Chapter 7
Capturing, Modeling, Overseeing, and Making Credible: The Functions of Vision and Visual Material at the *Accademia del Cimento*

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Abstract The *Accademia del Cimento* (Florence) is the first European academy to be supported by a public power and to put experimentation at the core of scientific activity. During its activity (1657–1667), the Cimento carried out hundreds of experiments. A minor part of them is collected in the only printed work produced by the Accademia, the *Saggi di Naturali Esperienze* (1667). Almost one hundred illustrations accompany the twelve groups of experiments presented in the *Saggi*. They are mainly drawings of instruments and experimental apparatus. In spite of the sumptuousness of the edition, these drawings are characterized by a functional simplicity. Tables, diagrams and illustrations also punctuate diaries, handwritten notes and correspondence. A study of the unpublished documents shows the role of visual images in experimental design and allows to explore the wider problem of the relationship between thought and vision. This contribution analyses the epistemic function of vision in the Cimento's experiments and debates around the issue of natural freezing and the properties of heat and cold. Discussions on the topic include geometrical demonstrations and mathematical representations, punctually excluded from the *Saggi* but occasionally resumed by individual members in later works.

Keywords *Accademia del Cimento* · Institutions · Experiments · Heat/cold · Geometrical demonstrations

7.1 An Institutional Context: The Florentine *Accademia del Cimento* (1657–1667)

This contribution examines an institutional context; specifically, it explores the use of vision and visual material within the activities of the Florentine *Accademia del Cimento.*

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The *Accademia del Cimento* was one of the first scientific academies in Europe to be supported by a public power, and to pay increased and exclusive attention to the study of natural phenomena through the systematic use of experiments.

It lasted only ten years (1657–1667)—the same years that saw the establishment of societies of greater fame and longevity, such as the *Royal Society* and the *Académie Royale des Sciences*—and its research was based not only on experimental practice, but also on collegial activity. Experiments were proposed by the members of the Cimento or its patron, Prince Leopoldo de Medici (1617–1665), and then collectively carried out within academic sessions. As will be seen, the collegial and public nature of the Accademia is also reflected in the role that images took on within the group's work and its dissemination.

During the ten years of its activity, the Cimento carried out hundreds of experiments: The diaries, compiled by the members, list more than six hundred academic sessions, and at least one or more experiments was carried out during each meeting. The objects of such experiments were varied. The question of air pressure and the void was one of the most debated within the Cimento. Besides replicating Evangelista Torricelli's (1608–1647) experiment, famously described in a letter to Michelangelo Ricci (1619–1682) in June 1644, with many variations, the academicians also observed various objects placed in the "void:" from the shape taken by water drops to the attraction of a magnet, from the swelling of bladders to the unique motion of smoke. They did not hesitate to create a vacuum and trap birds, butterflies, flies, crickets, lizards, and fish therein to observe their reactions. The academicians also carried out a large number of experiments on the nature of heat and cold, and on the process of natural freezing. Whereas pneumatics and thermology where undoubtedly the predominant research strands in the Cimento, various experiments were also performed in other areas of physics. To name a few examples, the Cimento academicians studied falling bodies, projectile motion, and pendulum motion; they analyzed the weight and incompressibility of liquids; they conducted experiments on distillation and combustion, and studied changes of color in liquid mixtures; they investigated the "electric virtue" of various substances and carried out experiments involving magnets; building up on Pierre Gassendi's (1592–1655) experiments, they attempted to measure the speed of sound. Moreover, the members of the Cimento took an interest in astronomical questions and demonstrated an inclination—though perhaps never too deep—toward the study of the nature of life, the structure and forms of living bodies, and the sensibility and physiological complexity of the various parts of an organism.

7.2 The Function of Visual Material in the Only Work Published by the Cimento: The *Saggi di Naturali Esperienze* (1667)

A small part of the experiments carried out between 1657 and 1667 is collected in the only printed work produced by the Cimento, the *Saggi di Naturali Esperienze* (1667).

The book was intended to revive the glory of the Medici family, whose extraordinary patronage of science had been celebrated all over Europe. It was published in a sumptuous folio edition with ornate chapter initials and section headings featuring floral and figural decorations and images. A full-page portrait of Grand Duke Ferdinand II (1610–1670), to whom the book was dedicated, followed the title page printed in red and black.

Curiously, one of the first pieces of information circulating about the book (at that time still unpublished) concerned an image, and the precise description of the Cimento's device (*impresa*) that should have been printed on the frontispiece. At the beginning of 1666, Lorenzo Magalotti (1637–1717) wrote to Alessandro Segni (1633–1697), his predecessor as secretary of the Cimento, at that moment in Paris:

> …I send you the title decided upon by the Academicians, that shall serve to correct the one you wrote to me: *Saggi di naturali esperienze fatte nell'Accademia del Cimento sotto la protezione del Serenissimo Principe Leopoldo di Toscana descritte dal Segretario di essa Accademia. A Ferdinando Secondo Gran Duca di Toscana.* Below this is set the figure with the following: A jug that they use for the royal cementation of gold, with a mass of gold at the bottom that dissolves in aquafort; it is recognizable to the experienced from the shape of the container and from the smoke coming out, even if it has no fire under it. The motto is taken from Dante: "Provando e riprovando" ["By testing and testing again"]. At the foot of the figure there is written "Cimento," which is the name.[1]

Actually, in its final form, the *impresa* depicted a furnace with three crucibles filled with molten metals to be tested (Fig. 7.1). On the top of the picture, a fluttering decorative ribbon set out the Dante motto: "Provando e riprovando:" "trying and trying again" or "testing and retesting"). There are no records disclosing what led to the choice of the image and we do not possess (or cannot exactly identify) the preparatory drawings of the illustration described by Magalotti to Segni. At any rate, both images emphasized the experimental nature of the Accademia. The *impresa* was a fundamental totem for many Renaissance and Early Modern academies (Quondam

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[1] "…le mando il titolo fermato e stabilito da' Signori Accademici, che intanto servirà a corregger quello che V.S.Ill.^{ma} mi ha scritto darsele costà: *Saggi di naturali esperienze fatte nell'Accademia del Cimento sotto la protezione del Ser.^{mo} P.^{pe} Leopoldo di Toscana descritte dal Segretario di essa Accademia. A Ferdinando Secondo Gran Duca di Toscana.* Sotto a questo va la cartella con la seguente impresa: Una caraffa di quelle che s'adoprano al cimento regio dell'oro, con una massa d'oro nel fondo che si solve in acqua forte, il che si riconosce da' periti dalla figura della stessa boccia e dal fumar ch'ella fa, quantunque non abbia sotto il fuoco. Il motto preso da Dante: "Provando e riprovando." In piè della cartella v'è scritto: "Cimento, ch'è nome." Lorenzo Magalotti to Alessandro Segni, January 15th, 1666, ACF, Stanza 5, *Carteggio Segni*, 130r–131v, published in (Mirto 2016, 140–141). English translation in (Mirto 2009, 144).

Fig. 7.1 The impresa printed in the *Saggi*. From (Magalotti 1667, frontispiece). Smithsonian Libraries / Public Domain

1982).[2] It was a deep, communicative intertwining of pictures and words, between the visual image and the motto that accompanied it. In keeping with this Renaissance academic tradition, the *Accademia del Cimento* displayed its *impresa*: a visible mark, a figurative expression of its identity.

