in general covering material quite similar to Alhazen's). They are

79. Ibid., p. 1: "Parte secunda experientias pro re nata adferimus: ut ex illis veritatem stabiliamus, refellamus errores. Una enim vera experientia, Philosopho teste, plus valet, quam mille rationum subdolarum fallaces argutiae."

80. Ibid., p. 29: "Occupatur haec libri primi pars altera, in proponendis atque explicandis variis, reconditis, probatisque experimentis, singulari industria, labore pertinaci, sudore plurimo diligentissimè investigatis, atque ex abditis naturae thesauris in lucem fideliter protractis, ut ex ijs tanquam praecognitis indubitatis in verum Visiuae [*sic*] potentiae thronum absque ambagibus devenire tandem liceat."

81. Ibid., pp. 29–32.

presented in the form of instructions or in the form of a geometrical constructional problem (typically commencing "Sit . . . ").[82]

Scheiner's terminology is, therefore, quite clear: an "experience" is sensory knowledge about an aspect of the world which must be deliberately brought into being, or constructed. It is expressed as a universal statement, thereby corresponding to Aristotle's definition and so fit for use in scientific demonstration. An "experiment," by contrast, is a particular procedure whereby the experience may be instantiated. Thus the experiments are the *means* by which an experience is constructed; one can come into possession of the experience that the pupil contracts when exposed to bright light by performing a number of different experiments that contribute to its formation.[83] Blancanus had similarly described his universal "observations" as "particular concepts, provided by experiments," the latter here being instrumentally manufactured pieces of astronomical data. The contrast with Scheiner's other category, "phenomena," again as with Blancanus's, is that the individual instances constituting phenomena are not codified or made explicit, because they are presented routinely by nature.[84]

At the beginning of book I, part I, Scheiner had considered "the necessity of anatomical inspection concerning the eye." That necessity arose, he explained, from the requirement for firm premises on which to build optical science. As Clavius had said, every science demonstrates its conclusions from "particular assumed and conceded principles," but no science "demonstrates its own principles."[85] Scheiner needed, therefore, to justify his principles through experience, and that justification would, strictly speaking, be *outside* the science itself. He writes, "For our purpose it is not so much phenomena that are foreknown as singular experiments *[experimenta]* derived from study. They

82. Material running up to ibid., p. 52.

83. This terminological distinction, apparently quite consistently applied in the headings under consideration here, is not otherwise fully consistent even for Scheiner himself, however; to find the word *experimentum* where one might expect *experientia* is not uncommon in this work. A striking example appears in Scheiner's *Disquisitiones mathematicae* of 1614, where an item headed "De luce Solis, Experientia notabilis" (p. 72) appears, followed by another, "De igne Experimentum" (p. 74). These two items describe almost identical procedures, each given in universalized terms, involving the spreading out of light passed through holes; nonetheless, one is called *Experientia*, the other *Experimentum*.

84. There is another contrast with Aguilonius here, who, in dealing with this same question, adduces the way in which the pupil is known to dilate habitually in the gloom so as to admit more light and vice versa. He considers it necessary only to refer to common experience, not to formulate discrete, artificial procedures. Aguilonius, *Opticorum libri sex*, pp. 19–20.

85. See above, text to n. 34.

are of two kinds; one from inspection of the eye, the other selected from consideration of appearances diffused out from observable things into the eye. We will gather something from both."[86] What Scheiner calls *experimenta* are not necessarily artificial contrivances; the word refers equally to simple anatomical inspection. It should not, therefore, be confused too readily with the modern English "experiment," since *experimentum* in Scheiner's usage means, as we have seen, those items of empirical knowledge that go to make up a universal generalization—an authenticated experience that can act as a scientific principle. The two parts of Scheiner's book I detail such a procedure for experiences to do both with the eye and with reflection and refraction, making them available as principles for use in properly scientific demonstrations. In book II, the newly established principles are turned to account: propositions are demonstrated on the foundations of the experiences previously constructed. For example, demonstrations concerning the refraction of light at the surface of the cornea involve such forms as these: "Demonstratio II. Per Experientiam citati Capitis 8"; "Demonstratio III. Sumitur ex Experientia 4.c.4.p.2.1.1"; "Demonstratio IV. Obvia est ex Experientia 8. Capite II allata."[87] The experiential roots of the science of optics remain constantly on view.

