# Art, Optics and History: New Light on the Hockney Thesis

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ABSTRACT

David Hockney's recent book *Secret Knowledge: Rediscovering the Lost Techniques of the Old Masters* argues that 15th-century painters employed optical devices to achieve realistic portraiture. A reexamination of the history of optical projection techniques raises problems for Hockney's provocative hypothesis.

David Hockney's recent book *Secret Knowledge: Rediscovering the Lost Techniques of the Old Masters* argues that painters from Van Eyck to Ingres achieved a remarkable imitation of nature not through sheer painterly talent but by employing optical devices. Specifically, Hockney argues from a bewildering array of visual evidence that, from around 1430, many painters employed a concave mirror to project brightly lit subjects onto a canvas, thus allowing them to render figures with an unprecedented naturalism. Hockney's claim derives from experiments carried out in his home with a shaving-mirror and the assistance of optical scientist Charles Falco of the University of Arizona. Together, Hockney and Falco suggest that, in addition to the "natural" depiction of their subjects, a number of anomalous features of 15th- and 16th-century paintings can easily be explained by assuming that the artists employed the "mirror-lens," Hockney's slightly confusing term for the concave mirror [1]. According to Hockney, the patterned tablecloth in a 1543 painting by Lorenzo Lotto exhibits "optical artefacts" associated with refocusing, for example, multiple vanishing points and loss of focus on the pattern. Regarding the famous convex mirror depicted in Van Eyck's *Arnolfini Wedding* (1434), Hockney remarks, "If you were to reverse the silvering and then turn it round, this would be all the optical equipment you would need for the meticulous and natural looking detail in the picture" [2]. Hockney, however, does not consistently describe the exact technique by which artists moved from the projected image to the finished painting. Sometimes, he suggests that artists traced the projected image. On other occasions, he states that they merely used the projection to mark a few key points.

According to Hockney's chronology, around the end of the 16th century, painters began to use refractive lenses instead of concave mirrors to project their tracing images. Unlike concave mirrors, convex refractive lenses have the property of reversing left and right, in addition to inverting the image. Hockney points to a sudden increase in the number of left-handed drinkers in paintings executed after the last decade of the 1590s as conspicuous evidence of the shift from mirror to lens, citing paintings by Caravaggio as marking the point of transition from reflection to refraction [3].

Visual evidence is essential to Hockney's argument. Playfully, his book is prefaced by a forged document purporting to be a quotation from art historian Roberto Longhi: "Paintings are primary documents. Archival documents can be faked; critical judgements, not." Perhaps unsurprisingly, not all of Hockney's revelations have been embraced enthusiastically by the scholarly community. At the colloquium organized by Lawrence Weschler at the New York Humanities Center in December 2001, a number of vociferous critics attacked Hockney's thesis.

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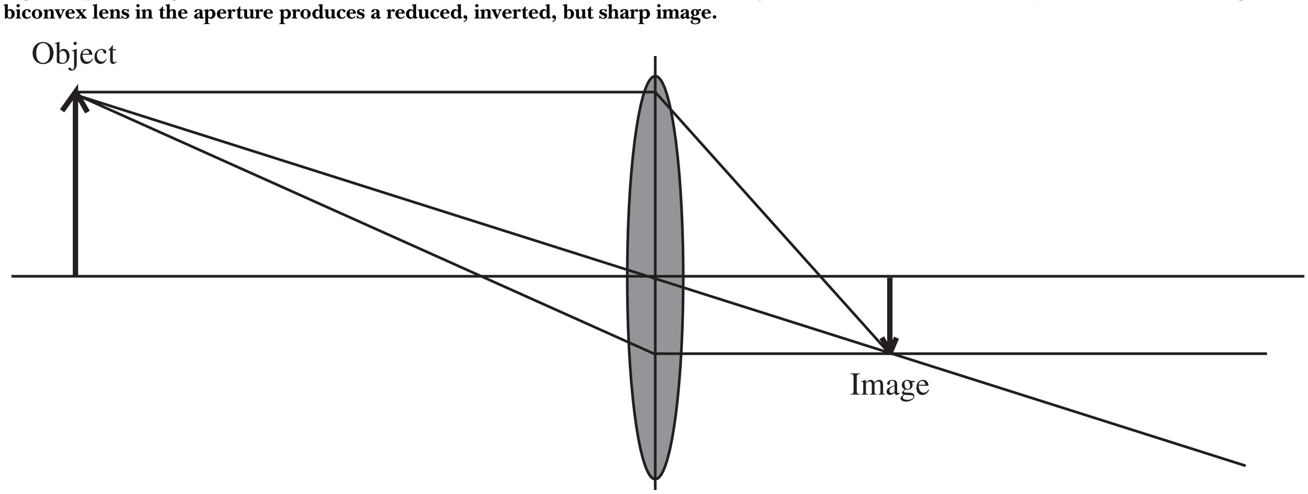
**Fig. 1. Optical diagram of Girolamo Cardano's 1550 camera obscura (i.e. Hockney's "late" device). (© Michael John Gorman) Placing a biconvex lens in the aperture produces a reduced, inverted, but sharp image.**



