Art as science: scientific illustration, 1490–1670 in drawing, woodcut and copper plate

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Observation, depiction and description are active forces in the doing of science. Advances in observation and analysis come with advances in techniques of description and communication. In this article, these questions are related to the work of Leonardo da Vinci, 16th-century naturalists and artists like Conrad Gessner and Teodoro Ghisi, and 17th-century micrographers like Robert Hooke.

So much of our thought begins with the senses. Before we can postulate rational formulations of ideas, we actually feel them – intuit them. Artists operate at and play with this intuitive stage. They seek to communicate their understandings nonverbally, in ink, paint, clay, stone or film, or poetically in words that remain on the intuitive level, mediating between feeling and thought. Reasoned explication involves a logical formulation of ideas for presentation to the rational faculties of other minds trained to be literate and articulate.

Science (including scholarship) today or in the past makes use of these various levels of understanding and expression. Even as we write, we know before we find the words what it is we wish to express. An idea hovers in some compartment of our mind (which we might call the Platonic manifestation – or simply the immaterial projection[1] – of the brain's functioning) waiting to be clothed in words before it can go out into the world, taking its message with it. And, once committed to paper (or even made explicit in thought), the idea stimulates further comprehension of both itself and the object of study or meditation. In the doing of science – especially, but by no means exclusively, the doing of the life sciences – this ricochet process often passes through a visual phase. Our understanding is what we might call 'visually intuited'. To get this understanding out of our mind's eye and into communicable form, we may sketch or draw it on paper.

A similar process occurs even when copying (the ancients and Renaissance writers called it 'imitating') a phenomenon or an organism under observation. In this process, the technique of drawing is used to help describe what we observe. In the process, too, the artist–scientist is forced to observe more closely so that he or she may accurately depict the object of study on paper and thence communicate it to other minds. The artist's understanding is required for the depiction and, in a feedback mechanism, this understanding is enhanced by the act of depicting. The artist enters into the object of study on a deeper level than any external study, minus subjective participation, would allow.

Techniques (*technai* or *artes* as they were called in antiquity and the Middle Ages) for the execution of drawings were needed to depict nature accurately. As these techniques became more refined (which they did, at times, depending on the development of media or other techniques such as linear perspective), they permitted an increased accuracy of depiction. Perspective is perhaps the clearest case in point in the early modern period. Linear perspective enabled the creation of an understandable portrayal of nature; its use allowed the artist to recreate and the viewer to seize at once the object of depiction, to visualize it in its three-dimensional form and to understand its volume in space and relative to other objects around it.

However, even in the doing, the use of perspective allowed the artist, including the artist–scientist, to see more clearly by means of the feedback mechanism I have already mentioned. The technical ability to successfully depict what he saw with extreme accuracy reinforced his own ability to see clearly. This is a process we are all familiar with to one degree or another, in any scientific or scholarly work – when our investigative techniques, our methodologies, are well enough honed, we are better able to elicit from our surroundings (e.g. archives, libraries, museums, specimens or experiments) more precise and pertinent data from which to draw more accurate conclusions.

Armed with this technique, and released by a renewed (if tacit) permission from the 'powers that were' to view the physical world on its own terms, close observers of the natural world were increasingly able in the 15th century to communicate their observations on paper, while in the process refining those same observations.

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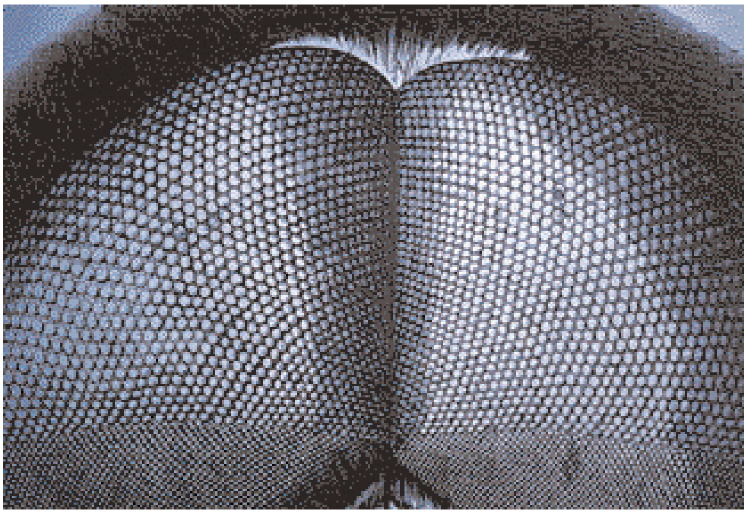