Almost one hundred illustrations accompany the twelve groups of experiments presented in the *Saggi*. They are mainly drawings of instruments and experimental apparatus. In spite of the sumptuousness of the edition, these drawings have a functional simplicity and an absence of decorations and embellishments. They often are simplified abstractions of the experimental apparatus showing the apparatus' internal workings.

The publication was anonymous. By omitting the names of the authors, a maximum emphasis was given to the Accademia and its patron. As a result, the Cimento was presented as a cohesive institution working on behalf of the Medici family. Lorenzo Magalotti, the secretary of the Accademia, became the Cimento's voice on paper. Prince Leopoldo de Medici assigned him to select the experiments to be published and to draft the text. The manuscript of the *Saggi* was substantially ready in 1664 (Mirto 2009), but the volume was only published in 1667. The rough copies went through various changes and edits from the other members of the Cimento. Among the notes and corrections to Magalotti's draft of the *Saggi*, one can also find remarks on the figures (Figs. 7.2 and 7.3).

[2] According to Maylander's classification, forty-three percent of sixteenth-century academies and 50% of seventeenth-century academies used an *impresa*. For many such academies, the *impresa* is the only surviving artifact aside from their name (Maylender 1926–1930).

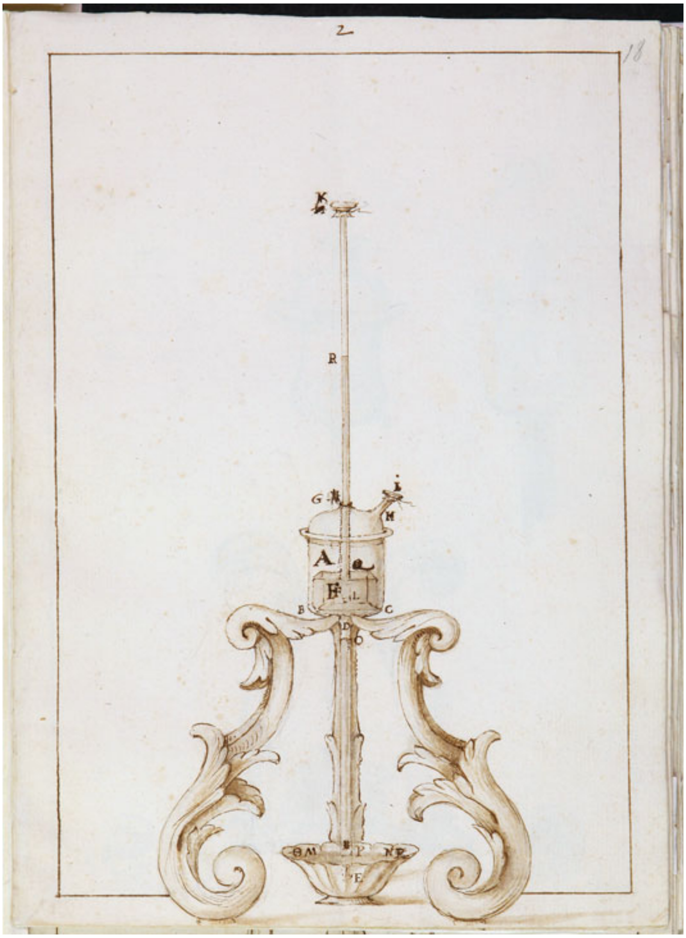

Fig. 7.2 The "void in the void" experiment in the *Saggi*'s draft. From (BNCF, Gal. 270, c. 18r). Su concessione del Ministero della cultura / Biblioteca Nazionale Centrale. Firenze. Divieto di riproduzione

The main criticisms, primarily made by Carlo Rinaldini (1615–1698)[3] and then summarized by Magalotti, concerned the general style of the proposed illustrations

[3] "Quanto alle figure. -Non mi piace la prima, si perché il quadrante deve aver per costa tutta l'altezza del cannello A B, come anche perché il vaso bisogna tingerlo trasparente, onde si vegga la parte immersa del cannello tanto eretto perpendicolare quanto inclinato. Inoltre, il vaso sole esser messo in prospettiva, e che sia liscio e pulito senza lavori, perché meglio si distingua la parte immersa sotto il livello dell'argento vivo stagnante. La figura vorrebbe esser disegnata in prospettiva da chi intende queste materie, e così disegnata darla all'intagliatore perché l'intagli per l'appunto. Le figure non vogliono aver tanta scarsità di lettere, onde quel vaso avrebbe a essere chiamato con lettere proprie, la parte immersa del cannello, tanto perpendicolare quanto inclinata, con lettera propria, cos ì anche

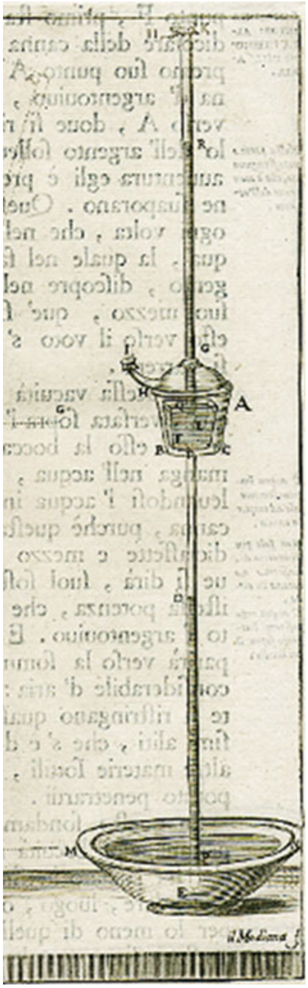

Fig. 7.3 The "void in the void" experiment in the *Saggi*. From (Magalotti 1667, 69). Smithsonian Libraries / Public Domain

l'argento vivo stagnante con lettere proprie, così anche la parte del cannello fuori dell'argento, così il quadrante etc. Quanto alla seconda figura. -La seconda figura non mi piace. Prima, perché non è in prospettiva, non mostrandosi bene il fondo del vaso, che pure si puol mostrare esquisitamente; secondo perché ci sono dei sostegni con lavori e cose puerili; terzo perché quel vaso deve mostrare trasparenza perché si vegga l'effetto dell'immersione del cannello; quarto perché il vaso deve essere liscio e pulito; quinto perché la parte immersa del cannello non è chiamata con lettere; sei perché il bicchier quadro non mostra la sua trasparenza, onde non si scopre il suo fondo; settimo, perché il coperchio non è disegnato bene, mentre non si scorge in che maniera si commetta, e si confondono i vivi del vaso principale con i vivi del coperchio; ottavo, perché presa tutta la macchina insieme è mal disegnata in prospettiva, onde l'estremo H del cannello non risponde con l'altre partu sino all'estremo del catino. In oltre la lettera G dovrebbe essere all'estremo inferiore del cannello, tanto più che la lettera G sola è posta per significare il bicchiere, quale piuttosto chiamarei con più lettere; e mi parrebbe che dentro il vaso A si dovesse accennare la vescica. La terza figura patisce al solito la and focused on their function; in short, the pictures should have been designed to be practical and useful, rather than attractive. In particular, (1) the figures should have been in perspective and the vases drawn smooth and clean, so as to allow the reader to better see the inside; (2) letters indicating the different parts of the figure were too scarce—each element of the figure should have been marked with its own letter to make the narrative more understandable and clear; and (3) it was necessary to remove ornaments and childish decorations ("cose puerili").