Art historians noted that Hockney did not give adequate credit to the significant corpus of previous scholarly work on artists' use of optical devices including the camera obscura. Perhaps the most scathing criticisms, however, came not from the historians but from two optical scientists invited to the colloquium, David Stork of Stanford University and Christopher W. Tyler of the Smith-Kettlewell Eye Research Institute [4].

The criticisms leveled by Stork and Tyler concern the technical details of the optical techniques that Hockney and Falco suggest were employed by artists from the time of Robert Campin (c. 1375–1444). I do not intend to review all their criticisms here. However, one of Stork's arguments appears potentially fatal to Hockney's hypothesis. Stork notes that in order to produce an image of appropriate scale for a Renaissance painting, a mirror of long focal length would be required. Hockney's shaving-mirror had, according to Stork, no optical equivalent in the Renaissance. The mirrors (almost all convex, rather than concave) depicted in paintings of the 15th and 16th centuries can all be seen to have focal lengths significantly shorter than the approximately 55 cm estimated by Hockney and Falco to be necessary for projection of an image of the dimensions of the final painting. Van Eyck's *Arnolfini* mirror is no exception. If we assume that the artists actually traced directly from the optical images, then we encounter a serious difficulty here. Moreover, as Stork points out, a spherical concave mirror of 55 cm focal length, if made of glass, would have to be cut from an enormous sphere almost 7 feet in diameter! It was absolutely impossible, Stork claims, for a Renaissance glassblower to create a sphere of such huge dimensions [5].

Considering the relevance of the history of optical instruments to this debate, it is surprising that historians of science have not had much to say about the Hockney thesis thus far. In spite of the protests of art historians, I do not believe that Hockney's point is unoriginal. True, many art historians have emphasized the geometrical investigations of artists and the instruments that they have used. The work of Hockney's correspondent during the writing of his book, Martin Kemp, is exemplary in this respect [6]. Some historians have even pointed to the importance of the camera obscura, particularly for Vermeer and other 17th-century Dutch artists [7]. However, the specific device considered by Hockney, at least for the earlier period—i.e. the concave mirror used as a projective device—is not one that has been investigated as a vital tool for artists by anyone prior to him, to my knowledge. So, either Hockney is completely wrong about the use of concave mirrors for projection or he has hit on a device that has been almost completely ignored by historians.

As an artist's tool, the concave mirror has some shortcomings. Assuming for the moment that one can find a concave mirror of sufficient focal length and optical quality, and that there is sufficient illumination on the subject—all assumptions that have been challenged at one point or another by Hockney's critics—the image projected by the mirror in the darkened chamber of the artist is still inverted, undeniably not the ideal situation for a painter. A further objection to Hockney's hypothesis is the absence of a significant written record about artists employing concave mirrors, an absence that Hockney ascribes to fear of the Inquisition, adding the spice of a conspiracy of silence to the story. "Heresy kept the lenses secret," Hockney suggests mysteriously [8].

In this article I intend to shed light on those parts of the debate relating to the history of science and technology. Did Hockney's proposed projective system exist? If so, when was it created? Who might have used it? These are the questions that I address here. Surprisingly, the documents, when read carefully, do have a great deal to say about the use of concave mirrors to project images. By looking closely at the documents concerning the history of the camera obscura, we can make a fairly precise estimate of the date of creation of a camera obscura employing a concave mirror. We need not resort to any conspiracy of silence and we can access a vivid picture of the technical limitations governing image-projection techniques in the crucial period of the late 16th century, the time at which Hockney dates the transition from reflective to refractive projection techniques.