Thus Scheiner distinguished constructed "experiences," which required the work of "special empirics," from the evident "phenomena" that ought to have been sufficient in an ideal Aristotelian universe but were not in the real one, just as Blancanus distinguished between constructed "observations" and evident "phenomena." Furthermore, Scheiner's "experiences" were constructed from "experiments" just as Blancanus's "observations" were made from "experiments" in a way that echoed the conceptualization (and corresponding attributed Latin terminology) of Alhazen.

At the end of the century, Étienne Chauvin's *Lexicon philosophicum* (1692 and 1713), under the heading "Experientia," displayed a similar distinction as one that had evidently by then become a commonplace. Experience, he says, holds a place among physical principles second

86. Scheiner, *Oculus*, p. 1: "Praecognita ad institutum nostrum non tam sunt Phaenomena, quam experimenta singulari studio hausta, eaque duplicis generis; altera ex oculi inspectione; altera e specierum a rebus aspectabilibus in oculum diffusarum consideratione desumpta. De ambobus nonnulla delibabimus." Things "foreknown" (*praecognita*), like *suppositiones*, need to be accepted by a science at the outset, prior to the production of scientific demonstrations; however, unlike *suppositiones* as a general category, this term implies consideration of the grounds on which they are accepted. See Wallace, *Galileo's Logic of Discovery and Proof*, pp. 149–150.

87. Scheiner, *Oculus*, p. 79.

only to reason, "for reason without experience is like a ship tossing about without a helmsman." There are three kinds: the first is the experience that is acquired unintentionally in the course of life; the second is the kind gained from deliberate examination of something but without any expectation of what might happen; and the third is experience acquired deliberately so as to determine the truth or falsity of a conjectured cause *(ratio)*. The second and third are the most useful philosophically, especially the third, which determines straightaway the truth or falsity of an opinion.[88] He proceeds to elaborate on what characterizes a properly philosophical experience: it should be based on *experiments (experimenta)*, of varying kinds and of considerable number, since "those err the most who refer the whole basis of their philosophizing to a few experiments over which perhaps they have reflected studiously," chemists being Chauvin's prime example.[89] Furthermore, such experiments should encompass mechanical artifice as well as natural history. Thus an experience is made from numerous experiments, as a kind of hybrid of the new and the old—it is experiments that stand for the Aristotelian "many memories of the same thing," as Scheiner and Blancanus had exemplified near the century's beginning.[90]

III. Recipes and *Problemata*

Jesuit mathematicians, then, formulated and tried to codify the methodological problems involved in making the mixed mathematical disciplines into genuine Aristotelian sciences. The central problem—that of establishing the principles from which scientific demonstrations could proceed—admitted a welcome degree of flexibility. The principles of a true science had to be evident and acceptable as true, but the means by which that acceptability should be established fell outside the formal procedures discussed in the *Posterior Analytics*. There were some restrictions, in that principles should be primitive and indemonstrable (with the special provisions for subordinate sciences and their borrowed suppositions providing a partial exception); otherwise, if a purported empirical principle could be made evident, however that might in practice be accomplished, then it was fit for use in scien-

88. Chauvin, *Lexicon Philosophicum* (1713/1967), p. 229 col. 2: "est enim ratio sine experientiâ velut navis sine rectore fluctuans."

89. Ibid., p. 230 col. 1: "ut illi maximè fallantur, qui ad pauca experimenta, in quibus forsan studiosè versati sint, omnem philosophandi rationem revocant." Francis Bacon had criticized such people as William Gilbert for doing just this, in Gilbert's case building a philosophy from magnetism: Bacon, *Novum organum* 1, aph. 54.

