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Epistemic Images in Early-Modern Mixed Mathematics

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1. Related Topics

Mechanics, *disegno*, art and science, engineering, physico-mathematics, machines,

2. Introduction: Epistemic Images

Challenging Ancient textual authorities, images are ubiquitous in the early-modern regime of knowledge: from Vesalius’ *De humani corporis fabrica*, to Newton’s *Principia* through Hooke’s *Micrographia*, illustrations, depictions, figures, diagrams, and schematics are legion. Drawing on the history of books (Kusukawa 2012), the history of art (Galison and Jones 1998), and visual studies (Bredekamp et al. 2015), recent scholarship on scientific imagery within the print culture helped to shed light on various aspects of the many early-modern visual cultures. Images of knowledge are situated and have to be contextualised with their surrounding texts and other images; they are embodied in a material medium – a book, a leaflet, a letter –; they are embedded in a network of practitioners – drawers, engravers, editors, readers... These studies highlighted the central epistemological role played by inscriptions at large in the early-modern development of natural knowledge (Latour 1990), as well as they made more complex the interplay between art and science from the 15th to the 18th century (Dupré 2010; Marr 2016).

If medicine, botany, and natural history (Magureanu, this volume), schematics, trees, and diagrams (Lee, this volume), statics and machine drawing (Lefèvre 2004), or alchemy (Forshaw, this volume) have been studied, mixed mathematics, on the other hand, have hardly been dealt with. Two main reasons can be invoked to explain this negligence. First, images in mixed mathematics are scarce before the end of the 16th century – the very term “mixed mathematics” only appears at the beginning of the 17th century under Bacon’s pen – and are either replaced by schematics with the advent of physico-mathematics at the beginning of the 18th century (Bertoloni Meli 2006), or even completely disappear with the conjoint development of algebraic analysis and symbolic notations (see conclusion). Second, images *in* mixed mathematics are not specifically images *of* mixed mathematics. Indeed, situated at the crossroad of several knowledge traditions, mixed mathematics is also at the crossroad of many pictorial traditions (see next section); thus, when seen from the perspective of print culture, images of mixed mathematics can be assigned to either of these traditions, thereby eschewing their specificity.

Therefore, in order to seize the peculiarity of images of mixed mathematics during the 17th century, it is of utmost importance to go beyond print culture and focus on inscriptions in the making. Dodging the debate on the naturalism of visual representations, that usually reduces images to mere illustrations, we would better understand images and their making as fully-fledged instruments of knowing: endowed with a peculiar materiality, they are a *medium* that at once allows and shapes knowledge, as well as it entails specific bodily practices. They are therefore a second nature, or, in the words of Lorraine Daston, epistemic images: “An epistemic image is one made with the intent not only of depicting the object of scientific inquiry but also of replacing it. A successful epistemic image becomes a working object of science.” (Daston 2015, 13) Thus, turning to the making of epistemic images in mixed mathematics, and focusing on the material practices they foster and require, we will try to circumscribe their specificity.

3. At the Crossroad of Pictorial Traditions

First, let us briefly outline what constitutes mixed mathematics and its visual representations. In Aristotelian philosophy, physics, or *scientia naturalis*, is the science of a specific kind of being: nature or *physis*. A quick detour by the first book of Aristotle’s *Posterior Analytics* now teaches us that a science can only embrace one kind of being. Physics and mathematics therefore seem incommensurable; the former dealing with change, the latter with eternal beings. Yet, turning to book M of Aristotle’s *Metaphysics*, and more particularly to the legitimation of mathematical abstraction, we learn that it is possible for the philosopher to use a specific science to deal with a different kind of being, if and only if existence and essence belong to two distinct genera, and therefore are described by two distinct philosophies.

These mixed sciences, from an Aristotelian point of view, are subaltern sciences: describing an object of a specific kind with methods and tools drawn from a science dedicated to a different kind, they are subordinated to the latter. Within this regime of subalternation, they are also called *scientiæ mediæ*. Therefore, in between pure mathematics – encompassing geometry, arithmetic, harmonics – and natural philosophy, stands mixed mathematics. Such is the case for mechanics in general, and in particular hydraulics, the science of machines, ballistics, celestial mechanics or astronomy, as well as optics or perspective. Reciprocally, mixed sciences can put physical machines to work in order to carry out reasoning or mathematical reckoning, as is the case for Renaissance *maestri d’abaco* who ran their shops thanks to practical algebra. The progressive convergence between mathematics and natural philosophy and their eventual merging into a physico-mathematics, where only contempt for subaltern sciences reigned before, is the matter of the 17th century, from Galileo in Italy to Varignon in France.