The evidence that I review here relates to the crucial issue of what type of optical projection was technically achievable at a particular historical moment. It is important to emphasize, however, that the fact that a type of projection was technically feasible does not imply that any particular artist used the technique, in the absence of further evidence, visual or documentary. This article will not enter the dispute on internal visual evidence in paintings that is currently raging between the Hockney camp and Stork and Tyler, but the evidence provided should, I hope, affect the historical and technical parameters of that debate. Ironically, it will become clear that concave mirrors began to be used as projective devices in the mid-16th century and were used in combination with convex lenses from that century's end, precisely the moment that Hockney associates with the transition from mirrors to lenses.

However, nobody in this debate, to my knowledge, has so far suggested that mirrors were used both alone and in conjunction with convex lenses. The combination of concave mirror and convex lens produced a magnified, upright image in which left and right were not reversed.

Moreover, the addition of a convex lens had the effect of increasing the effective focal length of the concave mirror. Thus, given a suitable convex lens, even a mirror of small focal length could aid in producing a life-size or magnified erect image.

## A Condensed History of the Camera Obscura

In the 4th century B.C.E., Aristotle noticed that during a solar eclipse, the circles of light on the ground under a plane tree gradually turned to thin crescents, thus recognizing the fundamental phenomenon of image projection through small apertures on which the camera obscura is based. The 10th-century Arab scholar Ibn Al-Haytham described how the image of the sun could be projected through a hole in the wall of a room onto a wall opposite during an eclipse, and for almost 600 years, until the mid-16th century, the camera obscura remained just this: a small hole in the wall, described by a great number of scholars, including Francesco Maurolico, Gemma Frisius, Leonardo da Vinci and Erasmus Reinhold [9].

Then, in 1550, the Milanese astrologer and physician Girolamo Cardano suggested a dramatic improvement to the camera obscura in his work *On Subtlety*: inserting a convex lens made of glass into the hole. This produced a much clearer image (Fig. 1). Here are Cardano's words:

> If you want to see the things that go on in the street, at a time when the sun shines brightly place in the window shutter a bi-convex lens [*orbem e vitro*]. If you then close the window you will see images projected through the aperture on to the opposite wall, but with rather dull colors; but by placing a piece of very white paper in the place where you see the images, you will attain the eagerly awaited result in a wonderful manner [10].

Cardano's discovery, which does not seem to have gone into common use, was

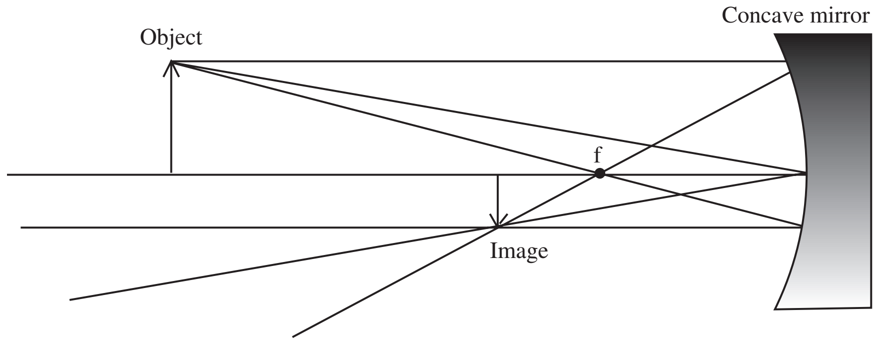



**Fig. 2. Optical diagram of Della Porta's 1558 system (i.e. Hockney's "early" device). (© Michael John Gorman) Note that the concave mirror has a long focal length (i.e. it is quite "flat"), but still produces an image reduced in scale.**

later echoed in 1585 by Giambattista Benedetti, philosopher to Carlo Emanuele, Duke of Savoy, in his *Diverse Speculations on Mathematics and Physics*. Benedetti, in a letter to Pirro de Arzoni about the properties of optical images, writes:

> On this subject, I don't wish to remain silent on a certain marvellous effect of a thing of this kind. This is that a round hole is made, of the size of a lens, and the hole is stopped up with one of those lenses that are made for old people (not for short-sighted people), I mean one both of the sides of which are convex, not concave. Then place a sheet of white paper at a sufficient distance from the hole so that the objects outside appear on it. If these objects are illuminated by the sun, they will be seen so clearly and distinctly that nothing more beautiful or delectable can be imagined, but they will be inverted. But if you wish to see them upright, this we do very well by means of reflection in a plane mirror [11].