The other two figures (relating to the "void in the void" experiment) (Figs. 7.2 and 7.3) exemplify the changes that the illustrations underwent during the publication process of the work.

The volume collected the experiments to be presented to the outside world, and the illustrations therein were primarily intended to support the description and explanation of such experiments. This is why, if we just look at the *Saggi*, we can attribute to the images a transmission function and little more.

As in many other experimental reports of the time (suffice it to mention Boyle's work), the textual and visual descriptions of the instruments functioned here to establish the credibility of the experiment; by means of visual and textual material, the reader could reproduce and repeat the experiment or virtually witness it as described in the book.

7.3 Other Sources: The Unpublished Documents

But in order to fully understand the role and the functions that visual material played within the Cimento, it is necessary to go beyond the *Saggi*, through the large amount of manuscripts the members left behind.

The Galileo collection at the Biblioteca Nazionale Centrale in Florence (BNCF) preserves an extensive corpus of manuscripts of various kinds showing the concrete activity of the Cimento behind the exhibited neutrality of the *Saggi*. In terms of their purpose, the documents connected with the activities of the Cimento are mainly of three types: (1) the *Saggi*, which were to present the work of the Medici's academy to the outside world; (2) the diaries, mainly complied with the aim of collecting experiments for the *Saggi*; (3) the correspondence, which served for communication abroad and between the members of the group before and after the academic sessions.

Because of its collegial nature, the work of the Cimento was carried out through a constant dialogue, a dialogue that took place above all between the walls of the Pitti palace—the residence of the Gran Duke—where the academicians gathered to

prospettiva; levarei quei trabiccoli, fingerei il vaso liscio e trasparente, e mostrarrei l'immersione del cannello. Nella quarta sono gli stessi difetti, come nella quinta, sesta e settima, in tutte le quali parmi ancora che ci sia scarsezza di lettere delle quali parerebbe che dovessi esser maggior abondanza. L'ottava figura parmi difettosa; prima, per mancanza della prospettiva; secondo, perché il vaso deve essere liscio e trasparente; terzo perché è scarsa di lettere onde la narrazione si rende confusa." Rinaldini's notes to draft A of the *Saggi* (BNCF, Gal. 267, cc. 39r–40r); published in (Abetti and Pagnini 1942, 345).

design and carry out the experiments. The large majority of the experiments were the result of discussion and exchange between the members. Traces of these debates can be found in the correspondence, which also report academicians' discussions on experiments proposed and performed.

Moreover, tables, diagrams, and illustrations punctuate diaries, handwritten notes, and letters. The presence of visual material in these "unofficial" reports cannot be merely attributed to the desire to make the experiments more credible.

It is thus through the study of the unpublished documents that it is possible to clarify the role of visual material not only in the dissemination of the Cimento's activity but especially in the design of its experiments, and to explore the wider problem of the relationship between thought and vision.

This contribution will analyze the epistemic functions of visual material in the Cimento's experiments and debates around the issue of natural freezing and the properties of heat and cold. Indeed, the group's activity on thermology provides a key example of the various uses of visual material within the Accademia. Through some of the experiments carried out on this topic, the various phases in which visualizations enter the Cimento's reasoning and procedures will be considered.

7.4 The Experiments on the Nature of Heat and Cold

The academicians performed a multitude of experiments on the nature of heat and cold, on the existence of "frigorific" atoms, and on hypotheses advanced to explain the process of natural freezing. This is one of the subjects that reveal more clearly the diversity of principles held by the academicians, and that produced the most violent internal clashes on interpretive matters, in spite of the neutral tone that characterized the *Saggi.*

7.4.1 Leopoldo's Trial: Explaining Nature's Mechanisms by Making Them Visible

Within the Cimento, the scholastic idea of heat and cold as "qualities" and the atomistic interpretation of heat and cold as "bodies" coexisted. The academicians' work on this topic was animated by contrasting natural philosophical beliefs.

The expansion of volume that takes place when water turns into ice questioned the theory that cold is the mere absence of heat. Gassendi and his followers claimed that the ice was produced by atoms of cold that, by insinuating themselves into the water, made its bulk grow and hardened it by welding its particles.

In order to justify this phenomenon and salvage the idea of cold as deprivation, many experiments and hypothesis were put forward. From at least October 4, 1657, the members of the Cimento were engaged in a series of experiments on the freezing process.[4] Prince Leopoldo—the Accademia's patron and sponsor—was very involved in this debate; not only did he urge his fellow academicians to work on this problem, but he himself designed and carried out experiments.

For example, he chilled an empty carafe with a long, fragile neck by putting it in ice, and then he turned it upside down into a bowl filled with water.[5] After breaking the neck of the carafe he observed that the water entered the carafe without encountering any oppositions. On the other hand, by heating up a similar carafe and repeating the same experiment, not only did the water not enter the carafe, but one could visibly observe something resembling a waft coming out from the mouth of the carafe. This experiment seemed to visually demonstrate the corporeity of heat and the privative nature of cold.

Actually, many of the experiments carried out by the academicians—from those performed in Torricelli's void to those on the effects of heat and cold—aimed at explaining nature's mechanisms by making them visible. In this sense, the entire operation of the Cimento could be read as an attempt to explore nature by means of visualizations. By focusing on their effects, invisible entities such as cold and heat could be perceived through the sense of sight.

In the diaries, the experiment proposed by Prince Leopoldo was not accompanied by any visual material. The experiment did not require particular instruments and the internal report, drafted by the academicians, only contains a textual description of the experimental procedure and its outcomes. As for the *Saggi*, in which a later version of the experiment was included, only a couple of images were printed to support the description of the apparatus (Fig. 7.4): "A glass bulb (Fig. XI) about one-eighth of an ell [7.3 cm] in diameter with a thin neck about an ell and a half [88 cm] long, closely divided in degrees." And a "smaller one (Fig. XII)" made "so that the cold might insinuate itself into all the water more easily and quickly" (Magalotti 1667, 147, 150; Middleton 1971, 181, 183). Figure XIII in (Fig. 7.4) shows the container of crushed ice in which the bulb of the instrument and a thermometer were immersed in order to analyze the movement of the water in the freezing process.

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[4] "Posta l'acqua a diacciare, s'è osservato che da principio scema il livello, e poi nel diacciarsi va tuttavia rarefacendosi, infino a che riman congelata; e fu veduto in conformità di quello che scrive il Padre Zucchi, nell'agghiacciarsi l'acqua, salire dal fondo del vaso alcune gallozzine minutissime di figura sferica, di differenti grandezze, le maggiori delle quali ascendono più velocemente dell'altre" (BNCF, Gal. 262, 36r–v). The reference is to the second edition of the work *Nova de machinis philosophia* (Rome, 1649) of Father Zucchi, included in the list of books "on the subject of experimental things" sent by Rinaldini to Prince Leopold in November 1656: "Anno 1647 per aestatem exhibitum spectaculum infrigidations aquae, amphora vitrea inclusae, per immissionem, & agitationem convenientem intra praeparatam glaciem contusam. In quo primò aqua visa est ad minus spatium restringi, relicta parte colli, quam, ante inchoatam frigoris actionem, occupabar; tum progrediente ab ambiente frigido alteratione, coepit dilatari; ut non solum spatium relictum repleret; sed exundaret, aliquot eius partibus ex amphora defluentibus: cum assurgerent interim intra aquam maiores bullae, quae ad superficiem accurrentes, postqua, supernatassent, rumpebantur; crebrescebant verò minutiores multae, quarum extimae, adhaerentes passim vitro amphorae, spectabantur" (Zucchi 1649, 61).