Figure 1 Hooke, 'Eye of the Fly'. [Ref. 5, Schema XXIV (detail)]

Robert Hooke: active observation and description

We must pause to consider the term 'observation'. Ernst Mayr's thoughts on the role of observation in science are pertinent: in natural history, he considers nature to be the experimentor and the scientist's function in the investigation to be precisely that of the observer of nature's experiments[2]. Robert Hooke, in his posthumous *General Scheme or Idea of the Present State of Natural Philosophy*, proposed (even in his, or his associate and editor Waller's, extensive title) to remedy natural philosophy's defects, 'By a Methodical Proceeding in the Making Experiments and Collecting Observations, Whereby to Compile a Natural History, as the Solid Basis for the Superstructure of True Philosophy'[3] (as in the medieval term 'natural philosophy'). (There was no doubt in his mind that truth was an attainable goal, any more than there is in the minds of most practitioners of science today, for particular discernable phenomena or, in some cases, even previously undiscernable phenomena.) Throughout this text, Hooke continues to refer to the duo of Observation and Experiment.

Indeed, observation is by no means the passive state some investigators have labelled it[4]. To make fruitful observations requires active participation by the observer, and one means of participating in the object of our observation is to draw or otherwise depict it, using drawing techniques such as perspective, fineness of line, colour and so forth. In the Preface to his *Micrographia*, that remarkable work from 1665 by which the world was made aware of the precision of nature even among its minutiae, Hooke opens his book by saying that Mankind can behold the works of nature and consider, compare, alter, assist and improve them to various uses. (Notice the pragmatic emphasis in science even then – he even thanks the businessmen who have sponsored the Royal Society's researches and their diffusion.) He can do this, continues Hooke, with the help of Art (meaning, in those days, *techne*) and Experience, and with the help of artificial Instruments and Methods, which will lead him to Observations and Deductions (in the same breath)[5].

Hooke goes on to say that our Senses (which, he notes, 'are in many ways outdone by other creatures') can and should be supported and supplemented by the use of instruments, including the microscope (Ref. 5, fol. *a*2). He allows that our Memory, or retentive faculty, is aided by writing, thereby registering our experience and adding it to what has been accumulated (and also written) over many hundreds of years and by many thousands of men (Ref. 5, fol. *d*). This sort of material, presented to the rational or deductive faculty (usually through vision), allows it to contemplate nature and to draw conclusions from observations of one's own and others' senses, duly recorded by means of writing.

For Hooke, writing is thus a technique, an instrument that furthers knowledge. We can therefore take those other traces on paper or other surfaces – drawings – to be analogously important instruments in the furthering of knowledge. Because he was trained as an artist, we know that his own drawings (of which he closely supervised the engraving) were more than competent representations. We also learn that in making a 'true representation of an object of study', Hooke needed to understand it, by studying it in different light, as he said:

> [B]ecause of these kind of Objects there is much more difficulty to discover the true shape, then (!) of those visible to the naked eye, the same Object seeming quite differing, in one position to the Light, from what it really is, and may be discover'd in another. And therefore I never began to make any

Figure 2 Leonardo da Vinci, ventricles of human brain, *in situ* (early version)[22]. Reproduced with permission from the Royal Collections, Windsor.

Figure 3 Leonardo da Vinci, dissection of human brain[23]. Reproduced with permission from the Royal Collections, Windsor.

> draught before by many examinations in several lights, and in several positions to those lights, I had discover'd the true form. For it is exceedingly difficult in some Objects, to distinguish between a *prominency* and a *depression*, between a *shadow* and a *black stain*, or a *reflection* and a *whiteness in the colour*… The Eyes of a Fly [Figure 1] in one kind of light appear almost like a Lattice… In the Sunshine they look like a surface cover'd with golden Nails; in another posture, like a surface cover'd with Pyramids; in another with Cones; and in other postures of quite other shapes; but that which exhibits the best, is the Light collected on the Object, by those means I have already describ'd. (Ref. 5, fol. *f* 2 verso.)

(The 'means I have already describ'd' were light rays collected by globes filled with saline or by planar convex lenses, from the sky, the sun or a lamp and filtered if necessary through an oiled paper onto the object.)