So, we have two interesting new additions to the camera obscura: the lens by Cardano in 1550 and an oblique plane mirror by Benedetti in 1585. Cardano and Benedetti were both among the most advanced mathematical practitioners of their time, and it is impossible to believe that they would be unaware of a projection technique being used widely by artists. Another version of the camera obscura was described for the first time by Giambattista Della Porta in 1558. Della Porta is mentioned several times in Hockney's book, and an excerpt from his *Natural Magic* figures prominently in the "Textual Evidence" section [12]. However, there is a problem with this excerpt as published by Hockney: It is completely incomprehensible. The excerpt is taken from an anonymous 17th-century translation of Della Porta's work that was clearly carried out by somebody who had at best a mediocre command of Latin and failed to understand the technical details, confusing lenses with mirrors to an extent that the text becomes gibberish.

What did Della Porta really say about the camera obscura? And, given that Hockney locates his second crucial transition with Caravaggio at the end of the 16th century, could Della Porta's camera obscura have implications for this transition?

Della Porta was as famous as a playwright and impresario as for his investigations of secret natural processes and amusing mechanical contrivances. We will see that his theatrical productions and camera obscura are intimately connected. Indeed, the sophisticated camera obscura described in the enlarged 1589 version of *Natural Magic* was designed specifically to project theatrical performances to allow them to be viewed by an audience of nobles sitting inside Della Porta's dark chamber.

*Natural Magic* was first published in 1558, when Della Porta was 23 years old, in four books. It included a brief description of a basic "hole-in-the-wall" camera obscura—ignoring Cardano's improvement of 8 years previous. However, Della Porta went on to describe how to use a concave mirror to project an image onto a piece of paper—without using a lens—prefacing his account with the very portentous words: "Now I will describe that about which I have remained silent until now, and thought to keep secret: how you can see all things with their colors if you desire." Della Porta continues:

> Opposite, place a mirror, not the kind that disperses the light by dissipating, but the kind that unites by collecting together. Move it closer and further away from the hole until you see it reach the perfect and true quantity, approaching the necessary distance from the center. If you look attentively, you will see the face, gestures, movements and clothes of men, the blue sky with dispersed clouds, the very distant mountains, and, in a small circle on a piece of paper, which you will attach above the hole, you will see almost an epitome of the world. These things, when you see them all inverted, will make you marvel to no small degree [13].

This is precisely the device that David Hockney claims was used by artists beginning in the 1430s—his "early" device (Fig. 2). Della Porta, in the 1558 edition of his work, goes on to explain "how someone who doesn't know how to paint can paint the likeness of a man, or another thing, if he only knows how to match the colors," by using this device [14]. The second edition of *Natural Magic*, published over 30 years later in 1589, contained a vastly expanded discussion of the camera obscura. After his description of the old hole-in-the-wall device, Della Porta added a new line: "If you place at the hole a crystal lens, you will immediately see things much more clearly, the faces of those walking in the street, the colours of their clothes, their clothes and all things, just as if you saw them close up, not without enormous pleasure, so that those who see this cannot marvel enough" [15]. This was simply the convex lens suggested by Cardano and Benedetti.

In the second edition, however, Della Porta also added a dramatic revision to his concave mirror camera obscura. First, he had suggested, following Cardano and Benedetti, the use of a lens in the aperture. Now, to turn the images upright, he combined the lens with the concave mirror projection system that he had proposed in 1558. The extraordinary result was a device that projected magnified, upright images. In modern terminology, the inverted image formed by the convex lens, falling at a short distance in front of the focal point of the concave mirror, served as an object for the mirror, which turned it upright and magnified it (Fig. 3).

The crucial section begins:

> But if you wish for the images to appear upright, this will be a great feat, attempted by many but not discovered by anyone until now. Some [perhaps Della Porta refers here to Benedetti] place flat mirrors at an oblique angle near the hole, which reflect an image onto the screen opposite that is more or less upright but dark and confused. We, by placing the white screen at an oblique angle to the hole, and looking towards the part facing the hole, saw the images almost erect but the pyramid [of light] cut obliquely showed the men without any proportion and confusedly. But in the following way you will have what you desire. Place an eyeglass made from a biconvex lens [*specillum e convexis fabricatum*] in front of the hole. From here the image falls on the concave mirror. Place the concave mirror far from the center [i.e. from the focal point of the lens] so that the images which it receives inverted it will show upright, because of the distance from the center. In this way, above the hole on the white paper you will see