[5] A description of the experiment can be found in (BNCF, Gal. 263, 50r–51r). The document indicates that these phenomena were first noted by Prince Leopold.

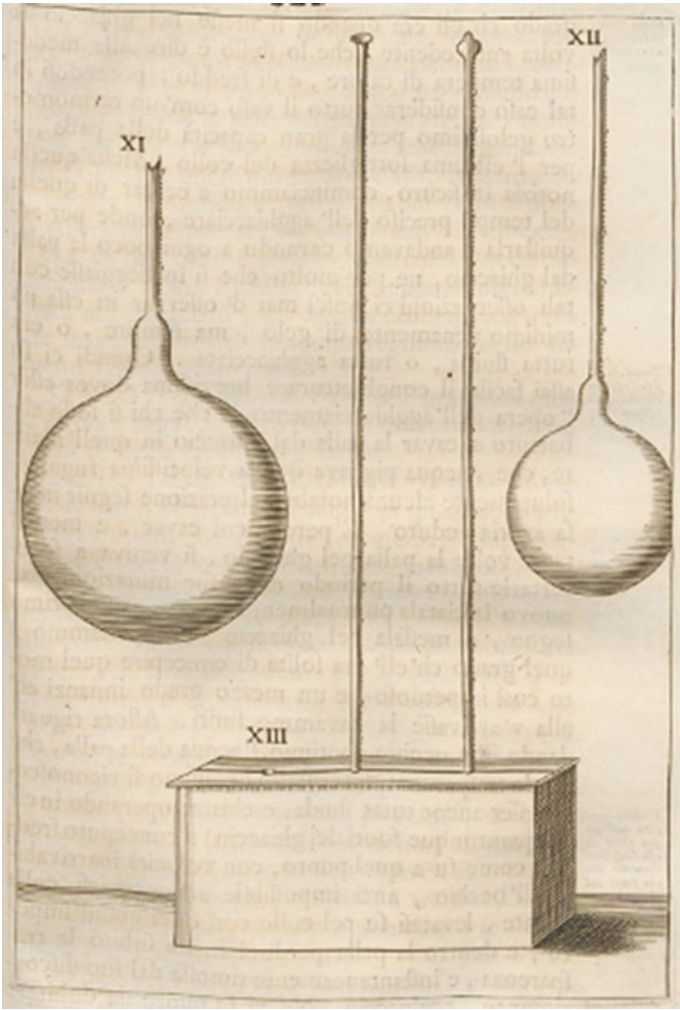

Fig. 7.4 Illustration of the apparatus used in the experiments on the progress of artificial freezing. From (Magalotti 1667, 151). Smithsonian Libraries / Public Domain

This example depicts the main use of images in the *Saggi*, where visual material basically fulfills the role of enriching textual descriptions of the instruments and the experimental apparatus.

7.4.2 The Use of Tables: Exploring by Creating a Synthetic Image of the Data

The experiment designed by Leopoldo was only the starting point for deeper research into the behavior of various liquids in the freezing process. Through Leopoldo's experiment, the academicians came to identify six different phases in the process of artificial freezing: a "natural state" (namely the degrees the liquid reaches when simply poured in the vessel), a "jump upon immersion" (the degrees the liquid reaches rising in the tube once the instrument is inserted in a container with crushed ice), a "fall" (the degrees the liquid reaches descending slowly because of the cold, after the initial jump), a "point of rest" (the degrees the liquid maintains in the tube for some time, with no apparent sign of motion, once the descent in the tube ends), a "rise" (the degrees the liquid reaches slowly rising in the tube after the point of rest), and a "jump upon freezing" (the degrees the liquid speedily reaches at the moment of freezing before breaking the tube and bursting the bulb once transformed into ice).

From then on, the academicians tried to study the process in different liquids, noting the variations in temperature in the transition from one state to the other and, by means of a pendulum, the particular timing of every change occurring in the fluid.

It is at this stage that another kind of visual representation enters the *Saggi*: the results are gathered in tables (Fig. 7.5).

Each table shows the degrees a specific fluid reaches in each phase, the temperature of the liquid in that phase, and the time needed by the fluid for attaining it. For each of these data, the academicians also added a column displaying the difference in respect to the previous phase.

This was not merely a means of presenting the results in a simpler and more immediate way. Since the beginning of the experiments, the members of the group started to compile tables (Fig. 7.6). The aim was to visualize the phases of the freezing process at one glance in order to easily relate the results. The creation of synthetic images from the collection of data could in fact provide new insight into the process of artificial freezing. Tables did not only allow for the rapid comparison of the results of different trials with the same liquid, they could also show analogies or differences in time or temperature variations from one state to another.

In this sense, they became a means for exploring possible causes and effects in the process of artificial freezing.

7.4.3 Exploring Physical Effects Through Geometrical Demonstrations

The rise of the liquid after the insertion of the instrument in the ice was not caused by its increase in volume but from the contraction of the apparatus because of the cold. Cold and heat would cause a contraction or a dilatation, respectively, of the glass tube and bulb, causing the rise or the fall of the liquid inside them. Giovanni

PRIMO AGGHIACCIAMENTO

Dell' acqua di fonte.

Agghiacciamento dell'acqua di fonte, Primo.

	Gradi del vaſo.	*Differenze.*	*Gradi del term.*	*Differ.*	*Vibraz.*	*Differ.*
Stato naturale	142	1 ½	139	6	—	23
Salto dell' immerſ.	143 ½	23 ½	133	64	23	232
Abbaſſamento	120	—	69	20	255	75
Quiete	120	10	49	16	330	132
Solleuamento	130	36	33	—	462	—
Salto dell' agghiac.	166		33		—	

ESP: INTORNO AGLI AGGHIACCIAMENTI.

SECONDO AGGHIACCIAMENTO

Della ſteſs' acqua.

	Gradi del vaſo.	*Differenze.*	*Gradi del term.*	*Differ.*	*Vibraz.*	*Differ.*
Stato naturale	144	2 ½	141 ½	23 ½	—	25 *Secondo.*
Salto dell' immerſ.	146 ½	27	118	80	25	255
Abbaſſamento	119 ½	—	38	10	280	135
Quiete	119 ½	11 ½	28	11	415	467
Solleuamento	131	39	17	—	882	—
Salto dell'agghiac.	170		17		—	

TERZO AGGHIACCIAMENTO

Della medeſima.