Observation and description in Leonardo da Vinci's methods

Leonardo da Vinci also understood this in his investigations, in which he clearly uses his pen or pencil as an aid to studying an object or a phenomenon[6]. Although they have, as recently as 1983, been labelled as drawings of an ox's brain, Leonardo's studies of the human brain on Windsor sheet 19127, as convincingly analysed by Georges de Morsier in 1964[7] and confirmed through dissection in May 1999[8], lead us through the process. Looking first at an earlier drawing from Milan (Figure 2; about 1490), we see Leonardo beginning his study of the human brain, here represented *in situ* and in cross section. Clearly, despite Leonardo's detailing of the layers transversed, this drawing was made without actual dissection on his part, for he depicts the three ventricles of the human brain as they were described by Galen from an ox brain.

Windsor 19127 (Figure 3) is clearly later and exhibits several stages of understanding as they develop in the process of dissection and depiction. In the upper left-hand corner, there is a sagittal section of the human brain, the ventricles of which Leonardo had injected with wax in order to see them better. The drawing is clear, although probably made by averaging knowledge from several dissections and is therefore more schematic than accurate: we see the posterior horns of the lateral ventricles as well as the third ventricle in the middle, and the fourth ventricle behind and slightly below it.

The next drawing is of the brain cut sagittal at the midline from the top almost to its base and spread apart so that we see the two halves splayed, and with the lateral ventricles opened for study by cutting the corpus callosum;

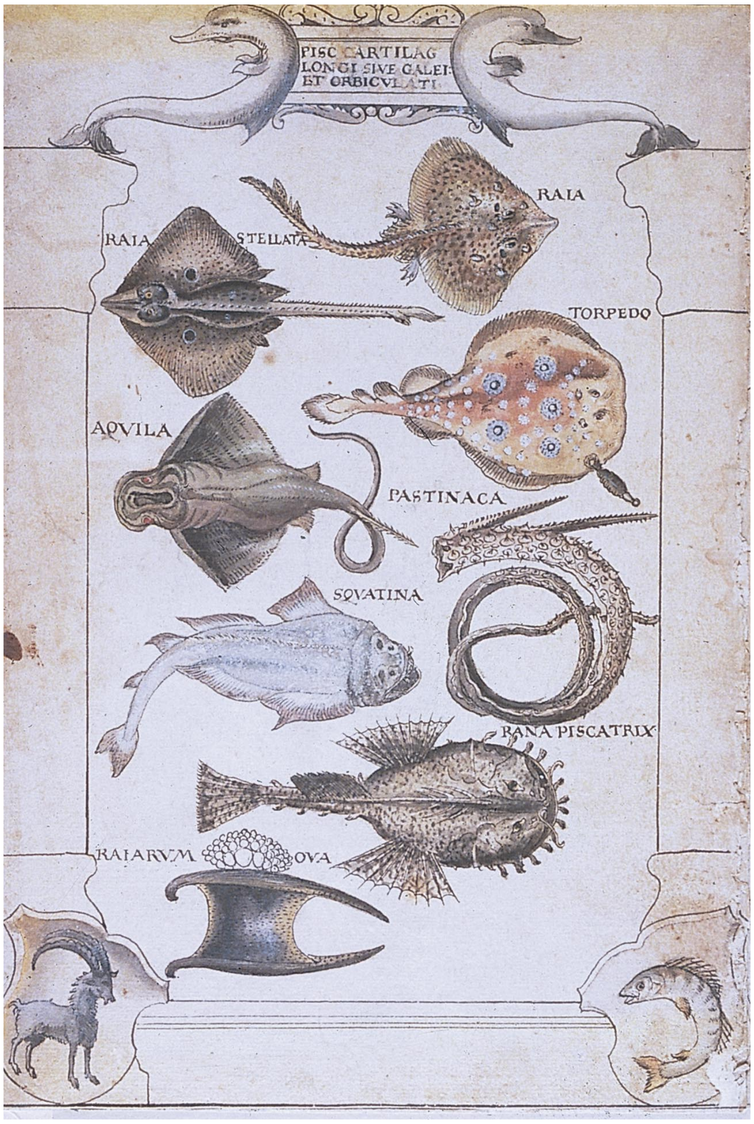

Figure 4 Conrad Gessner, cartilaginous fish and egg case[24].

the round orifice at the centre corresponds to what we now call the Foramen of Monro, leading into the third ventricle[9]. The cerebellum is clear in this drawing – Leonardo is the first to depict it. He is also the first to depict, faintly, to the right of the sagittal cut, a view of the surface of the human brain, complete with cortical convolutions; below this is a small diagram of the principal fissures of the brain (A. Cavaggioni, pers. commun.).

