True North—And Why It Mattered in Eighteenth-Century America

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PRIVATE OWNERSHIP of land was widespread in the British colonies of North America, providing self-sufficiency for many and extravagant wealth for a few, and serving as the basis for civic rights and responsibilities. The idea of land as property came from England, but much land in England was controlled by feudal ideas and much was restricted by entail. The rise of commercial and industrial wealth in the eighteenth century brought some change to the old patterns. But as we know from Jane Austen, these patterns were still a reality for many English men and women, even in the early nineteenth century.

American surveying practice derived from English experience, but differed because of different environmental and cultural conditions. English surveyors were primarily engaged in measuring and subdividing valuable properties that were already bounded with such things as walls and hedgerows. Their instrument of choice was the delicate, accurate, and expensive theodolite. With it they took sights on two landmarks and measured the intervening angular distance along a graduated scale. Americans needed to establish boundaries within a vast wilderness that was often difficult to traverse, and do so as expeditiously as possible. Their instrument of choice was the relatively rugged and inexpensive magnetic compass. With it they measured the angular distance between a landmark and magnetic north. American surveys were thus inevitably affected by magnetic variation. If Americans wanted property lines that could be recovered at a later date, surveyors had to compensate for variation. The quest for a solution to this problem led to the vernier compass, the first important mathematical instrument developed in America.

A surveyor's compass has two essential elements: a magnetic needle for determining magnetic north, and a pair of vertical sights for sighting along a line. The form probably originated in England shortly before

1610, when the first description appeared in print.[1] British texts refer to this instrument as a circumferentor, and often mention its drawbacks. William Gardiner explained in 1737 that a compass might be used for commons, roads, or wastelands, but "is by no means a fit Instrument for taking a Plan where exactness is required; because we can't be certain of its giving any particular angle so near as two degrees."[2] George Adams, a leading instrument dealer in London later in the century, said that the compass was favored in America "where land is not so dear, and where it is necessary to survey large tracts of ground, overstocked with wood, in a little time."[3]

Magnetic variation (also known as magnetic declination) is the difference between magnetic north as defined by the needle and true north as defined by the earth's axis of rotation. European navigators had encountered variation in the fifteenth century and found that it varied from one place to another.[4] Henry Gellibrand in London in the early seventeenth century found that variation varied with time as well as with space.[5] And an English surveyor named John Holwell reported in 1678 that the magnetic needle "doth vary much in some Grounds more than in others."[6] Recognizing the problems that variation could cause on land, the Royal Society of London recommended in 1670 that precise meridians be made in several places in England so that variation could be determined from time to time.[7] In 1697 it published an article critical of surveyors who used compasses but did not take variation into account. William Molyneux, the author of that article, was an Anglo-Irish natural philosopher who served as surveyor general of Ireland, and he referred in particular to the Down Survey of Ireland

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[1] William Folkingham, *Art of Surveying* (London, 1610) describes the circumferentor as a rectangular box with a small magnetic compass inset into its top face, and two vertical sights at either end. So, too, does Aaron Rathborne, *The Surveyor in Foure Bookes* (London, 1616), 127–29; William Leybourn, *The Compleat Surveyor* (London, 1722), 40–41 (this is the fifth edition of a work first published in 1650); and William Emerson, *The Art of Surveying, or Measuring Land* (London, 1770), 3. A circumferentor of this sort is depicted in the portrait print of Rathbone.

[2] William Gardiner, *Practical Surveying Improved* (London, 1737), 48.

[3] George Adams, *Geometrical and Graphical Essays* (London, 1791), 206.

[4] Deborah Warner, "Terrestrial Magnetism: For the Glory of God and the Benefit of Mankind," *Osiris* 9 (1994): 67–84. See also Penelope Gouk, *The Ivory Sundials of Nuremberg, 1500–1700* (Cambridge, 1988), 14–15.

[5] Henry Gellibrand, *A Discovrse Mathematical on the Variation of the Magneticall Needle. Together with its Admirable Diminution Lately Discovered* (London, 1635).

[6] John Holwell, *A Sure Guide to the Practical Surveyor* (London, 1678), 2.