	Gradi del vaſo.	*Differenze.*	*Gradi del term.*	*Differ.*	*Vibraz.*	*Differ.*
Stato naturale	143	2	141 ½	16 ½	—	23 *Terzo.*
Salto dell' immerſ.	145	25 ½	125	74	23	346
Abbaſſamento	119 ½	—	51	7	369	196
Quiete	119 ½	10	44	6	565	368
Solleuamento	129 ½	39 ½	38	—	933	—
Salto dell'agghiac.	169		38		—	

Fig. 7.5 Tables gathering the experimental results in the *Saggi*. From (Magalotti 1667, 156–157). Smithsonian Libraries / Public Domain

Alfonso Borelli (1608–1679)—one of the staunchest followers of Galileo Galilei (1564–1642) in the Cimento and a key figure in the scientific and experimental activity gravitating around Prince Leopoldo de Medici—was convinced of this, but not all the members of the group agreed with him. To disprove the hypothesis, Carlo

Fig. 7.6 One of the tables gathering the experimental results in the diaries. From (BNCF, Gal. 260, c. 26r). Su concessione del Ministero della cultura / Biblioteca Nazionale Centrale. Firenze. Divieto di riproduzione

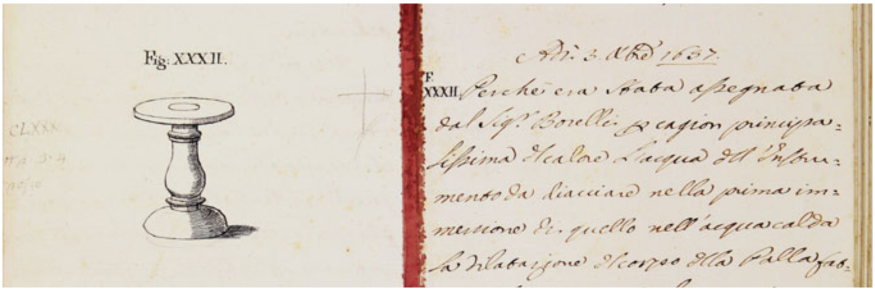

Fig. 7.7 The heated ring experiment in the diaries. From (BNCF, Gal. 262, c. 47r). Su concessione del Ministero della cultura / Biblioteca Nazionale Centrale. Firenze. Divieto di riproduzione

Rinaldini—promoter of an innovation of the classical framework of Aristotelian tradition through experimentation—put forward another experiment (Fig. 7.7).

In October/November of 1657—while he was teaching in Pisa—Rinaldini suggested to Borelli[6] that they take a metal ring made for fitting perfectly on a plug. He proposed to observe how it would react once heated or frozen. Rinaldini's

[6] Either the proposal was made in person or Rinaldini's letter to Borelli is lost. Evidence of the fact that the experiment was proposed by Rinaldini to Borelli is preserved however in some subsequent

proposal is an important step toward a geometrical abstraction of the problem: the ring represented a section of the tube and allowed him to reduce the problem to its essential form. The inner and outer circumferences of the ring corresponded to the inner and outer surfaces of the container.

The experiment is recorded in the diaries on the dates of December 3, 4, and 5 of 1657,[7] but it was probably performed a few weeks earlier.[8] In the records, it is presented as a test of Borelli's hypothesis, according to which the "jump upon immersion" was caused by a contraction of the container. Similarly—according to Borelli—in the heating experiments carried out in the weeks before, the water in the instrument went down due to an expansion of the glass container caused by the intrusion of igneous atoms following its immersion in hot water. Since "someone had challenged the hypothesis, in order to confirm this enlargement of the container's surface due to the heating, it was observed that a brass ring, which put on a plug fit perfectly, once heated, widened so much that when tightened on one side against the plug, the maximum eccentricity would have contained the size of a Giulio. The opposite happened by chilling it."

In confirmation of Borelli's opinion and of what was observed with the ring, the following day the academicians noted that horn rims were heated in order to let glass into them; then they were cooled to make the rims shrink around the glass.[9]

Like the others, Rinaldini too believed that the dilatation due to the heat would have caused an expansion of the ring in all the directions. But in his opinion, once the ring was heated, its inner circumference would have to decrease and fit more tightly on the plug. Even if the trials revealed the contrary, Rinaldini was hard to convince.

In order to explain the failure of the experiment he proposed in relation to his predictions, Rinaldini started looking for alternative explanations. For instance, he appealed to the "effect of the latch" ("effetto del chiavistello"), that is, to the fact that the air surrounding the ring could become more rarefied and therefore offer less resistance.[10]

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letters. See for example: Rinaldini to Viviani, November 11, 1657 (BNCF, Gal. 283, 12r–13v); Rinaldini to Prince Leopold, November 11, 1657 (BNCF, Gal. 275, 82r–83v).

[7] "Perché era stata assegnata dal Sig. Borelli per cagion principalissima del calare l'acqua dell'Instrumento da diacciare nella prima immersione di quello nell'acqua calda, la dilatazione del corpo della palla fatta per l'intrusione degli atomi ignei nelle particelle del vetro, et era tale opinione da qualcuno stata impugnata, per confermare questa ampliazione di superfice pel riscaldamento, si vedde che un anello d'ottone, che messo nel mascolo combagiava ottimamente riscaldato poi allargava tanto che stretto da una parte addosso al mascolo, la massima eccentricità avrebbe capito la grossezza di un Giulio. Il contrario succede diacciandola." (BNCF, Gal. 262, 47r; BNCF, Gal. 260, 280r).

[8] "Si sono fatte l'esperienze dell'anello di metallo, e di legno come propose V.S.…" Viviani to Rinaldini, November 15, 1667 (BNCF, Gal. 252, 40r).

[9] "A dì 4 Dicembre 1657. In Conferma dell'oppinione suddetta del Sig. Borelli, si vedde, che i vetri degli occhiali si cavano dalle loro casse di corno, col riscaldarle, e si ristringono in esse col freddo" (BNCF, Gal. 262, 47v).

[10] "Il Signor Borelli mi ha participato una di V.A.S. nella quale significa la sperienza dell'anello riscaldato et cetera. Ci sento qualche difficultà et è che quanto si pone riscaldato nel mascolo mentre giuochi più di quello faceva postovi freddo, o pure ch'all'ora vi fosse quasi calzante. Io temo che

The problem could not therefore be considered solved. By then, Rinaldini and Borelli were in Pisa to hold their courses at the university. The discussions that followed mainly involved, in addition, Vincenzo Viviani (1622–1703) and Prince Leopoldo, still in Florence. Traces of the discussion is preserved in the letters exchanged between Pisa and Florence in November/December 1657.

The main sense employed in Rinaldini's experiment was the sense of touch; the effect of heating the ring was tested by "touching" the play between the ring and the plug. For convincing their colleague(s), Viviani and Borelli proposed a number of other physical and theoretic demonstrations. In particular, Viviani tried to persuade Rinaldini by shifting the focus from the sense of touch to the senses of hearing and sight:

> Your doubt, based on the effect of the latch, really comes as a surprise to me. I believed that in order to demonstrate the enlargement and contraction of the vase through heat and cold, you could not do more than find a way to touch it with your hand, as His Most Serene Highness has recently pointed out to us by means of that metal core applied inside the metal ring, which is once hot, once cold. So, if the sense of touch does not seem to you to be that reliable a guide to making judgments (since you attribute the effect of the greater play of the Male in the heated ring to the attenuation of the air enclosed between them caused by heating the ring), consider whether some other of our senses, such as hearing or sight, seem more reliable to you.[11]

The visual demonstration consisted of several steps. Viviani started with an easily viewable example, namely the lengthening of a heated copper rope in a pendulum.