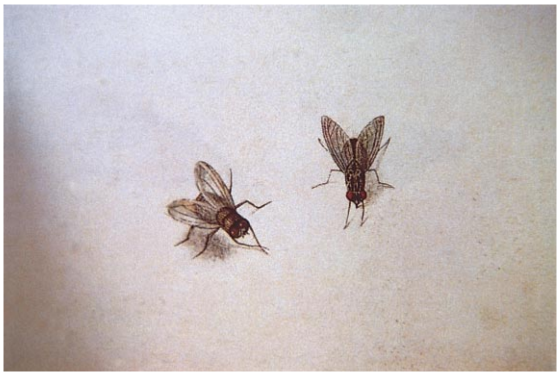

Figure 5 Two of the three species of fly painted by Teodoro Ghisi[25].

Figure 6 Painting by Teodoro Ghisi of the silkworm *Bombyx morae*[26].

On the lower half of the sheet, at the left, there are two faint sketches, the upper one of the inner base of the cranium and the lower one of the base of the brain. Leonardo was evidently interested in matching these two as he drew (as he would do with greater confidence in later drawings[10]). Just to the right of the sketches is the first known drawing of the base of the brain, with the frontal and temporal lobes, and the cerebellum visible, again reasonably correct if we recall that the dissection was being made without directions, on a fresh (unfixed, hence soft) specimen, and that dissecting is an art or technique to be developed in and of itself. The reticulum of blood vessels depicted is indeed a feature of the human brain, the Circle of Willis and its feeders, not the *rete mirabile* deduced by many who have tried to identify this as a bovine brain, which has in any case an entirely different (heart- or arrow-like) shape, with the cerebellum protruding posteriorly.

Passing over the sketch of the trachea flanked by the carotid arteries and jugular veins[11], we come to another drawing of the ventricles in profile, with an indication of the contour of the cerebral cortex. Here, the lateral ventricles are correctly separated along almost their entire length, and the fourth ventricle is not bilobed. The drawing thus comes closer to a correct understanding of the anatomy of the human brain than even the earlier drawing on the same sheet. We have been able to watch Leonardo discovering this through the process of looking, seeing and drawing.

Visual description in 16th-century natural history

During the 16th century, drawing was increasingly used as a tool for understanding and communication. We find the naturalists John Caius, William Turner, Pierre Belon and Guillaume Rondelet communicating by means of drawings the appearance of specimens too fragile to send to each other or to Conrad Gessner of Zürich[12]. Gessner himself recognized the importance of copiously illustrating his text on natural history with drawings, later converted to woodcuts for printing.

Throughout his life, Gessner made wash drawings of plants, preparing to publish an equally extensive set of works on botanical natural history, although this was never realized. We have his drawings for this work, however, and they are made with a keen understanding of the importance of detail to grasping and conveying the characteristics of a plant. So, too, we have some of his own drawings of animals, especially marine animals[13] (Figure 4). These are not only accurate and made with care but are also often heavily annotated, illustrating another of Leonardo's tenets: in order to know a thing, it is necessary to represent and to describe[14].

Gessner's mid- to late-16th-century *Historiae animalium* (one posthumous) became the model for most of the tempera illustrations of Vatican MS Urb. lat. 276, painted by the Mantuan naturalist–artist Teodoro Ghisi in the 1590s[15]. However, at the same time, we find Ghisi working from nature on the illustrations of creatures that he was able to study first hand. There are, for example, three species of fly in the manuscript (Figure 5) and, although Ghisi did not publish in words on the fly (he was a collector and illustrator of natural-history objects, primarily a painter rather than a scholar), close inspection of these flies shows us the level of detailed, critical observation that he applied to his descriptions. The two species here can be identified as *Fannia canicularis* and *Stomoxys calcitrans* by their markings and by the wings. He was thus learning about the flies as he painted them, practicing scientific distinctions.

Some may object that similar accuracy was used by medieval miniaturists in their work of decorating the margins of missals, but Ghisi is focusing instead on matching his illustrations to a textual description, an occupation requiring a critical approach more akin to doing modern science. His ants[16], while not surely identifiable, are captured in a behavioral study, moving their eggs as they do when their nest is disturbed. His silkworm (Figure 6) is justly famous enough to have been included as an illustration for the *Enciclopedia Italiana*[17]. Suffice it to say, its accuracy is valid to this day.

Jacopo Ligozzi, like his contemporary Ghisi, did some work for Ulisse Aldrovandi the Bolognese naturalist. Ligozzi was one of the most accomplished artist–naturalists and was retained by the Medici[18]. The accuracy of his work can be seen in his drawing of the larva of *Saturnia pyri* (Figure 7), which was clearly done with a lens, and probably from a living specimen.