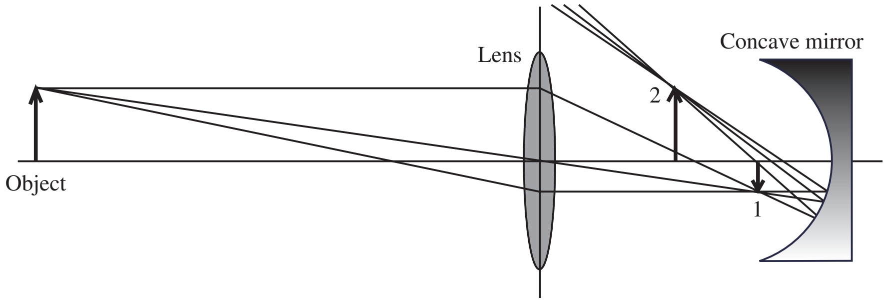



**Fig. 3. Optical diagram of Della Porta's 1589 system. (© Michael John Gorman) The object (on the far left) at 4 m from the lens; the focal length of the lens is 84 cm. The focal length of the concave mirror is 12 cm. A life-size, erect image of the object is produced at circa 1 m from mirror (this is the image numbered "2" in the diagram). The focal point of the lens is a short distance outside the focal point of the mirror, as Della Porta advises. For practical purposes, it is necessary to tilt the concave mirror slightly so that the image (2) is formed on a screen above the aperture containing the lens.**

> the images of the things that are outside so clearly and openly that you will never cease to be delighted and amazed. But here I should warn you, so that you do not waste your efforts, that it is necessary for the lens to be proportioned to the concave mirror, but, as you will see, here we will speak of this many times [16].

Despite this promise, Della Porta never spoke of it again, and never gave away the proportion required between the focal length of the lens and that of the concave mirror. In this way, even a concave mirror of 20 cm in focal length could be used to project life-sized images, given an appropriate convex lens. Such a mirror, and the appropriate lens, unlike the long focal-length concave mirrors required by Hockney's thesis, were within the manufacturing capabilities of the late 16th century, as described by Della Porta himself in vivid detail in *Natural Magic*. This device is never described in Hockney's book (apart from in the garbled translation) and, as far as I know, has not been considered in any of the ensuing discussion.

Clearly, between writing the first and second editions of *Natural Magic,* Giambattista Della Porta made a startling discovery: combining a convex lens with a concave mirror, placed at the correct distance with suitably proportioned focal lengths, could allow very clear, large, upright images to be projected on a screen above the aperture. What happened to the Neapolitan magician between 1558 and 1589 to inspire this new invention? For one thing, he traveled extensively, collecting secrets for publication in his *Natural Magic* and directing performances of his plays for private audiences throughout Italy. One such journey in 1580 took Della Porta to Venice. The following is the description taken from Louise Clubb's account of Della Porta's life:

> Settled in Venice for the time being, Della Porta began work on a parabolic mirror and an "occhiale." The latter was probably a large magnifying or burning glass, or perhaps an experiment in eyeglasses. Campori believed that it was a telescope, hoping to connect the project at Venice with the widespread belief that Della Porta was the original inventor of the telescope. Cardinal d'Este returned alone to Rome, but Della Porta kept him informed of all progress. He was delighted to have at his disposal the skilled glassworkers in the environs of Venice, and reported on November 29, 1580 that with the help of Giacomo Contarini he had found an artisan of Murano capable of constructing the delicate mirror. But if the Venetian craftsmen pleased him, the aria grossa of the lagoons did not, and he blamed it for the new attack of fever which now forced him to bed. When the Cardinal returned to Ferrara, he sent for Della Porta, but the eager lens-designer was loath to leave his Murano project. He used bad weather and his own illness to excuse the delay. Finally, with rather bad grace, he agreed to leave Venice in December 1580, but his love of secrecy was outraged by having to reveal his plans to Contarini and to leave the lens-grinding under his supervision [17].

Although Clubb does not mention this possibility, there can be absolutely no doubt that the "parabolic mirror and occhiale" that Della Porta worked on so intensely in Venice were the vital components of the new camera obscura presented in the 1589 edition of *Natural Magic*. This edition also included a detailed account of the way lenses and mirrors were made in Venice, another by-product of Della Porta's time on the island of Murano in 1580.