As he explained in his letters to Rinaldini, Viviani took a copper rope about an ell in length and attached a lead ball to the bottom end of the rope. Then he placed a glass plate under the ball, leaving about three cm of space between the ball and the plate. By heating the rope with the flame of a candle, the ball came to touch the glass plate. Once the flame was removed, the ball returned to the same height as before. Viviani added to the description of the experiment an illustration of the apparatus (Fig. 7.8).

The fact that a heated body increase its sizes (and in all directions) was not questioned by Rinaldini, who could not raise objections to this experiment. The problem laid in determining what it meant that the body increases its sizes in all

quel calore non attenui l'aria, di modo che possi quell'anello meglio giuocare ch'essendo l'aria non tenue. Sappiamo che quando l'aria è più crassa i chiavistelli delle porte giuocono meno ne' loro sostegni che quando l'aria sia pura e ben tenue." Rinaldini to Prince Leopoldo, November 11th, 1657 (BNCF, Gal. 275, cc. 82r–83v).

[11] "Il dubbio di V.S. Eccellentissima fondato su l'effetto del Chiavistello veramente mi giugne nuovo, perché mi credevo che per dimostrar l'allargamento e strignimento del vaso mediante il caldo et il freddo, non si potesse far più che trovar modo di toccarlo con mano come ultimamente c'ha fatto osservare S.A.S. per mezzo di quell'anima di metallo applicata dentro l'anello pur di metallo ora caldo, et ora freddo. Se dunque il senso del tatto non gli par questo giudice (già che ella attribuisce l'effetto del meglio giocar del Maschio nell'anello riscaldato all'attenuazione dell'aria racchiusa tra l'uno, e l'altro cagionata dal calor dell'anello) consideri in grazie V.S. se gli par di dover prestare più fede ad alcun altro de nostri sensi come a quel dell'udito o più della vista." Viviani to Rinaldini, November 17, 1657 (BNCF, Gal. 252, 31r–34v).

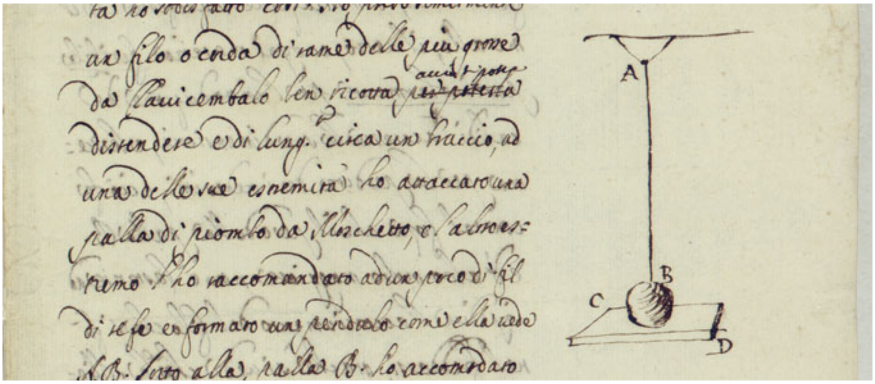

Fig. 7.8 Viviani's rope experiment in the correspondence. From (BNCF, Gal. 252, 32r). Su concessione del Ministero della cultura / Biblioteca Nazionale Centrale. Firenze. Divieto di riproduzione

directions, and in particular in determining if this dilatation in all directions resulted in an increase or in a reduction of the inner circumference of a ring.

The pendulum example was only the first step of the demonstration. It allowed the conversation to begin from common ground. The following steps aimed to mentally visualize, and thus in a sense foresee, what would happen in the case of the ring.

Viviani's physico-mathematical hypothesis was that dilatation occurred proportionally to the body's dimensions. For this reason, according to him a heated ring would necessarily increase its inner circumference. Viviani thus sharpened the pendulum example until he came to the desired result.

In particular, he invoked a rope whose length is "a hundred and a thousand times greater than its thickness"[12] and folded it into a ring; the lengthening and enlargement or the shortening and thinning of the rope would be the same in the wrapped and folded one as in the extended one. This change of measure would occur with the same proportions. One cannot lengthen the circle of a ring and proportionally enlarge its width if the inner circle does not widen, nor can one shorten its circle and proportionally shrink its thickness or width if the inner circle does not become smaller.[13]

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[12] "…et essendo la lunghezza della corda cento e mille volte maggior della grossezza della medesima" Viviani to Rinaldini, November 17, 1657 (BNCF, Gal. 252, 33r).

[13] "…se dunque tali esperienze son vere come V.S pure le troverà verissime, dicami di grazia per qual ragione non mi concederà ella che l'istessa variazione di misure, che segue per il caldo o per il freddo nel suddetto filo disteso non habbi da seguire per appunto nel medesimo filo ma piegato in anello: son certo che V.S. affermerà che giustamente altrettanto sarà l'allungamento et ingrossamento o l'accorciamento et assottigliamento nel filo avvolto e piegato in giro che nel disteso, data la parità del caldo e del freddo etc. e che tal mutazione di misura si farà pure come prima con la proporzione delle medesime dimensioni, ma non si può mai allungare il giro d'un anello e proporzionalmente ingrossare la larghezza di esso, se non si fa maggiore il cerchio interno, nemmeno si può accorciare il suo giro e ristringer proporzionalmente la grossezza o larghezza se il cerchio interiore non si fa minore come il tutto si può geometricamente dimostrare adunque parmi che a bastanza resti

On the same day, Viviani sent to Borelli a geometrical demonstration with an invitation to share it with Rinaldini too. However, Rinaldini never received the letter from Borelli.[14] The rope experiment did not convince him and he proposed varying the experimental conditions—using rings of different thicknesses, shape, and materials—in order to see if the experiment would lead to the same result (Fig. 7.9).[15]

Rinaldini learned of the geometrical demonstration in a later letter from Viviani—dated November 21, 1657—which contains the only surviving version of the demonstration.[16]

Through the geometrical demonstration, Viviani determined that the lengthening and proportional widening of the rope give rise to an increase in the ring's circumference (both internal and external).

As the length of the ring is determined by two circumferences (an external and an internal) that, a priori, could act independently (one could for instance increase while the other decreased), Viviani took the average circumference as a point of reference. In Viviani's demonstration, the increase of the average circumference resulted in an increase of both the external and internal circumference of the heated ring.

He first presupposed the expansion of the ring, and thus that the average circumference EI grew to another circumference FH (greater than the previous one and corresponding to the average circumference of the heated ring).

His demonstration was substantially based on the fact that the ratio of two concentric circumferences is equal to the ratio of their radii. The circumference EI should thus be to the increased circumference FH as the width AD to the increased width

provato che la capacità dell'anello e del vaso deva necessariamente farsi maggiore e minore per la introduzione o partita dei calidi dalla sua solidità." Viviani to Rinaldini, November 17, 1657 (BNCF, Gal. 252, 33r–v).

[14] See: Borelli to Viviani, November 21, 1657 (BNCF, Gal. 283, 19r–20v) and Viviani to Borelli, November 24, 1657 (BNCF, Gal. 283, 21r).