Therefore, during the 17th century, mixed mathematics is still considered a subaltern science which, for a majority of natural philosophers is not a branch of physics but a mere practical application of quantitative tools. Still in an ambiguous position, astride many contradictory fields, it is precisely because it is counted among the *scientiæ mediæ* since the Antiquity and linked with the *artes mechanicæ* that mixed mathematics is, throughout the whole 17th century, at the nexus of experimentation, arts, mathematics, engineering, and natural philosophy (Stan, this volume). Thus, in the early-modern period, mixed mathematics draws on a wide variety of mathematical and philosophical knowledge as well as practical and pictorial know-how.

At the crossroad of statics, mechanics, and mathematics, mixed mathematics equally stands at the crossroad of diverse pictorial traditions. First and foremost, it draws from statics, or the science of weights, as it was refined from Medieval heritage notably by Flemish mathematician and engineer Simon

Stevin at the turn of the 16th and 17th centuries. Modelling machines and mechanisms with the combination of a finite set of simple machines, the graphical representations of statics rely on the assemblage of weights, ropes, pulleys, wedges, screws, and inclined planes. This kind of graphical representation can be seen, for example, in an attempt by Tuscan engineer Vincenzo Viviani in 1697 to model cracks and fissures in Brunelleschi's cupola with a set of planes representing the cupola itself, levers standing for internal rotational displacement, and weights acting as forces through pulleys and ropes (see fig. 1) (Dumas Primbault 2020a).

Second, mixed mathematics draws from the mechanical arts and the visual representation of machines and mechanisms either *as seen by the eye* or *as it would be seen cut or disassembled*. To that end, it relies heavily on the use of linear perspective – rooted in Euclidean geometry and supported by *chiaroscuro* (see next section) – and on the development of new modes of technical representation that were first in use in engineering and architecture, in particular machines and fortifications: cross-sections, exploded views, and projections (Lefèvre 2004). Figure 2 is an exploded cross-section representing Viviani's design for a simple telescope and that evokes earlier modes of depiction used by Vinci or in Ghiberti's famous *zibaldone*.

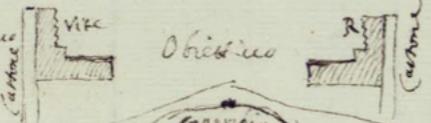
Third, as a species of mathematics, mixed mathematics also makes use of more abstract analytical schematics such as curve representations, geometrical modelling, and symbolic notation (see conclusion).

Copula
pulsatilis oculi

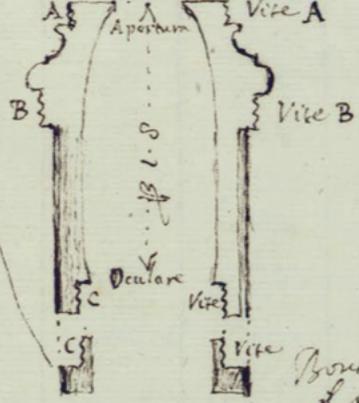


Grillo d'osso che con la
Vite R serve l'obietivo
nella Brucetta in colla
alla bocca del canone
maggi.

Spicchetto di
Borsolo l'obietivo
in colla dentro la
bocca del canone
maggi. di altre



Corona
A lunghezza dell'oculare
Borsolo



Questi due pezzi
trattati insieme
concongono il canone
dell'oculare, che entra
nel p. dello d'osso
di cartone DD e s'adi
serva ad essere in colla
nella Vite B.

Brucetta di Borsolo che ferma
il p. Oculare

Brucetta di Borsolo che
è in colla alla bocca del p.
dello d'osso

Bravo pezzo d'osso
di cartone che serve a
sostenere il p. dell'
oculare e in colla
nella Vite B. e in colla
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nella Vite Y. e in colla
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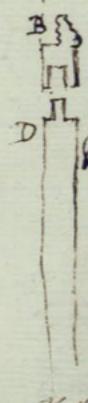
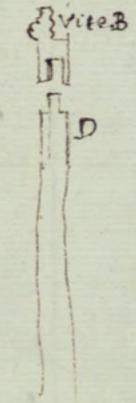
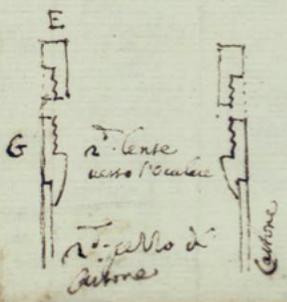


Figure 2 BNCF, Gal. 243, f°24r.