90. And cf. chapter 1, section III, above.

tific demonstration. The very imprecision of Aristotle's talk of "induction" indicates the wealth of possibilities open to those who sought new ways of grounding a science of nature.

The classifications used by Blancanus and Scheiner allowed that certain kinds of supposition were only truly evident to specialized investigators operating with tools designed for the purpose. In the purely pedagogical context such suppositions might be treated as *petitiones*, premises voluntarily granted on the word of the teacher, but such a recourse was inadequate to establish scientific status.[91] This was empirical knowledge that depended on the diligence and expertise of observers and experimenters, with their specialized instruments and skills; it was not a straightforward matter for others to reproduce for themselves the experiences claimed by astronomers or opticians. How could "experiences" be established as common property if most people lacked direct access to them?

A partial solution to the difficulty was to present the material from which the "experience" itself was formulated, although this of course only set the problem back a stage. Blancanus described his astronomical "observations" as being provided by "experiments"—that is, developed from the comparison of observational data on the positions of celestial bodies. Thus the presentation of the observational data itself could render more credible the observations resting upon them. Astronomical tables were also equivalent to observations, to the extent that they derived from predictive models that themselves depended on observational data. They could thus serve a similar purpose: the gradual realization of the tables' predictions provided a continuing opportunity for experiencing the planetary motions embodied in the models.[92] In optics, Scheiner similarly used experiments as the underpinnings of his scientific experiences, allowing the detailed description of experiments—accounts of what happens when certain situations are created—to render more immediate the properties of nature purportedly determined by them.

A common technique in optics for rendering an experiment immediate was, as we have seen, to present it in the form of a recipe. The reader is instructed to perform a series of operations and then told what outcome will result, or else (more revealingly) the series of operations is presented in the subjunctive mood of a geometrical *problema*.[93]

91. On *petitiones*, see Wallace, *Galileo and His Sources*, p. 113.

92. Cf. chapter 4, section I, below, for more on this point.

93. Cf. above, text to n. 82.

This literary device afforded to experiential claims a status that transcended what appears to us as an obvious difference between geometrical constructions and novel empirical findings: the latter's unpredictability. A geometrical construction is transparent, because in following its steps one sees the outcome generated inevitably before one's eyes; even recourse to compass and ruler is unnecessary. To render evident the proper result of a contrived empirical situation, by contrast, one would need to manipulate specialized apparatus with appropriate skill. However, the geometrical literary structure did in fact serve to accord a sort of transferred transparency to described experimental procedures. Procedure and outcome appeared formally inseparable: optical experiments, for example, detailed procedures for generating those conditions under which particular effects would be manifest—such as a specific change in the apparent position of a pointer in refraction. As constructional techniques, empirical descriptions were justified by their intended outcomes; there appeared to be no question of the outcome differing from the one presented. Just as constructions in geometry were generated from postulates that expressed conceded possibilities, so the use of a geometrical paradigm served to re-create unfamiliar experience by generating it from familiar experience—that is, easily picturable operations.[94] Steven Shapin has described the reading of Robert Boyle's detailed experimental narratives as "virtual witnessing";[95] a broadly similar characterization applies here, but with one crucial qualification. There is indeed a real difference between geometrical construction and novel empirical outcome, but these contrived situations were not intended to appear *novel.*

Indeed, the avoidance of apparent novelty, and hence disputability, in the presentation of empirical suppositions even allowed Aguilonius, in his work on vision, to dispense with the kind of detailed protocols that Scheiner provided.[96] By the same token, Blancanus described the use of an apparatus to show the rarefaction and condensation of the air that was eminently presentable precisely because it was not crucial. He notes that although this behavior of air "is established by many experiences" (which he regards as unnecessary to recount), "it is however agreeable to bring forward now a more beautiful as well as most evident one: let a glass flask be constructed, as you see in the figure,"

94. See, for more on this point in regard to mathematical postulates, chapter 8, section II, below.

95. Shapin, "Pump and Circumstance" (1984); see also Shapin and Schaffer, *Leviathan and the Air-Pump* (1985), chap. 2.

96. Cf. n. 84, above.

and so forth.[97] If claimed results were neither especially surprising nor overly recondite, inherent plausibility reinforced the persuasive effect of the overall presentation. The efficacy of this technique was enhanced if no controversial issue rested on the claimed results: as long as not too much rested on any particular procedure, the geometrical form sufficed.