[15] "Ma parlo dell'esperienza fatta da S.A.S. dell'anello di metallo posto nel mascolo pur di metallo, che se non è notabile l'effetto del giuocolare in esso doppo riscaldato, non credo basti per conchiudere l'a[lla]rgamento, potendo venire da quel aria attenuata che meno impedisce, e ciò perché nelle sperienze da registrarsi deve haversi riguardo a più e più cose. Né V.S. mi haverà mai sentito dire che l'ingresso de' corpusculi caldi non facci crescere le dimensioni del corpo riscaldato, ma dico bene che la fa crescere per tutti i versi e, se quell'anello è di figura circulare, non fa per ciò che non possi far alargamento per il largo, di modo che si stringhi il concavo di esso. Confesso però potersi dire che sarà più il crescimento per l'altro verso che per questo, di ciò ne miango [sic] capace. Qual sia poi il mio parere circa gli effetti dell'acqua nella boccia col collo lungo, non mi vo' dichiarar per ora, se prima non ho combinato esperienze diverse. Per tanto V.S. mi facci grazia dir a S.A.S. che facci far l'esperienza dell'anello su detto in questi modi: si facci l'anello grosso per un verso nella sua orbita tre diti in circa, per l'altro un mezzo dito. Un altro largo per ogni verso mezzo dito, et ambidue si misurino con le seste per di dentro senza adoprar mascolo. Poi si riscaldino che scottino un poco e si torni a misurar i diametri, havendo segnato con linee l'estremità di essi nell'orbita per poter subito ritruovar il diametro. Poi si faccino riscaldar da vantaggio e si misurino. Poi si infuochino, sì che rimanghino rossi ferventi e si misurino. Il simile si facci di due quadrati e mi facci grazia darmi aviso di quanto occorre perché all'ora potrò dir qualche cosa." Rinaldini to [Viviani], November 19 (BNCF, Gal. 283, 16r–18r).

[16] Viviani to Rinaldini, November 26, 1657 (BNCF, Gal. 252, 35r–39v).

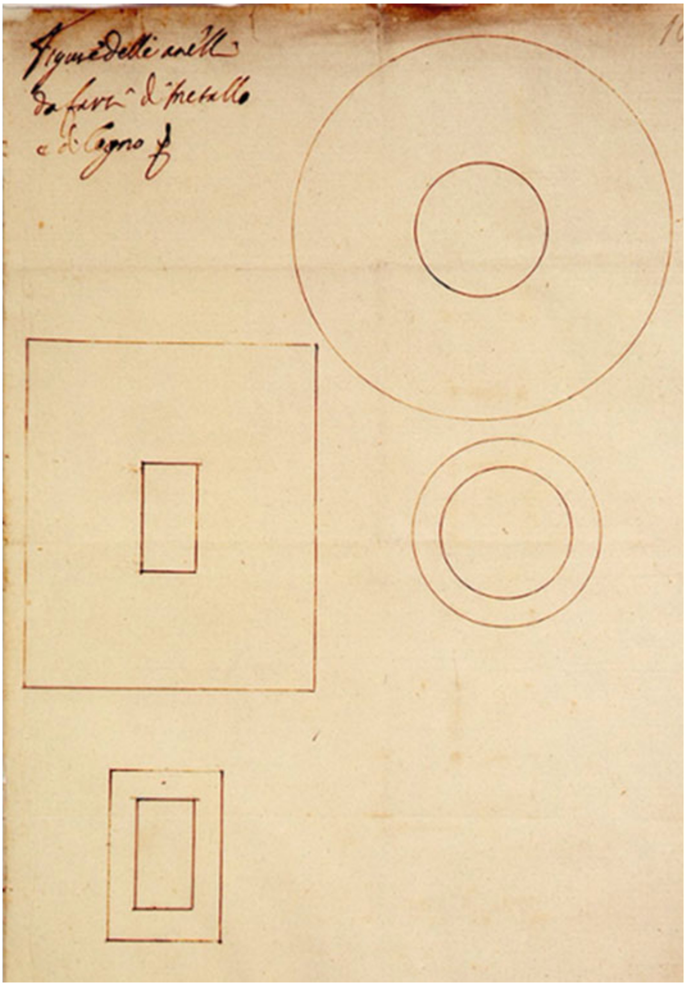

Fig. 7.9 Figures of the rings to be made in wood and metal. From (BNCF, Gal. 268, 108r). Su concessione del Ministero della cultura / Biblioteca Nazionale Centrale. Firenze. Divieto di riproduzione

BG, and the circumference radius EC to the increased circumference radius FC as the internal width of the ring ED to the internal width of the heated ring FG.

Consequently, he demonstrated that it was impossible to increase the circumference of a ring (and proportionally its width) without increasing its inner circle. The images he suggested provided convincing evidence. In his letter, Viviani also provided two mathematical representations (Fig. 7.10).

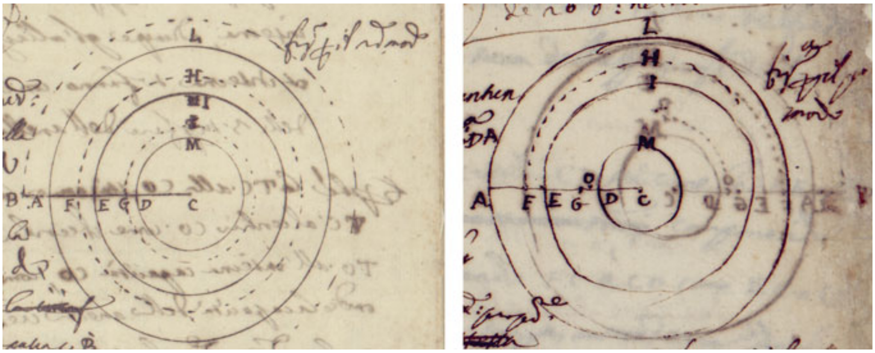

Fig. 7.10 Viviani's geometrical demonstration. From (BNCF, Gal. 252, 36r, 37v). Su concessione del Ministero della cultura / Biblioteca Nazionale Centrale. Firenze. Divieto di riproduzione

Even the geometrical demonstration did not immediately persuade Rinaldini. In his reply to Viviani of December 3, 1657,[17] Rinaldini asked him not to be surprised if he posed several problems—he was the one who proposed the experiment to Prince Leopoldo and wanted to obtain the maximum knowledge from it.[18] Actually, his doubts did not concern the geometrical proof in itself. Assuming that the increase must take place in every direction, and that it occurs proportionally, the demonstration is very clear and effective. He had already demonstrated this himself—Rinaldini wrote—with a parallelepiped, proceeding in the same way.[19] But the geometrical explication did not correspond to what happens in practice; in practice, things could be more complicated.

> Nonetheless, while experiments are being carried out, I would like them to be done to remove any scruple; and although geometry does not lie, nothing less, it conflicts with matter, its whiteness can be stained by it; so that, speaking of an orbit abstracted from matter, and I of my parallelepiped, I have no doubts that we conclude, but when we move to the work of nature, we pass the boundaries of geometry; therefore, in my opinion, it is advisable to try again to make up for the discrepancies that could arise from matter.[20]

[17] Rinaldini to Viviani, December 21, 1657 (BNCF, Gal. 283, 24r–25v).

[18] "In risposta le dico che per sua informazione quest'esperienza dell'anello fu proposta da me al Serenissimo Leopoldo, come S.A.S. gli puol attestare, onde V.S. non se maravigli s'io ciò ho fatto qualche difficultà, perché pretendo poterne cavar molte notizie," Rinaldini to Viviani, December 21, 1657 (BNCF, Gal. 283, 24r).