Refining communication as part of science

There is another aspect to this subject: communicating the results of observation. The publication of results can be considered to be part of science for, without it, science (like the history of science) cannot evolve as fruitfully. Here, we encounter the sort of macro-feedback mechanism referred to by E. Eisenstein between the published result and the evolving thought and practice of later scientists[19]. (This is distinct from the feedback mechanism I referred to earlier, which is more subtle and is related to the electronic feedback occurring in the neurons of the functioning brain itself.)

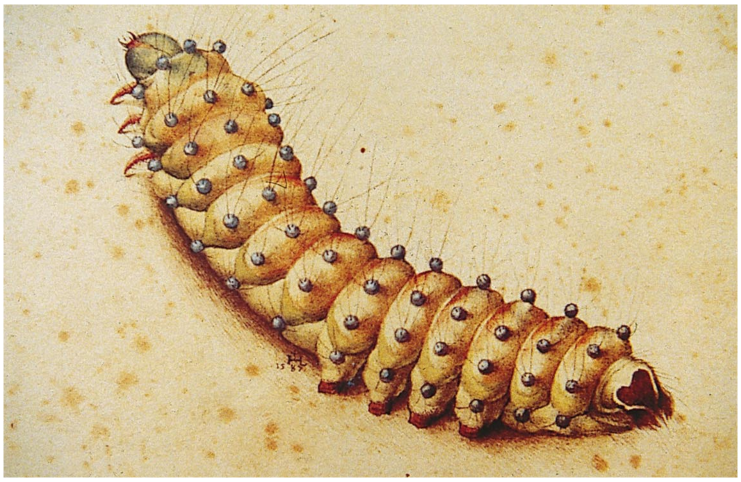

Figure 7 Jacopo Ligozzi, larva of *Saturnia pyri*. (Ref. 18, p. 35)

As early as the 15th century, there began to be a call for illustration as opposed to decoration: in 1460, Ludovico Gonzaga asks Pier Candido Decembrio to leave large margins at the bottoms of the folios of his zoological natural history so that he may better understand the text[20]. This revolutionary request eventually led to the creation of the remarkable document that is the Vatican MS Urb. lat. 276, some of whose illustrations we have been discussing.

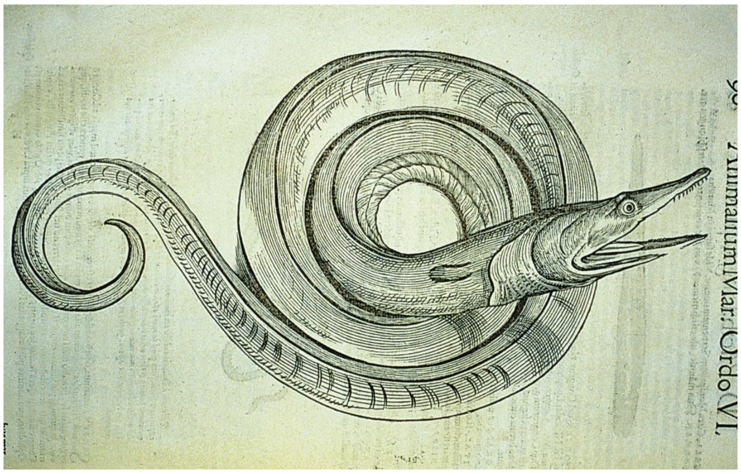

Figure 8 Gessner, *Serpens maris*[27]. Photograph: C.M. Pyle, courtesy of the American Museum of Natural History.

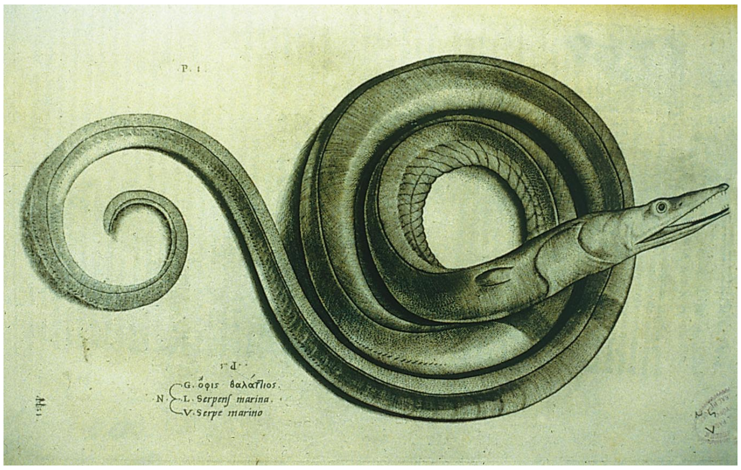

Figure 9 Salviani, *Serpens marina*[28]. Photograph: C.M. Pyle, courtesy of the American Museum of Natural History.