Why did Della Porta invest so much time and money in building his new camera obscura? The principal reason seems to have been for his extravagant theatrical productions. The 1589 edition of *Natural Magic* gives a vivid account of using the new device to "see in a dark room a hunt, a battle, and other wonders":

> Now, to reach the end of this material, I will add a secret that is surely the most ingenious and beautiful for pleasing great lords. In a dark room, on white sheets, you can see hunts, banquets, battles of enemies, games, and finally, everything you like, so clear and luminously, and minutely, as if you had them right before your eyes. Let there be a spacious area outside the room where you are going to make these appearances, which can be well illuminated by the sun. In this, you will place trees, houses, woods, mountains, rivers, real beasts or animals made with skill from wood or other materials, which have children inside them who move, as we frequently use in the intermissions of comedies, deer, wild boar, rhinoceroses, elephants, lions and other animals that please you. Each of these emerges one by one from its lair, and comes into the scene, then the hunters come with spears, nets and other necessary instruments, and are seen to hunt the animals, playing horns, trumpets and conches, so that those inside the room see the trees, the animals, and the faces of the hunters, and the other things, so naturally that they cannot tell whether they are real or due to trickery.
>
> Unsheathed swords shining in the sun will give a great splendor inside, which will frighten the audience. Many times I have given such spectacles for my friends, who admired them with great wonder and astonishment. Even though I gave them the explanations of Philosophy and Perspective they did not want to believe that these were natural things, until, opening the door, I showed them the trick [18].

Della Porta's description of theatrical stage settings and "unsheathed swords" frightening the audience makes one think immediately of the dramatic stage-management in the paintings of Caravaggio in the Contarelli chapel in Rome. If Caravaggio had experimented with Della Porta's 1589 device, rather than his 1558 device (Hockney's "early" device) or Cardano's 1550 device (Hockney's "late" device) he would have benefited from an upright image much larger in scale than the image produced by the same mirror without a convex lens.

So, to recap, until 1550, the camera obscura was just a hole in the wall. Then Cardano and later Benedetti fitted a convex lens (a "lens for old people") into the hole. Benedetti added a further oblique mirror to produce a horizontal image.

Della Porta, in 1558, suggested, for the first time, using the "early" Hockney technique: a concave mirror placed in front of the hole in the wall, without a lens. After his visit to Venice in 1580, Della Porta returned to Naples with a new instrument: a long focal length bi-convex lens and a good concave mirror, combined to produce extraordinary quasi-cinematic experiences for his friends and noble patrons. He published the description clearly in the 1589 edition of *Natural Magic,* with an important warning: that the device would not work unless the curvatures of lens and mirror were in suitable proportions. His new device projected magnified, bright, upright images. This device was not described elsewhere beforehand, and we have no reason to believe that it existed before Della Porta made it, with great effort, in Venice in 1580.

Could artists have used Della Porta's latter device, which has not even figured in the debate on Hockney's book so far? It certainly would have solved some of the problems of Hockney's devices as tools for artists: inverted images, the necessity for implausibly long focal lengths and so on. Caravaggio would seem to be an obvious candidate, as he arrived in Rome, as has been noted before, shortly after the publication of the second edition of *Natural Magic.* Della Porta's second device, however, would not produce the left-handed drinkers that Hockney has noticed in some of Caravaggio's paintings. Caravaggio's patron Cardinal del Monte and his brother the mathematician Guidobaldo del Monte would certainly have known Della Porta's work, if not the man himself, and could probably have provided Caravaggio with a suitable mirror and lens, although there is no evidence that they did so. Guidobaldo was even a correspondent of Contarini, who personally supervised the final work on Della Porta's new camera obscura in Venice.

As he wrote to Galileo in 1611, Cardinal del Monte had contacts in Rome who were skilled at grinding rock-glass lenses, still used for more expensive pairs of spectacles in the 17th century. One does not need to invoke a conspiracy of silence to suggest that Caravaggio may have been familiar with the new instrument: the description was published, and the device had in all likelihood been demonstrated theatrically by Della Porta himself in the fashionable salons of Rome and Naples in the manner that he describes in the 1589 *Natural Magic.* Incidentally, one person who was deeply interested in Della Porta's description of his camera obscura was the astronomer Johannes Kepler, who used it as the basis of his account of image formation in the eye and used his own rotating camera obscura to sketch landscapes [19].