[7] Notes appended to "An Observation of M. Adrian Azout, a French Philosopher, made in Rome (where he now is) about the beginning of this Year 1670, concerning the Declination of the Magnet," *Philosophical Transactions* 5 (1670): 1184–87.

conducted in 1656–57, the first major survey done with surveyor's compasses.[8]

Since many conditions in Ireland resembled those in North America, it is not surprising that the earliest extant surveyor's compass is an Irish instrument signed and dated "W. R. Dublin. fe. Latitude 53° 20′ *1667*."[9] Nor is it surprising that the first book that told surveyors how to determine magnetic variation was Robert Gibson's *Treatise on Practical Surveying* (Dublin, 1739). The first step of this project was establishing a meridian, and for that Gibson would have surveyors observe the amplitude or azimuth of the sun. Amplitude in this context is the angular distance along the horizon from the east or west point to the center of the sun, measured at sunrise or sunset, while azimuth is the angular distance between the sun and true north.

Compasses were probably introduced to America in the mid-seventeenth century, and were already fairly common when John Love discussed them in his 1688 text instructing surveyors who would "lay out New Lands in America."[10] A compass made in Dublin in the early 1720s is said to be "the first ever used to run a line in Georgia."[11] The popularity of compasses increased steadily in the early eighteenth century. By the 1740s Anthony Lamb in New York was trading "At the Sign of the Quadrant and Surveying Compass,"[12] Stephen Greenleaf in Boston was offering "circumferences" [*sic*] and other mathematical instruments,[13] Thomas Greenough in Boston was buying "needles for

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[8] William Molyneux, "A Demonstration of an Error Committed by Common Surveyors in Comparing of Surveys Taken at Long Intervals of Time Arising from the Variation of the Magnetic Needle," *Philosophical Transactions* 19 (1697): 625–31. William Petty, *The History of the Survey of Ireland, Commonly Called The Down Survey*, edited by Thomas Larcom (Dublin, 1851), reprinted in New York, 1967. Larcom notes (p. 323) that in his *Political Anatomy*, Petty wrote that "[t]he admeasurement of land in Ireland hath hitherto been performed with a circumferentor, with a needle of three two-thirds [*sic*] long, as the most convenient proportion."

[9] J. E. Burnett and A. D. Morrison-Low, *"Vulgar and Mechanick," The Scientific Instrument Trade in Ireland 1650–1921* (Edinburgh and Dublin, 1989), 13–14. This instrument has a wooden body, paper compass face, and brass sights; it is now in the Museum of the History of Science at Oxford.

[10] John Love, *Geodaesia: Or, The Art of Surveying and Measuring Land Made Easy* (London, 1748), 58. The first edition appeared in 1668.

[11] Farris Cadle, *Georgia Land Surveying History and Law* (Athens, Ga., 1991), 47.

[12] Silvio A. Bedini, *At the Sign of the Compass and Quadrant. The Life and Times of Anthony Lamb*. Transactions of the American Philosophical Society, 74.1 (1984). Lamb's advertisement in the *New-York Post-Boy* (1 July 1745) is reproduced on p. 38; his handbill, dated ca. 1751–55 and including an image of a surveyor's compass, is reproduced on p. 46.

[13] Greenleaf's advertisement in the *Boston Gazette* (18 June 1745) is reproduced in Charles Smart, *The Makers of Surveying Instruments in America Since 1700* (Troy, N.Y., 1962), 56.

surveying" from a firm in London,[14] and Aaron Miller in New Jersey was advertising "Compasses and Chains for Surveyors."[15] Joseph Avery, who was appointed surveyor of Georgia in 1742, received from England a "large circumferentor for surveying Woods" and two "strong Chains for Woods," as well as a Jacob's staff and an extra ball and socket.[16] We do not know what George Washington used to survey the Virginia frontier, but we do know that in 1760, after settling at Mount Vernon, he sent to London for "A Light handy Circumferentor for Surveying Lands—the Dial plate to be large and well graduated—the Sights to let down by Hinges (and not to slip of [*sic*] as is common) [and] a spare needle in case of accidents." Martha Ayscough, who sold this compass to Washington, was the widow of a prominent optical instrument maker. It cost £4.10 and, with a length of eighteen inches, it would have been heavy and sturdy rather than light and handy.[17]

The correspondence between Cadwallader Colden and James Alexander in the early 1740s illustrates a growing concern with magnetic variation. Colden was a physician of Scottish descent who was interested in history, botany, and natural philosophy, and who served as the surveyor general of New York.[18] Alexander was an engineer from Scotland who served as the surveyor general of East and West Jersey. Alexander had emigrated to America "with the hope of improving his fortunes in a country short of engineering talent." His technical talents were useful, but, like George Washington, he acquired a substantial estate through prudent land acquisition and marriage to a wealthy widow.[19]

The correspondence began when Colden informed Alexander about an improved circumferentor that he had recently ordered from Jonathan Sisson, a leading mathematical instrument maker in London. Alexander then ordered a similar instrument for himself, hoping that it "would far exceed any instrument that had ever been in America, especially for taking the variation of the compass." Although neither instrument seems to have survived, we do know that Sisson's bill read, "For 2 Circumfer-

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[14] Information from Dale Beeks.