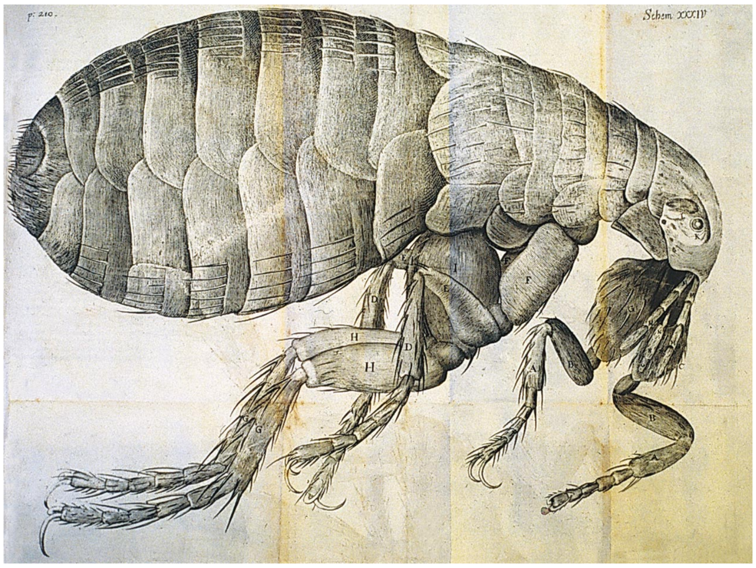

Figure 10 Hooke, *Flea*. (Ref. 5, Schema XXXIV)

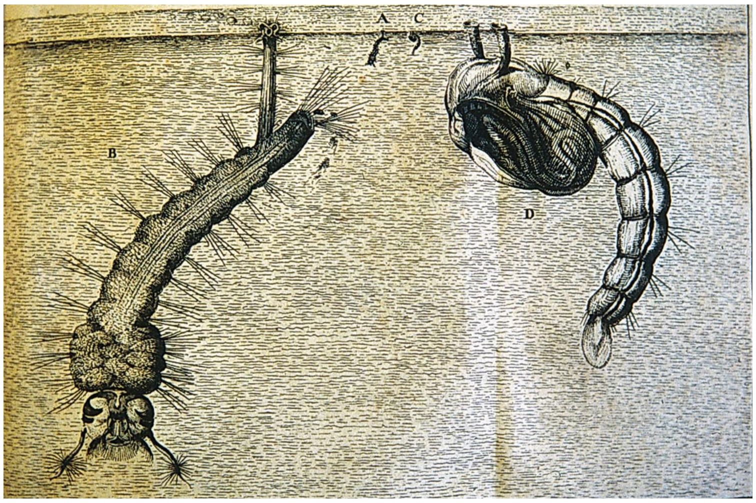

Figure 11 Swammerdam, *Culex* larva and pupa. (Ref. 20, Table II)

In the 16th-century printings of the earliest signal texts on natural history, as well as those on astronomy and physics, woodcuts were used, being the easiest to insert into the printer's form in creating a page format. The positive, uncut surface accepts the ink like the surface of the letters. We can use as an example the so-called *Serpens maris* (now known as *Ophichthys serpens*), which first occurs in a wash drawing by Ligozzi and is later found in Gessner's version of 1560 (Figure 8). However, even in 1554, we find Ippolito Salviani illustrating his remarkable *Aquatilium Animalium Historiae*, not with woodcuts but with separate plates engraved in copper (that is, employing the reverse technique to woodcuts, by printing with the ink collected in the grooves engraved in the plate rather than the ink on the surface). This allowed much more accurate communication of the artist's description of the same fish (Figure 9).