It is likely that an artist like Caravaggio would have taken a great interest in optical experimentation with the camera obscura, given his interest in dramatic chiaroscuro effects and the "theatricality" of scenes such as *The Martyrdom of St. Matthew* (Fig. 4). The frescoes in the Contarelli chapel, in particular, represent a striking use of lighting effects that has been the subject of much commentary. Suggesting that Caravaggio may have experimented with the images produced by the new camera obscura does not necessarily imply that he used it to produce "tracing images," a hypothesis that is very problematic. In any case, any painting is, as Michael Baxandall puts it, "the deposit of a social relationship," bearing the traces of a variety of constraints that include available technical equipment, the nature of the commission, the space for which the work is destined, painting materials and the artist's training, so to posit a simple relationship between the image produced by Della Porta's later camera obscura and Caravaggio's works would be naïve, to say the least [20]. Additionally, the use of even Della Porta's improved camera obscura would imply the careful manipulation of natural lighting. Artificial lighting, as David Stork has argued, would not provide sufficient illumination to create a usable image [21]. In the case of the Contarelli chapel frescoes, the use of natural light is plausible. The fact that the window depicted in *The Calling of St. Matthew* is not a source of light suggests that the scene was staged outdoors (Fig. 5). A large flat mirror found in Caravaggio's studio may have been used to reflect sunlight onto his figures.

Where does all this leave the earlier paintings discussed in Hockney's book? The device that he claims was used by artists including Robert Campin and Jan van Eyck in the 1430s was, in all likelihood, invented by Giambattista Della Porta just before 1558 and then rendered obsolete by Della Porta himself in 1580. At the very best, it had perhaps a 35-year working life as an artist's instrument, assuming that it was not just an amusing toy for those unable to draw, as Della Porta himself suggests. If Caravaggio used a camera obscura, he would have had every opportunity to avail himself of the latest technology—Della Porta's combination

**Fig. 4. Michelangelo Merisi da Caravaggio, *The Martyrdom of St. Matthew,* oil on canvas, 127 × 135 in, 1599–1600. Contarelli Chapel, San Luigi dei Francesi, Rome. (Photo © Scala/Art Resource, New York)**

**Fig. 5. Michelangelo Merisi da Caravaggio, *The Calling of St. Matthew*, oil on canvas, 127 × 134 in, 1599–1600. Contarelli Chapel, San Luigi dei Francesi, Rome. (Photo © Scala/Art Resource, New York)**

convex lens–concave mirror instrument. If 15th-century painters ever used the camera obscura, however, they used a simple hole in the wall: no mirror, no lens.

We can nonetheless be grateful to David Hockney and Charles Falco for bringing to our attention a forgotten device that had a short-lived vogue in the 16th century: the camera obscura employing a concave mirror described in the 1558 edition of Giambattista Della Porta's *Natural Magic*.

## POSTSCRIPT: *THE ROMANCE OF THE ROSE*

After the first draft of this article was submitted to *Leonardo,* Charles Falco made the suggestion that *The Romance of the Rose,* composed by Guillaume de Lorris and Jean de Meun in the 13th century, contained a reference to a concave-mirror optical projection system. Falco cites the following passage from the allegorical poem as evidence that the concave-mirror camera obscura was known in the 13th century:

> Those who are masters of mirrors make one image give birth to several: if they have the right form ready, they create four eyes in one head, and they make phantoms appear to those who look within. They even make them appear, quite alive, outside the mirror, either in water or the air [22].

While the statement that "masters of mirrors" make images "appear quite alive, outside the mirror" could be a reference to the properties of concave mirrors, the phenomenon described could simply be the three-dimensional real image seen when one places an object (e.g. a finger) close to twice the focal distance away from the mirror, a phenomenon that was known in the Middle Ages and is familiar to us through optical-illusion toys available from science stores. This phenomenon does not require a surface or screen, and de Meun's text makes no reference to the kind of set-up described by Hockney and Falco. Ibn al-Haytham, whose extensive work on optics was becoming widely available during this period, in Latin translation as *De Aspectibus,* is a likely source of much of de Meun's description of the properties of mirrors. According to A.I. Sabra, an acknowledged expert on Ibn al-Haytham and translator of his optical works, "Ibn al-Haytham does of course treat of 'images' perceived by reflection from spherical, cylindrical and conical concave mirrors. However, I am not aware of any description, in any of his writings, of a projective system involving an aperture, a concave mirror and a screen" [23]. To conclude, *The Romance of the Rose* does not provide support for the existence of the concave-mirror camera obscura prior to 1558.