[15] Miller's advertisement in the *New York Gazette* (4 January 1748) is quoted in Rita Gottesman, *The Arts and Crafts in New York, 1726–1776* (New York, 1936).

[16] Cadle, *Georgia Land Surveying*, 24–25.

[17] *The Papers of George Washington*, Colonial Series, 7 (Charlottesville, Va., 1990): 464, 466.

[18] "Cadwallader Colden," *American National Biography* 5: 198–99. See also Brandon Brame Fortune with Deborah Warner, *Franklin & His Friends. Portraying the Man of Science in Eighteenth-Century America* (Washington, D.C., 1999), 34–39.

[19] Thomas L. Purvis, "James Alexander," in *American National Biography* 1: 271–72. See also Whitfield J. Bell Jr., *Patriot Improvers* 1 (Philadelphia, 1997): 87–93.

entors with sights and a staff head made Strong with adjusting Screw & Circular Spirit level all made after a new method in the Compleatest manner. £11:11:0."[20] Sisson had probably learned about magnetic variation when he worked for George Graham, an accomplished clock and mathematical instrument maker who had observed this phenomenon in the early 1720s, and found that it often varied from one moment to the next.[21]

Colden and Alexander believed that the spatial variability of magnetic variation increased in a regular manner from south to north. Since it was 5°30′ along the Pennsylvania-Maryland boundary and between 7°20′ and 7°30′ at Livingston Manor in New York, Alexander assumed it should be nearly 7° at Colden's house on Long Island.[22]

The *General Instructions* that Alexander issued to deputy surveyors in 1746 stated that "all the Courses of the Boundaries of the Lands of New-Jersey, are named so as the Magnetical Compass doth point them out," and thus "the Variation of the Variation of the Compass, may in time occasion much Confusion of Bounds, and Contention." To avoid this problem, each surveyor should determine local variation at least once a year. The meridian should be established by astronomical means: when the North Star and Alioth (a bright star in Ursa Major) appear one above the other, they lie along this line.[23]

Determining magnetic variation may have been easy in theory, but it was difficult in practice. For the surveyors who tackled the much-disputed boundary between Maryland and Pennsylvania in 1750–51, the problem was beyond their means. Time and again while at New Castle and again at Fenwick Island at the eastern end of the line, these men observed the North Star and Alioth by night and magnetic variation by day, and got different results every time.[24] The Americans

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[20] Ja. Alexander to Cadwallader Colden, 10 June 1744, in *The Letters and Papers of Cadwallader Colden* (New York, 1973), 3: 61–63. See also [George J. Miller], *The Printing of the Elizabethtown Bill in Chancery; The Quadrant and the Circumferentor; Flesh for Sale* (Perth Amboy, 1942).

[21] George Graham, "An Account of Observations made of the Variation of the Horizontal Needle at London in the latter Part of the Year 1722 and the Beginning of 1723," *Philosophical Transactions* 33 (1724–25): 96–107.

[22] Ja. Alexander to Cadwallader Colden, 10 June 1744, in *Letters and Papers of Cadwallader Colden* 3: 61–63.

[23] [James Alexander], *General Instructions by the Surveyor General to the Deputy Surveyors of the Eastern Division of New Jersey.* There was a similar publication for the deputy surveyors of the Western Division of New Jersey. Internal evidence establishes a publication date of 1746 or 1747.

[24] John W. Jordan, "Penn versus Baltimore. Journal of John Watson, Assistant Surveyor to the Commissioners of the Province of Pennsylvania, 1750," *Pennsylvania Magazine of History and Biography* 38 (1914): 385–406, and 39 (1915): 1–47.

who returned to this task in 1761 faced similar difficulties. When they could not see Alioth, "they could not agree among themselves on any other method of taking a meridian, and were therefore under a necessity of putting an entire stop to their work."[25]