4. *Disegno* for Artists and Scientists Alike

Beyond the apparent discrepancy that separates these pictorial traditions – static images, naturalist or technical depiction of mechanics, and schematics of pure mathematics –, their common denominator is to be found in the rationalisation of sight that began with the development of perspective in medieval Italy. According to Edgerton (2009), Giotto's practical linear perspective, hand in hand with Euclidean mathematics, helped geometrize the realm of the visible and order it along a few basic principles – vanishing point, line of sight, projection planes, foreshortening – with the consequence to disentangle objects and viewpoints by depicting the former *as seen*. This widening of the gap between an object and its representation is said to have fostered a certain definition of objectivity whereby, the properties of an object of study being theoretically independent of its representation, images become statements in themselves, they become epistemic images.

Prolonging this epistemological stance, we may now understand why the *Accademia delle arti del disegno* was founded in Florence in 1563 with the intent to train engineers and architects:

The teaching of mathematics in the academy was surely intended to engender a facility in the theory and practice of *disegno*. However, the instruction Viviani offered in the academy (like that offered by Coccapani, del Bianco, and Torricelli before him) must have served, at least in the mind of Ferdinando II, as an efficacious way of grooming civil and military engineers and architects, who could contribute to a program of public works as well as to a politics of culture in the Medici State. (Barzman 2000, 97)

One of the major concepts of Renaissance art theory in Italy, *disegno* includes both drawing, as the linear outline, and design, as the conception of a creative project. Inherited from Alberti and Vinci, then reappraised by Vasari (Ciaravino 2004), the discipline and practice of *disegno* rests on the three pillars of linear perspective, *chiaroscuro*, and Euclidean geometry. Borrowing from Flemish naturalism (Alpers 1983) and Bolognese painting, Florentine drawing stands in opposition to Venetian color and, within a court culture that does not differentiate between an artist and a scientist, is more than just a means of depiction. Through *scuole private* and the eponymous *Accademia*, *disegno* in 17th century Italy is a fully-fledged instrument of knowledge and a means of acting on the world.

Fundamentally mathematical, the theory and practice of *disegno* is then at the heart of a flourishing mixed mathematics. It is an “epistemological medium” that at once allows and shapes the practice of mixed mathematics by mediating between eyes and hands in the act of thinking: “The act of drawing thus appears as a resumption of the act of thinking, and it is noteworthy that these two activities, thinking and drawing, are shown as something nearly coincidental” (Oy-Marra 2014, 116). Indeed, *disegno* is as much a concept of art theory as it is an embodied skill relying not only on hand gestures but on eye know-how. It requires learning how to meticulously observe, how to extract relevant forms, masses, and volumes, how to translate them into a graphical language that will allow for knowledge and technical intervention.

Within the Florentine court culture where no clear distinction is made between the mechanical arts, the pictorial arts, and mathematics, *disegno* acts as a practice, an epistemology, as well as a discipline of body and mind for artists, scientists, and engineers alike, and is at the roots of the many ways of representing the natural world in mixed mathematics. Recent studies have indeed showed how Galileo's “graphical intelligence” essentially relies on *disegno* understood as a “visual form of thinking” (Bredenkamp 2019), or how his Urbinate contemporary Mutio Oddi saw his practice of mathematics, architecture, and engineering bound by *disegno* as “a coherent body of knowledge and practices” (Marr 2011, 167).

5. From Depicting to Modelling

In order to better illustrate the intricate relationship that existed then between ways of depicting in mixed mathematics and to see *disegno* at work at their core, it is necessary, as we saw, to go beyond print culture – where we would miss the continuity that exists between observing, depicting, geometrising, and modelling. To that end, let us go back to Vincenzo Viviani whom we very briefly introduced earlier, and more particularly to his field sketches.