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### References and Notes

**1.** David Hockney, *Secret Knowledge: Rediscovering the Lost Techniques of the Old Masters* (London: Penguin Putnam, 2001); David Hockney and Charles Falco, "Optical Insights into Renaissance Art," in *Optics and Photonics News* (July 2000). For further discussions of Hockney's thesis, see <http://www.artandoptics.com>.

**2.** Hockney [1] p. 82.

**3.** Hockney [1] p. 118.

**4.** David Stork, "Response to Hockney and Falco," and Christopher W. Tyler, "What Perspective Constructions Reveals about Optical Aids," articles posted on web site <http://www.artandoptics.com>.

**5.** Stork [4].

**6.** Martin Kemp, *The Science of Art: Optical Themes in Western Art from Brunelleschi to Seurat* (New Haven, CT: Yale Univ. Press, 1990).

**7.** See, for example, Svetlana Alpers, *The Art of Describing: Dutch Art in the Seventeenth Century* (Chicago: University of Chicago Press, 1984); Philip Steadman, *Vermeer's Camera: Uncovering the Truth behind the Masterpieces* (Oxford: Oxford Univ. Press, 2001); but see also Walter Liedtke's critical review in *Burlington Magazine* **CXLIII**, No. 1183, 642–643 (October 2001); and Walter Liedtke, *A View of Delft: Vermeer and His Contemporaries* (Zwolle, the Netherlands: Waanders Publishers, 2000).

**8.** Hockney [1] p. 246.

**9.** Helmut Gernsheim, *The History of Photography from the Camera Obscura to the Beginning of the Modern Era* (New York: McGraw-Hill, 1969) pp. 17–42; M.S. Hammond, *The Camera Obscura: A Chapter in the Pre-History of Photography* (Ph.D. dissertation), Ohio State University, 1986 (Ann Arbor, MI: UMI facsimile, 1990).

**10.** Girolamo Cardano, *De subtilitate* (Paris: Ex officina Michaelis Fezandas, 1550), book iv, p. 107, my translation.

**11.** Giovanni Battista Benedetti, *Diversarum speculationum mathematicarum & physicarum liber* (Turin, Italy: apud haeredem Nicolai Bevilaquae, 1585) pp. 270–271, my translation.

**12.** Hockney [1] pp. 208–209.

**13.** Giambattista Della Porta, *Magiae naturalis, sive de miraculis rerum naturalium Libri IIII* (Naples, Italy: Apud Matthiam Cancer, 1558) book iv, my translation.

14. Della Porta [13].

15. Giambattista Della Porta, *Magiae naturalis libri XX. Ab ipso authore expurgati, & superaucti,* 2nd Ed. (Naples, Italy: Apud H. Saluianum, 1589), book XVII, chapter VI, my translation.

16. Della Porta [13], book iv.

17. Louise Clubb, *Giambattista della Porta, Dramatist* (Princeton, NJ: Princeton Univ. Press, 1965) pp. 21–22.

18. Della Porta [13].

19. Johannes Kepler, *Optics: Paralipomena to Witelo and Optical Part of Astronomy,* William H. Donahue, trans. (Santa Fe, NM: Green Lion Press, 2000) pp. 224–226; Alpers [7].

20. Michael Baxandall, *Painting and Experience in Fifteenth Century Italy: A Primer in the Social History of Pictorial Style,* 2nd Ed. (Oxford, U.K.: Oxford Univ. Press, 1988).

21. Stork [4].

22. Guillaume de Lorris and Jean de Meun, *The Romance of the Rose,* Charles Dahlberg, trans., 3rd Ed. (Princeton, NJ: Princeton Univ. Press, 1995); line 18163; quoted by Charles Falco at <http://www.optics.arizona.edu/ssd/FAQ.html>.

23. A.I. Sabra, e-mail message to the author, 30 June 2002. See *The Optics of Ibn Al-Haytham: Books I-III: On Direct Vision,* trans. with introduction and commentary by A.I. Sabra (London: Warburg Institute, 1989). No English translation of the parts of Ibn al-Haytham's work dealing with the properties of curved mirrors is currently available.

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