If the accomplished surveyors employed for this important boundary had such trouble with magnetic variation, it is not surprising that common surveyors working on properties of lesser value ignored the matter altogether. In her study of surveying in colonial Virginia, Sarah Hughes found only a few instances of attention to variation, and most of these were connected with the lands owned by Lord Fairfax.[26] Barry Love found few surveyors in colonial Pennsylvania who determined variation, and fewer still who recorded this information on their returns.[27] Christian Gottlieb Reuter, a Moravian from Prussia who emigrated to America in the 1750s, knew about variation but chose to ignore it. His 1774 map of Salem, North Carolina, was based on a survey done "without declination."[28] A small surveying text published in New Jersey in 1771 suggested that surveyors might simply assume the value of magnetic variation by knowing that it changed by one degree every nineteen years.[29]

The Virginia General Assembly addressed the problem in 1772 with an act stating that surveyors must define boundary lines in relation to true north and indicate the extent and direction of variation on each plat. The act mentioned the "many inconveniences" that had "arisen from the inattention of surveyors to the variation of the magnetic needle," and proposed to prevent the "many mistakes and much confusion" that "may arise in comparing future surveys with the present." Surveyors who did not follow the new regulations risked a five-pound fine.[30]

The Virginia act was written by Thomas Marshall, a planter of middling circumstances who surveyed the Fairfax lands with George

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[25] Minutes of the Meeting of the Boundary Commissioners, 1761, Penn Papers, 11: #71, Historical Society of Pennsylvania.

[26] Sarah H. Hughes, *Surveyors and Statesmen. Land Measuring in Colonial Virginia* (Richmond, Va., 1979), 145, 147.

[27] J. Barry Love, *The Colonial Surveyor in Pennsylvania* (2000).

[28] Christian Gottlieb Reuter, "Das ganze Territorium von Salem in der Wachau oder Dobbs Parish in der Grafschaft Surry in der Provintz N Carolina in N America." This map is in the Moravian Archives, Winston-Salem, N.C.; Daniel Crews, archivist, brought it to my attention.

[29] Thomas Moody, *A Compendium of Surveying; Or the Surveyors Pocket Companion* (Burlington, N.J., 1771), 37.

[30] William Hening, comp., *Statutes at Large, Being a Collection of all the Laws of Virginia* (1819–23), 8: 526–27, quoted in Hughes, *Surveyors and Statesmen*, 127. See also W. M., "To the Printer," *Virginia Gazette* (13 May 1773).

Washington in the late 1740s, became county surveyor of Fauquier County in 1759, and is best remembered as the father of the first chief justice of the United States.[31] Marshall was also the inventor of an "Instrument for finding the VARIATION of the NEEDLE" that would be "singularly serviceable to Surveyors if the Act takes Place which obliges them to return Plot and protract their Surveys by the True Meridian."[32] Marshall's instrument was apparently cheap and portable, and could be had of Edmund Dickinson, a well-known cabinet maker in Williamsburg.[33] Thomas Jefferson owned "Marshall's Meridian Instrument Mahogany," for which he paid twenty shillings.[34]

Having served as surveyor of Albemarle County, Jefferson was familiar with the Virginia law concerning magnetic variation. In 1779, in his proposed bill concerning the salaries and fees of various officers of the Commonwealth, he noted that surveyors were to draw plats "protracted by the true meridian" and determine "the variation thereof, towards the east or west, from the magnetical meridian."[35] After the Revolution, as a leading member of the committee that planned a federal land office, Jefferson turned again to the problem of variation. The report of this committee stated that the public lands west of the original thirteen colonies should be divided into townships six miles square "by lines running due north and south, and others crossing these at right angles." It went on to say that surveyors "shall pay due and constant attention to the variation of the magnetic meridian, and shall run and note all lines by the true meridian, certifying with every plat what was the variation at the time of running the lines thereon noted."[36] Similar language appeared in the land ordinance that the Continental Congress enacted in 1785.[37]

The first line of this project—scheduled to run due west from that point where the western boundary of Pennsylvania crossed the Ohio

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[31] "Thomas Marshall," *Dictionary of American Biography* 12: 328–29. See also *Fauquier County, Virginia, 1759–1959* (Warrenton, Va., 1959), 76.

[32] Advertisements published in the *Virginia Gazette* for 7 May 1772 and 13 May 1773.

[33] Harold B. Gill Jr., "Portrait of an Artisan. An Eighteenth-Century Williamsburg Craftsman Profiled," *Colonial Williamsburg* (Spring 2001), online.

[34] Thomas Jefferson's Memorandum Book, quoted in Silvio Bedini, *Thinkers and Tinkers. Early American Men of Science* (New York, 1975), 142. See also Jefferson's list of his "Mathematical Apparatus," document 3 in Bedini, *Thomas Jefferson. Statesman of Science* (New York, 1990).