Viviani, who was born in Florence in 1622, was first taught at a local Jesuit college before being sent to Galileo's service in 1639. From then on until the astronomer's death in 1642, Viviani is Galileo's last disciple, a title that he cherished and put forward until his own death in 1703. He strove all his life to become a renowned mathematician. Extolling the supposed purity of Euclid's geometry, he sought to recover the lost knowledge of the Ancients, and fashioned himself a *persona* as the last heir of the Euclidean tradition. However, Viviani was not appointed *primo matematico* before 1666 and spent most of his life working as an engineer for the Tuscan Court. *Aiuto* for his second master, the engineer and artist Baccio del Bianco, then *ingegnere*, Viviani was taught *disegno* in private schools, on the field by imitating Bianco, and at the *Accademia*, where he will become professor after Torricelli's death in 1647.

Serving the engineering corps of the *Capitani di parte guelfa*, in charge of domanial territories, fortifications, court spectacles, and taxes, Viviani dealt, among other things, with water management in the whole Val d'Arno. First following Baccio del Bianco, then with his own personal aide, he frequently went on field trips in the Tuscan countryside so as to undertake topographic surveys and measurements in order to carry out the work necessary to control floods and droughts, and to prevent soil erosion and landslides eventually. Viviani's personal archive, conserved at the Biblioteca Nazionale Centrale di Firenze along with Galileo's papers, is replete with field notes – *appunti* – taken at different times and places across Tuscany and that illustrate well his practice of *disegno*.

Delving into Viviani's *appunti* of the year 1649, we promptly realise that grotesque genre scenes mix with rough sketches of the arms of the Arno (see fig. 3), that naturalist depictions of landscapes mingle with notes, calculus, and cross-sections of architectural plans (see fig. 4) – in other words, that all means of visual representation are inextricably entwined to the extent that they are sometimes drawn on both sides of the same sheet of paper. This continuity of *disegno* in mixed mathematics is undergirded by a set of field practices such as observing, describing, note-taking, sketching, measuring, locating, and eventually technically intervening on the land – first through *disegno*, then through local or lower scale experiments, and finally through long-term engineering projects.

It is tempting to see in these images the gradual abstraction of representation from naturalist depictions of landscapes to the Arno being modelled by a series of perfect rectangles whose dimensions result from field measurements (see fig. 5) (Maffioli 2010). Yet, this teleological understanding would obscure the fact that, sometimes mixing them by adding measurements on a seemingly naturalist landscape for example, Viviani constantly shuttles back and forth between different means of visualization “bound together through their common reliance on – or relationship to – geometry” (Marr 2011, 167). Just like Galileo's endeavor in his *Two New Sciences* to put Euclidean geometry to use in the study of the natural world, after Mutio Oddi's undifferentiated practice of arts and mathematics through *disegno*, a few years after Teofilo Gallicini's “*matematica media*” in Sienna (Payne 2012), Viviani's mixed mathematics is geometrical as well as mechanical through and through – a “geometrical mechanics” or “mechanical geometry” as he called it – and the images he produces are scattered along the continuous spectrum that goes from depicting to modelling.



Figure 3 BNCF, Gal. 238, ff°79r-82v.



Figure 4 BNCF, Gal. 238, ff°115r-118v.