Jesuit mathematicians in the early seventeenth century, then, employed techniques designed to incorporate recondite, constructed experiences into properly accredited knowledge about the natural world. The norms of scientific procedure to which they adhered derived from the Aristotelian model employed by Jesuit natural philosophers and logicians, and their incentive was the attempt, initiated by Clavius, to raise the status of the mathematical disciplines and their practitioners in the Jesuit academic system. The traditions of practice in astronomy and optics had exploited particular ways of generating and using experiential data, ways that created problems for the characterization and presentation of those subjects as sciences according to Jesuit philosophical criteria. Blancanus and Scheiner make clear the point that much of the experiential basis of astronomy and of optics was manufactured by expert practitioners and could not easily be transformed into the evident, universal experience that would provide adequate principles for a true science. Scheiner's approach to optics differed somewhat from Aguilonius's, although the latter shared in many ways Scheiner's Aristotelian methodological ideals. Aguilonius's lack of concern with some of the methodological specificities involved in converting the Latinized optics of Alhazen into a science that could meet the objections of certain Jesuit philosophers seems to have stemmed from his disregard for the dimension of *discovery.* The foundations from which his science develops are fairly fixed, whereas Scheiner's leaves open the possibility of making, and rendering "evident," new empirical truths—not just new formulations or new inferences.

Thus began a reformulation of the criteria by which specialized empirical suppositions—in Blancanus's astronomical terms "observations"—in the disciplines of mixed mathematics could be judged evident. Astronomical data and accounts of instrumental techniques, or procedures detailed as instructions or quasi-geometrical constructions,

97. Blancanus, *Sphaera mundi,* p. 111: "quod etsi multis constet experientijs, libet tamen pulcherrimam nunc aeque ac evidentissimam afferre: construatur, vitrea ampulla, uti in figura vides." Note that Blancanus refers to the kinds of procedures that Scheiner calls "experiments" as "experiences"; clearly the terminological usage cannot be taken as a clear or invariable indicator of epistemological status.

went some way towards making private knowledge-claims into public, self-evident truths. The closer that such presentations came to appearing like thought experiments—procedures that will, with correct presentation, create conviction of the truth of an untried outcome—the closer to proper scientific suppositions became their conclusions. Controversy, however, or the threat of controversy, demanded more radical measures. New means of employing experience then led towards a characteristically seventeenth-century—and modern—notion of the experiment as historical event.

Three EXPERTISE, NOVEL CLAIMS, AND EXPERIMENTAL EVENTS

I. Mathematical Form, Witnesses, and Novelty

The previous chapter showed how Jesuit academic culture at the beginning of the seventeenth century included a place for mathematical sciences that involved a unique methodological conceptualization of the place of experience in the making of scientific knowledge. The crucial notion may be characterized as that of expertise, whereby the experience of a specialist acted as a legitimate surrogate for common experience, which the dominant Aristotelian model required for the creation of the evident premises of true scientific demonstration. Jesuit mathematicians formulated the recondite, specialized experiences of astronomy and optics by using geometrical forms and operational instructions to the reader to expand the available stock of common experience in a way analogous to the role of the traditional commentary form in natural philosophy; their ability to do this rested on their credibility as competent practitioners of their specialties. The location of a statement of experience in a text bearing the marks of authority and laying claim to a standard place in the body of literature on its subject allowed the unquestioned acceptance of the experience, but only if it was not seen to *depend* on a specific textual citation. That is, the forms considered in chapter 2 for establishing statements of experience could not function successfully in the event of challenges.

New experiences of nature were proposed at a much faster rate in the seventeenth century than before—the Torricellian experiment, the moons of Jupiter, sun spots, the circulation of the blood, the differential refrangibility of light—and this novelty generated problems for the