[35] "A Bill for Ascertaining the Salaries and Fees of Certain Officers," in Julian Boyd, ed., *The Papers of Thomas Jefferson* 2 (Princeton, 1950): 432.

[36] "Report of a Committee to Establish a Land Office," in Boyd, ed., *Papers of Thomas Jefferson* 7 (Princeton, 1953): 140–48.

[37] The text of the ordinance appears in Albert C. White, *A History of the Rectangular Survey System* (Washington, D.C., 1982), 11–14.

River—was off by several degrees, even though it was done under the leadership of Thomas Hutchins, recently appointed geographer of the United States. Hutchins's field notes indicate that he made no effort to determine variation, and his report mentions the difficulty of surveying by reference to the meridian when the pay was only two dollars per mile. Recognizing the futility of the situation, Congress suspended the meridian requirement in May 1786.[38]

By 1796, when the meridian requirement was reinstated, American mathematicians and instrument makers had developed the vernier compass and a user-friendly method for determining the meridian. The key actors in this story were friends and colleagues who lived in and around Philadelphia, who were members of the American Philosophical Society, and who surely discussed the problem with one another. Andrew Ellicott was a geodetic surveyor.[39] Robert Patterson was an Irish mathematician who had emigrated to America in 1768.[40] David Rittenhouse was a clockmaker and a man of science.[41] Benjamin Rittenhouse, David's younger brother, ran a clock and instrument workshop in Worcester Township, Montgomery County, Pennsylvania.[42] David Rittenhouse and Robert Patterson were affiliated with the University of Pennsylvania, and both served as president of the American Philosophical Society and as master of the mint. Ellicott studied practical mathematics with Patterson, worked with David Rittenhouse to establish the western and northern boundaries of Pennsylvania, and owned several compasses made by Benjamin Rittenhouse.[43]

All of these men had direct experience with magnetic variation. While preparing for the 1769 transit of Venus across the face of the Sun, David Rittenhouse established a meridian line at his family home at Norriton, a few miles from Philadelphia, and found the variation to be 3°8′.[44] In 1785 he determined the variation at more than twenty locations along the western boundary of Pennsylvania. In 1787, when asked to resurvey the New York-Massachusetts boundary, he protested the assignment. Since the men who had originally run this

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[38] Ibid., 18–19.

[39] Silvio Bedini, "Andrew Ellicott, Surveyor of the Wilderness," *Surveying and Mapping* 36 (June 1976): 113–35.

[40] James Tattersall, "Robert Patterson," in *American National Biography* 17: 139–40.

[41] Brooke Hindle, *David Rittenhouse* (Princeton, 1964).

[42] Bruce R. Forman, *The Clockmakers of Montgomery County, 1740–1850* (Norristown, Pa., 2000), 42–44.

[43] One of Ellicott's Benjamin Rittenhouse plain compasses is in the National Museum of American History; the other is at the Fort Necessity National Battlefield.

[44] William Smith, "Account of the Terrestrial Measurement of the Difference of Longitude and Latitude Between the Observatories of Norriton and Philadelphia," *Transactions of the American Philosophical Society* 1 (1769): 5–11.

boundary had not indicated the variation, he said, the resurvey would be "impracticable."[45]

Although Ellicott's primary task was determining latitude and longitude by astronomical means, he did observe magnetic variation on the western boundary of Pennsylvania and in the town of Erie.[46] In 1791, as he was about to lay out the city of Washington along the Potomac, Jefferson told him to ascertain a true meridian and pay attention to variation.[47] Ellicott soon found that the "magnetic variation at this place is somewhat uncertain, arising no doubt from some local cause."[48] On his map of the area, he reported that he had drawn a true meridian line by astronomical observations, run the several boundaries with his geodetic transit instrument, determined the angles of the streets "by actual measurement" (presumably with his common theodolite), and "left nothing to the uncertainty of the Compass."[49]

In 1786, the American Philosophical Society published a paper written by Patterson that described a way to find the meridian by observing the pole star. Observations of the sun might give the most accurate results, Patterson said, but they require "time, attention and instruments" that surveyors can seldom command. His method, on the other hand, was easy enough for surveyors to use and "will generally give the variation of the needle true to a single minute of a degree." To help surveyors use this method, Patterson provided a table giving the azimuth of the pole star at 20-minute intervals, for latitudes 30°, 35°, 40°, 45°, 50°, and 55° north.[50]

Ellicott addressed the matter of magnetic variation in a pamphlet published in 1796, as Congress was debating the new land office bill. Like Patterson in 1785 and Alexander in 1746, he advised surveyors to determine the meridian by observing the pole star, but he favored observations at the star's greatest elongation from the meridian. He then described a simple instrument that a surveyor could make for this purpose, explained the necessary calculations, and assured his readers

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[45] Brooke Hindle, *David Rittenhouse*, 289.