Ad. r. Obbe in foud doppo mello: 511

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 stato fudo di 8^o - 15.4 della fase trarata obbe n. 10
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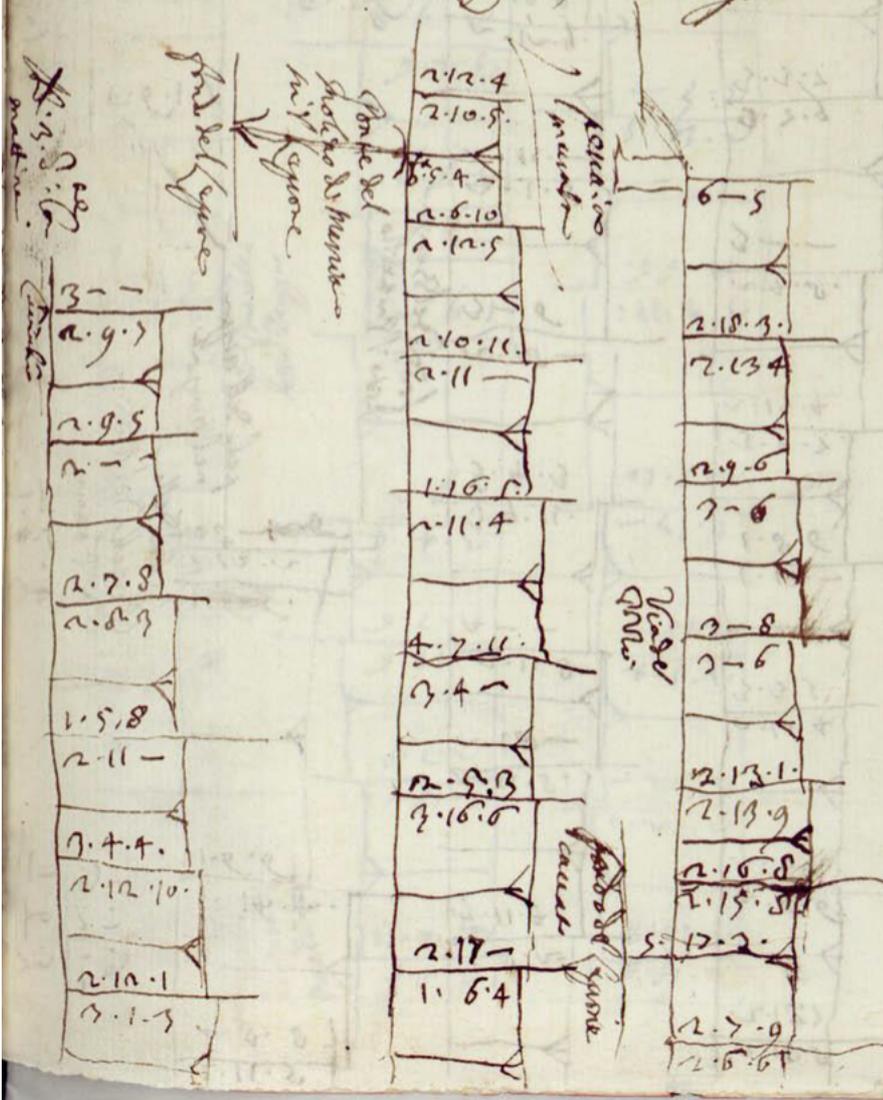


Figure 5 BNCF, Gal. 238, f°54v.

6. Conclusion: towards Physico-Mathematics

Nonetheless, the early-modern period is not the locus of a clear consensus on visual representation in sciences. No sooner than the 17th century, outside Italy, linear perspective is reappraised and gradually replaced by other means of representation: “The Renaissance naturalist image, built on the art of perspective and the ideal of imitation of nature, is replaced by an ‘art of dynamic interaction’” (Van Damme 2020, 167). Rather than looking to mimic its object, it is therefore expected of a visual representation that it exposes the very mediations that enables it to become an epistemic image. Although Viviani does so by modelling the course of the Arno with geometric shapes rather than stopping at its naturalist depiction, the practice of *disegno* is perspectival through and through and heavily relies on the practice of observation.

More than twenty years younger than Viviani, Gottfried Wilhelm Leibniz (Lyssy, this volume) is notably myopic and did not leave a single note on pictorial arts or architecture after his Grand Tour to Italy when, among others, he visited Viviani in 1689. Yet, Leibniz’s personal papers are replete with visual representations. If his mechanical drawings of a reckoning machine were too sketchy for a clockmaker to build a functioning prototype (Jones 2016), his schematics allowed him to model mixed mathematical problems with no practical skill of linear perspective (see fig. 6). By coining the term “blind thinking” to describe the specific way of thinking opened by his calculus (Aït-Touati and Gaukroger 2017, ch. 4), Leibniz may have suggested that he was operating a shift from the ‘eye of the body’ to ‘eye of the mind’. Rather, the epistemic images he manipulates on the surface of his working papers betray another kind of reliance on bodily visualisation: that of the analytical and combinatorial organisation of the page (Dumas Primbault 2020b), and of mathematical symbolic notation in relation with schematics (Knobloch 2004). In other words:

The materiality and visibility of the signs is the condition for their operative manipulability. The eye and the hand work together in these operations. A calculized expression is true if its syntax is proper. Calculization is an intellectual tool that actually permits a kind of “blindness”, a blindness to the semantic meaning of the signs. (Krämer 2012, 372)

At the turn of the 17th and 18th centuries, while a nascent physico-mathematics is slowly replacing mixed mathematics, entailing a shift in visual cultures from Italy towards the Holy Roman Empire, France, and England, the practice of *disegno* is gradually relegated to mere artistic craftsmanship. Images in physico-mathematics become a bone of contention to the extent that some Enlightenment physicists, like Lagrange, ban the use of geometry in order to root the straightforwardness and certainty of their demonstrations in the very absence of any kind of figures.