Owing to the exigencies of publishing many illustrations to a text as rapidly as possible, neither Gessner nor most of his contemporaries adopted the more-accurate medium of copper plate. However, it became *de rigueur* in the 17th century for the closely observed illustrations of such

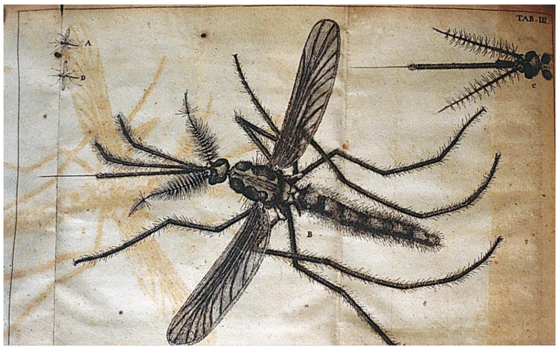

Figure 12 Swammerdam, *Culex* adult. (Ref. 20, Table III)

micrographers as Robert Hooke, whose eye of the fly we have already seen (Figure 1) and whose flea (Figure 10) is well known. Jan Swammerdam, like Hooke, was inclined to art and oversaw with enormous pleasure and care his illustrators' work, insisting on illustrating the relative sizes of the mosquito larva, pupa and adult as seen with the naked eye and with the microscope[21] (Figures 11, 12).

Conclusion

With the discovery of the microscope, we see a new order of analytical description emerging. This is not unlike the kind of analysis performed by Leonardo da Vinci with his lead or silver point in the 15th and early-16th centuries. It seems to represent active analysis in the process of drawing, and analysis deepened by the act of drawing. As the 17th century unfolded, this analysis extends, in the work of Marcello Malpighi and others, to physiological discoveries as well as anatomical ones, fulfilling the active process of discovery through depiction that was practiced by Leonardo da Vinci at the turn of the 16th century.

Acknowledgements

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Notes and references

1 But see Chomsky, N. (1993) *Language and Thought*, Moyer Bell, London, esp. pp. 16–18

2 Mayr, E. (1982) *The Growth of Biological Thought*, Harvard University Press, Cambridge, MA, USA, esp. pp. 31–32; Mayr, E. (1988) *Toward a New Philosophy of Biology: Observations of an Evolutionist*, Harvard University Press, Cambridge, MA, USA

3 Hooke, R. (1705) *The Posthumous Works of Robert Hooke Containing his Cutlerian Lectures and Other Discourses, Read at the Meetings of the Illustrious Royal Society* (Waller, R., ed.), Cass, London. Reprinted in facsimile (1971) Brown, T.M., ed.

4 As H.I. Brown would agree: see Brown, H.I. (1987) *Observation and Objectivity*, Oxford University Press. See also the insightful essay by Gell, P. (1983) Subjectivism and interactionism in arts and science. In *Common Denominators in Art and Science* (Pollock, M., ed.), pp. 81–83, Aberdeen University Press

5 Hooke, R. (1665) *Micrographia: Or Some Physiological Descriptions of Minute Bodies Made by Magnifying Glasses with Observations and Inquiries thereupon* (fol. *a*), Martyn and Allestry, London

6 See the important introduction by Sukale, M. (1987) Sehen als Erkennen: die Grundlagen der Ästhetik bei Leonardo da Vinci. In *Sehen als Erkennen: Wissenschaftliche Zeichnungen von Leonardo da Vinci*, pp. 11–28, Universität Konstanz. The process has been alluded to by other historians as well, for example Ackerman, J. (1985) Early Renaissance ‘naturalism’ and scientific illustration. In *The Natural Sciences and the Arts: Aspects of Interaction from the Renaissance to the 20th Century*, pp. 1–17, Almqvist Wicksell, Stockholm. On the optical techniques employed, see Kemp, M. (1990, rev. 1992) *The Science of Art: Optical Themes in Western Art from Brunelleschi to Seurat*, Yale University Press

7 de Morsier, G. (1964) Léonard de Vinci et l’anatomie du cerveau humain. *Physis* 6, 335–346. Ron Philo is judiciously undecided in Clayton, M. (1992) *Leonardo da Vinci: The Anatomy of Man*, pp. 76–77, Little, Brown and Co., Boston, MA, USA. Charles Gross considers them human with bovine traits, in Gross, C.G. (1998) *Brain, Vision, Memory. Tales in the History of Neuroscience*, pp. 102–103, MIT Press

8 I have recently been able to confirm de Morsier’s analysis by comparing the anatomy of the brains of three oxen (kindly supplied by Prof. A. Cavaggioni and dissected by me) with two human brains, one fixed and the other not (as would have been the case for Leonardo). The latter two were dissected in my presence, following Leonardo’s drawings, by Prof. R. De Caro

9 As we determined during the dissection by Dr De Caro. Compare Gray, H. (1901) *Anatomy: Descriptive and Surgical* (Pickering Pick, T. and Howden, R., eds), pp. 670–671, undated reprint by Running Press, Philadelphia, PA, USA