[46] Andrew Ellicott, "Observations made on the Old French Landing at Presqu'Isle, to determine the Latitude of the Town of Erie," *Transactions of the American Philosophical Society* 4 (1799): 231–32.

[47] Thomas Jefferson to Andrew Ellicott, 2 February 1791, in Boyd, ed., *Papers of Thomas Jefferson* 19: 68–69.

[48] Andrew Ellicott to Thomas Jefferson, 14 February 1791, in Boyd, ed., *Papers of Thomas Jefferson* 19: 70–71.

[49] Text on Andrew Ellicott's *Plan of the City of Washington in the Territory of Columbia*, engraved by Thackara and Vallence (Philadelphia, 1792).

[50] Robert Patterson, "An Easy and Accurate Method of Finding a True Meridian Line, and Thence the Variation of the Compass," *Transactions of the American Philosophical Society* 2 (1786): 251–59.

that these tasks were not as difficult as they might appear. Moreover, the results should be sufficiently accurate for at least two years before and after the observations were made, and for at least four degrees of latitude north or south.[51]

Patterson and Ellicott also referred to the vernier compass, although not by name. Patterson described a surveyor's compass equipped with a nonius scale that could be used to obtain greater precision—to "take the bearing of an object to a minute." Ellicott described a compass in which the North-South axis of the needle ring could be rotated relative to the line of sight, and thus be used to offset magnetic variation. His account was probably based on the "surveying compass made by Mr. Benjamin Rittenhouse upon the newest, and most approved plan" that Ellicott would use later that year for his survey of the Mississippi River. This "excellent" instrument, he said, could be "corrected for the variation of the needle."[52]

The earliest dated instrument of this sort is marked "Benjamin Rittenhouse Fecit 1790."[53] The earliest advertisement for an instrument of this sort is dated 1787. It was issued by Lewis Michael, who offered "all kinds of compasses with or without a nonius to lay off the variation on an old line." Michael was a German immigrant who worked in York, Pennsylvania, and who would later acknowledge that he had "obtained the knowledge" of the instrument trade from "the late Benjamin Rittenhouse."[54] William Dean in Philadelphia offered "Circumferentors on an improved plan, with a noneus, &c." in 1794.[55]

The new form was known as a nonius compass in Pennsylvania, and as a vernier compass in New York and elsewhere. As the new terms came into use, the traditional surveyor's compass became known

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[51] Andrew Ellicott, *Several Methods By Which Meridional Lines May Be Found with Ease and Accuracy* (Philadelphia, 1796).

[52] *The Journal of Andrew Ellicott, Late Commissioner on Behalf of the United States During Part of the Year 1796, the Years 1797, 1798, 1799 and Part of the Year 1800 For Determining the Boundary Between the United States and the Possessions of His Catholic Majesty in America* (Philadelphia, 1803), 137, and appendix, 46.

[53] This compass, now at the Adler Planetarium in Chicago, is depicted in Bruce Stephenson, Marvin Bold, and Anna Friedman, *The Universe Unveiled* (Chicago and Cambridge, 2000), 86.

[54] Silvio Bedini, *With Compass and Chain. Early American Surveyors and Their Instruments* (Frederick, Md., 2001), 440–45, "The Enigma of Lewis Michael." See also Lewis Michael advertisements in the *Carlisle Gazette* (4 March 1787), in the *Pennsylvania Chronicle or York Weekly Advertiser* (2 April 1788), and in the *Scioto Gazette* (7 and 14 November 1832).

[55] Advertisement in *Dunlap and Claypool's American Daily Advertiser* for 31 January 1794. Harold Gillingham, "Some Early Philadelphia Instrument Makers," *Pennsylvania Magazine of History and Biography* 51 (1927): 289–308, noted this advertisement but gave no date.

as a plain compass. Nonius refers to Pedro Nuñez, a sixteenth-century Portuguese mathematician who described a technique for interpolating between divisions on a larger graduated scale. Vernier refers to Pierre Vernier, a French military engineer who described a different solution to the problem of interpolating in 1631. Vernier's design came into use in the eighteenth century and was known as both a nonius and a vernier scale.