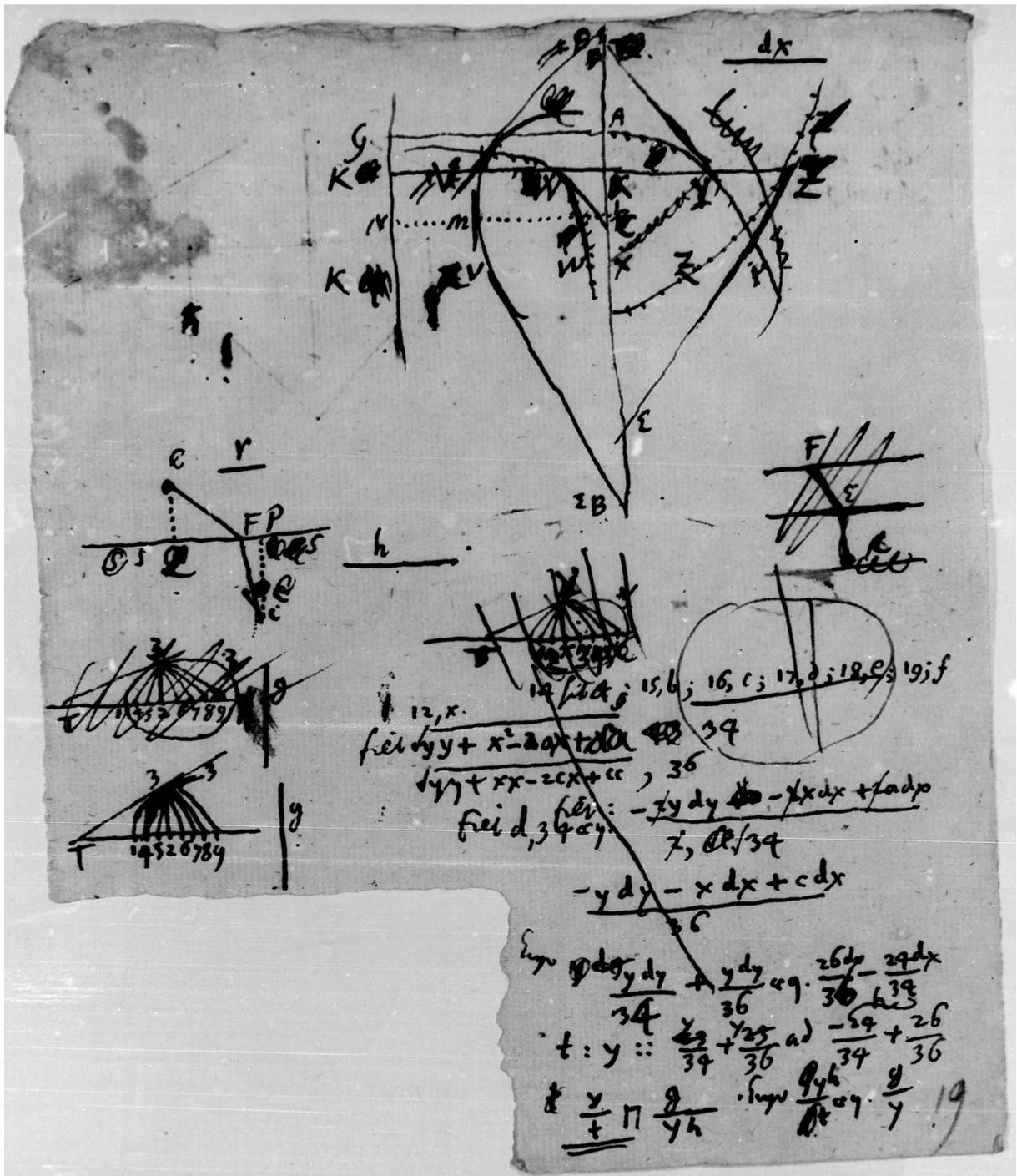


Figure 6 Gottfried-Wilhelm-Leibniz-Bibliothek (GWLB), Leibniz Handschriften (LH), XXXV, 5, 25, f°19r.

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