10 Such as the Weimar sheet [de Morsier, G. (1964) Léonard de Vinci et l’anatomie du cerveau humain. *Physis* 6, 341]; for the skull, Windsor 19057 and 19058, and see Kemp, M. (1971) *Il concetto dell’anima* in Leonardo’s early skull studies. *J. Warburg and Courtauld Inst.* 34, 115–134

11 However, whereas I had thought this to be an extraneous sketch, A. Cavaggioni plausibly believes it to be an integral part of the sheet, because Leonardo might have entered the neck in order to inject wax into the ventricles

12 Pyle, C.M. (1994) Some late sixteenth-century depictions of the aurochs (*Bos primigenius bojanus*, extinct 1627): new evidence from Vatican MS Urb. lat. 276. *Arch. Nat. Hist.* 21, 275–288; Pyle, C.M. (1995) Update… *Arch. Nat. Hist.* 22, 437–438; Pyle, C.M. Conrad Gessner on the spelling of his name. *Arch. Nat. Hist.* (in press)

13 L.B. Holthuis (Curator Emeritus of Crustacea, Nationaal Natuurhistorisch Museum, Leiden, The Netherlands) has published some of the drawings of crustacea used by Gessner in Holthuis, L.B. (1996) Original watercolours donated by Cornelius Sittardus to Conrad Gesner, and published by Gesner in his (1558–1670) works on aquatic animals. *Zool. Med. Leiden* 70, 169–196. Gessner’s drawings of insects are present, though shorn of their notes, in the draft of Moffet, T. (1634) *Insectorum sive minimorum animalium theatrum*, T. Cotes, British Library MS Sloane 4014

14 ‘E tu che vogli con parole dimostrare la figura dell’omo con tutti li aspecti della sua membrificazione, removi da te tale openione, perchè quanto più minutamente descriverai, tanto più confonderai la mente del lectore, e più lo removerai dalla cognizione della cosa descritta; adunque è necessario figurare e descrivere.’ Sabachnikoff, T. and Piumati, G., eds (1898) *I manoscritti di Leonardo da Vinci della Reale Biblioteca di Windsor. Dell’anatomia – Fogli A*, p. 153 and plate 14v, Paris

15 Pyle, C.M. (1984) *Das Tierbuch des Petrus Candidus. Codex Urbinas latinus 276* (2 vols), Belser Verlag, Zürich (Codices e Vaticanis Selecti, LX), Einführungsband, ch. ‘Die Illustrationen’; Pyle, C.M. (1996) The art and science of Renaissance natural history: Thomas of Cantimpré, Pier Candido Decembrio, Conrad Gessner and Teodoro Ghisi in Vatican Library MS Urb. lat. 276. *Viator* 27, 265–321

16 Ghisi, T. *Ants*, Biblioteca Apostolica Vaticana, MS Urb. lat. 276, fol. 195^{v}

17 S.V. Decembrio, P.C. *Enciclopedia Italiana*, Istituto G. Treccanni

18 Tongiorgi Tomasi, L., ed. (1993) *I Ritratti di Piante di Jacopo Ligozzi*, Pecini, Ospedaletto, Pisa

19 Eisenstein, E.L. (1980) *The Printing Press as an Agent of Change: Communications and Cultural Transformations in Early-Modern Europe* (Vols I, II), Cambridge University Press

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21 Swammerdam, J. (1685) *Historia Insectorum Generalis*, Jordanus Luchtmans, Lugduni Batarorum

22 Windsor 12603^{r}, ca. 1490. From Nosotti, S., ed. (1983) *Leonardo da Vinci: L’intuizione Della Natura*, Giunti Barbèra, Firenze

23 Windsor 19127^{r}, ca. 1504–1507. From Nosotti, S., ed. (1983) *Leonardo da Vinci: L’intuizione Della Natura*, Giunti Barbèra, Firenze

24 Handschriftenabteilung, Zentralbibliothek Zürich

25 Ghisi, T. *Flies*. Biblioteca Apostolica Vaticana, MS Urb. lat. 276, fol. 198^{r}

26 Ghisi, T. *Silkworm*. Biblioteca Apostolica Vaticana, MS Urb. lat. 276, fol. 197^{r}

27 Gessner, C. (1560) *Nomenclator Aquatilium Animalium*, p. 90, Zürich, in the American Museum of Natural History

28 Salviani, I. (1554) *Aquatilium Animalium Historiae*, Plate 2, Rome, in the American Museum of Natural History