David Rittenhouse probably invented the vernier compass and, although he never discussed it in print or in any manuscripts that have yet come to light, two examples survive to this day. Both were made after Rittenhouse's move to Philadelphia in late 1770. One is marked "David Rittenhouse Philadelphia" and the other "D. Rittenhouse Philadelphia." The former is now in the National Museum of American History, its provenance unknown. The latter is now in the New York State Library at Albany, and is said to have been owned by George Washington.[56] In both instances the vernier mechanism is at one side of the face. This design may have been functional, but it was not commercially successful. Indeed, only John Heilig, a German immigrant who was related to the Rittenhouse family and who worked in Germantown, Pennsylvania, is known to have made instruments of this sort.[57]

While David Rittenhouse made only a handful of surveying instruments, most of them innovative in one way or another, Benjamin Rittenhouse made many compasses, both plain and vernier. Moreover, he placed the vernier mechanism on one of the arms of the compass, and it was this form that would become standard. In 1798 the surveyor general of the United States, Rufus Putnam, instructed a prospective surveyor to obtain "a compass having a moveable band (Mr. Rittenhouse, near Philadelphia, makes the best I have seen)."[58] In 1800 William Lukens Potts advertised "surveying instruments of all kinds, and Rittenhouse's Circumferentors, with each a nounes and spirit level compleat."[59] In 1804 deputy surveyors working on the federal land survey were instructed to use a "Rittenhouse Compass with a Nonius."[60]

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[56] Charles Smart, *Makers of Surveying Instruments*, 138–41. See also Francois D. Bud Uzes, "David Rittenhouse. Colonial Surveyor and Instrument Maker," *Rittenhouse* 5 (1990): 1–16.

[57] Forman, *Clockmakers of Montgomery County*, 23–25. See also Smart, *Makers of Surveying Instruments*, 207.

[58] Quoted in Silvio Bedini, *Thinkers and Tinkers*, 141.

[59] Advertisement in *Claypoole's American Daily Advertiser*, 17 Jan. 1800, and later, quoted in Forman, *Clockmakers of Montgomery County*, 39–41.

[60] Jared Mansfield, "General Instructions to Deputy Surveyors," 1804, in Albert C. White, *A History of the Rectangular Survey System* (Washington, D.C., 1982), 237.

In the 1820s George Gillet in Connecticut reported using "Rittenhouse's compass to ascertain the diurnal motion" of magnetic north.[61]

David Rittenhouse died in 1796 and Benjamin Rittenhouse went out of business soon thereafter. Thomas Whitney, an English artisan who settled in Philadelphia, advertised "surveying instruments on an improved construction" in 1798, and by 1820 he had made about five hundred compasses, "the good qualities of which are well known to many Surveyors, in at least sixteen of the States and Territories of the Union." Whitney sold plain compasses for thirty to thirty-seven dollars, and "Nonius or Minute" compasses for forty to sixty dollars.[62] He also kept a "book of record for Magnetic Observations" and invited contributions from "any gentleman who is pleased to throw light on this important subject."[63]

American surveyors were soon using the new instruments and methods. Farris Cadle found that attention to variation in Georgia began in 1803, when the surveyors working on the lands recently ceded by the Creek nation were told to commence duties "by ascertaining with the utmost precision, the variation of your Compass or Needle from the true meridian."[64] Henry David Thoreau, who surveyed lands in and around Concord, Massachusetts, in the 1850s, advertised "[a]reas warranted accurate within almost any degree of exactness, and the Variation of the Compass given, so that the lines can be run again."[65]

American savants were also concerned with magnetic variation. In his instructions for the great exploring expedition to the Pacific Northwest, Thomas Jefferson told Meriwether Lewis to notice the variations of the compass "in different places."[66] Having been tutored by Ellicott and Patterson, Lewis would have known what to do. The famed navigator Nathaniel Bowditch published a list of variations in the United States in 1817. "Notwithstanding the difficulty of obtaining the correct values of the variation," he would later write, the task was especially

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[61] Abel Flint, *A System of Geometry and Trigonometry; Together with a Treatise on Surveying*, 5th edition with additions by George Gillett (Hartford, 1825), 85.

[62] Thomas Whitney's advertisement in the *Federal Gazette* (12 April 1798), 3, quoted in part in Gillingham, "Some Early Philadelphia Instrument Makers," 298–308, on 304–05; Whitney's advertisement in *Whitely's Philadelphia Annual Advertiser* for 1820. For prices, see Whitney's trade card, in private hands.

[63] Thomas Whitney, "Variation of the Compass," broadside in compass box at NMAH.

[64] Cadle, *Georgia Land Surveying*, 181–83.

[65] Thoreau broadside reproduced in Marcia Moss, ed., *A Catalog of Thoreau's Surveys in the Concord Free Public Library* (Geneseo, N.Y., 1976), 4.

[66] Thomas Jefferson to Meriwether Lewis, 20 June 1803, in Donald Dean Jackson, ed., *Letters of the Lewis and Clark Expedition With Related Documents 1783–1854* (Urbana, Ill., 1962), 62.

important "in this country, where most of the boundary lines of lands are determined by the compass."[67] Elias Loomis, who produced a magnetic chart of the country in 1840, hoped that this work "would contribute something to the cause of science, and might also be of practical utility to public surveyors, who very generally in this country make use of the magnetic needle in their surveys."[68] The same mixed motivation lay behind the first map of this sort published by the U.S. Coast Survey in 1856.[69]

While the vernier compass was an American invention, somewhat similar instruments were available in England and Ireland. George Adams in London offered a "small surveying compass, or portable theodolite, with a nonius," as well as an "Improved Circumferentor" that enabled surveyors to take angles "with or without the needle" and "with much greater accuracy than by the needle alone."[70] An Irish surveyor named John Hood devised a "Compass Theodolite" that was designed to compensate for magnetic variation; it could be had from two instrument makers in Dublin, Edward Spicer and James Lynch.[71] In 1810, also in Dublin, a Mr. Freeman described what seems to be a true vernier compass; he called it an improved circumferentor whereby "bearings or courses can be taken to one minute of a degree," and "corrected for the effect of the diurnal variation, in order to reduce the needle to a parallel position throughout a survey."[72] No examples of these instruments are now known, so I assume they were not commercially successful.

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[67] Nathaniel Bowditch, *The New American Practical Navigator* (New York, 1817), 117; Bowditch, "On the Variation of the Magnetical Needle," *American Journal of Science* 16 (1829): 64–69.

[68] Elias Loomis, "On the Variation and Dip of the Magnetic Needle in Different Parts of the United States," *American Journal of Science* 34 (1838): 290–307. See also "Magnetic Chart of the United States" accompanying Loomis, "On the Variation and Dip of the Magnetic Needle in the United States," *American Journal of Science* 39 (1840): 41–47.

[69] "Lines of Equal Magnetic Declination for the Year 1850," in *Report of the Superintendent of the U.S. Coast Survey for the Year 1856*. See also http://NOAA Photo Library/Historic C&GS Collection/Geophysics/Geomagnetism/theb1345.

[70] *A Catalogue of Optical, Philosophical, and Mathematical Instruments, Made and Sold by George Adams, Mathematical Instrument-Maker To His Majesty, at Tycho Brahe's Head, [No. 60] Fleet-Street, London* (ca. 1780). See also "A Catalogue of Mathematical and Philosophical Instruments," appended to George Adams, *Astronomical and Graphical Essays* (London, 1795); a facsimile copy appears in John R. Millburn, *Adams of Fleet Street, Instrument Makers to King George III* (Aldershot, 2000), 367–82; and George Adams, *Geometrical and Graphical Essays*, 2nd edition, corrected and enlarged by William Jones (London, 1797), 210–11 and pl. xv.

[71] John Hood, *Tables of Difference of Latitude and Departure for Navigators* (Dublin, 1772), 5–7.

[72] Mr. Freeman, "On the Improvement of the Circumferentor," *Transactions of the Dublin Society* 2 (1810): 47–66, with comments by James Lynch, 67–68.

Conclusion

Because of the significance and wide distribution of private property in America, surveyors played an important role in American culture. And because these surveyors used magnetic compasses, their lines could not be recovered unless magnetic variation was taken into account. Samuel Moore of Connecticut spoke for many when he noted that imprecise surveys opened "a Door for endless Litigation."[73] American surveyors began discussing magnetic variation in the 1740s, but it was the authorization of the federal land survey in 1785 that inspired the instruments and techniques that gave them a convenient means to locate true north and to compensate for magnetic variation. The various components had long been known, but the whole came together only in a context where skilled mathematicians and instrument makers—several of them affiliated with the American Philosophical Society—addressed a need that was not simply technical, but economic, social, and political as well.

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[73] Samuel Moore, *An Accurate System of Surveying* (Litchfield, Ct., 1796), iv.