[19] "Non negando ch'il crescimento possa esser più per un verso che per l'altro, anzi concedendo che debba farsi proporzionalmente, la cosa è chiarissima e quello che V.S. dimostra nell'anello io di già avevo dimostrato in un parallelepipedo, a punto procedendo nella maniera medesima." Rinaldini to Viviani, December 21, 1657 (BNCF, Gal. 283, 24v).

[20] "Con tutto cio, mentre si fa esperienze io le vorei fatte per levar ogni scrupolo e ben che la geometria non mentisca, nulla di meno, contratta alla materia, puol da questa ricever qualche macchia il suo candore, sì che parlando d'un'orbita astratta dalla materia, et io del mio parallelepipedo, non ha dubbio che conchiudiamo, ma quando si vien all'operar della natura, passiamo in confini della geometria, che per ciò, per mio credere, convien far riprove per supplire al mancamento che dalla materia potesse accadere." Rinaldini to Viviani, December 21, 1657 (BNCF, Gal. 283, 24v).

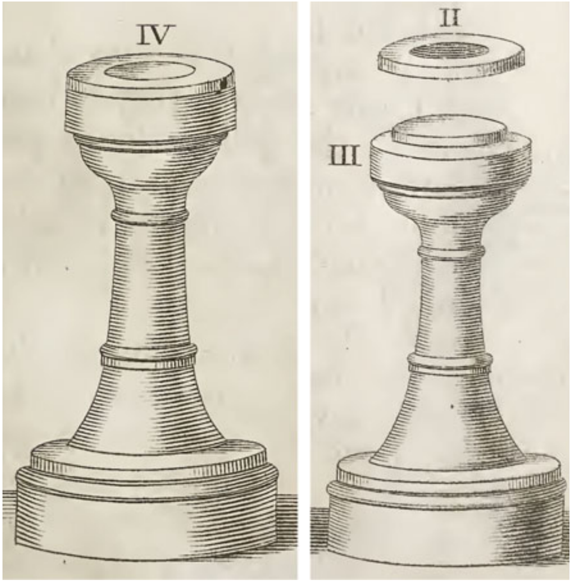

Fig. 7.11 The ring experiment. From (Magalotti 1667). Smithsonian Libraries / Public Domain

7.4.4 The Publication of the Heated Ring Experiment

There were no further developments on the issue and the experiment was published in the *Saggi* in its original form, with an illustration of the experimental apparatus (Fig. 7.11) and without any reference to Viviani's demonstration.

Rinaldini's notes to Draft A of the *Saggi* contain no relevant objections to the description of the experiment and its effects (Abetti and Pagnini 1942, 344). This leads us to believe that, at least from 1664, he was convinced of the enlargement of the inner circumference of the ring (and therefore of the container) due to the effect of heat. It is not clear whether it was the reduction of the problem to an image that eventually persuaded Rinaldini. Nevertheless, like Borelli, Rinaldini too, once he left Florence, published a series of works in which he reported—though not without claims—part of the work previously carried out in the Cimento.

In particular, in his *De resolutione et compositione mathematica* (1668), Rinaldini came back to the ring experiments. The experiment described by Rinaldini was a more elaborate version in which the plug was a conical frustum and the ring's dilatation was deduced from the fact that it descended further down the plug (Fig. 7.12).[21] The main sense employed in the experiment was no longer the sense of touch; the effect of heating the ring was not tested by "touching" the play between the ring and the plug but by "seeing" the ring's descent.

[21] A similar version is also published in the essays. However, in this case the ring is not heated but is immersed in water to investigate the effect of humidity (Magalotti Magalotti, 1667, 210–211; Middleton 1971, 210–211).

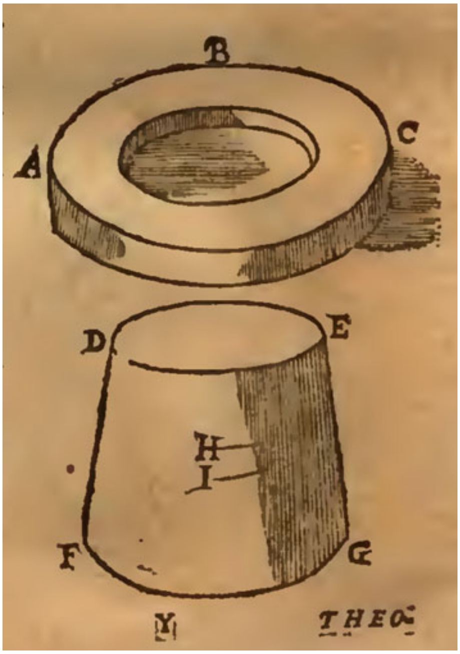

Fig. 7.12 The heated ring experiment described by Rinaldini. From (Rinaldini 1668, 169). Bayerische Staatsbibliothek, München, 2 Math.p. 53; urn:nbn:de:bvb:12-bsb10942366-1

As in the *Saggi*, Rinaldini's account begins with an observation of the "jump of the immersion." Then he explains that he conceived the ring experiment, silencing any doubts regarding his perplexities about the interpretation of the observed effects: "…from which I deduced the dilation of the ring itself."[22]

Rinaldini clearly no longer doubted that the internal circumference of the ring increases in the heating process. Interestingly, in order to prove it, he employed a series of geometrical demonstrations. He started from the dilation of a rectangle[23] to arrive at the example of the ring.

Although the demonstration did not follow Viviani's procedure, the figure proposed by Rinaldini was very similar to that drawn by his colleague and, curiously, it used exactly the same letters (Fig. 7.13).

It is not clear how Rinaldini became convinced of the ring's increasing internal circumference, but Viviani's reduction of the problem to an image appears to have played a significant role. Through this representation, Viviani not only transmitted his

[22] "Quinimo, ut impensius rem ipsam nostra contemplation persequeremur, anulum eneum fieri curavi, ut in tertia figura ABC, quem aptabam masculo DFGE, in quo descendere usque ad H advertebam: erat autem mascvulum etiam aeneum, mox in ignem anmulo iniecto, donec fere candesceret, eidem iterum aptabam masculo observans quousque descenderet; et adverti pervenisse ad I punctum infra H, existente anulo, tam prius, quam postea, parallel horizonti: unde eiusdem annuli dilatationem conieci" (Rinaldini 1668, 169).

[23] This is probably the demonstration of the parallelepiped he described to Viviani in his letter of December 21, 1657. Rinaldini to Viviani, December 21, 1657 (BNCF, Gal. 283, 24r–25v).

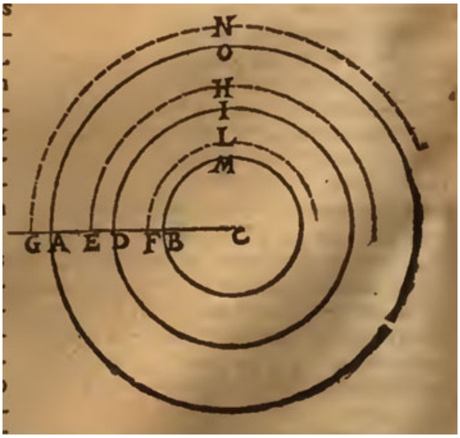

Fig. 7.13 Rinaldini's geometrical demonstration. From (Rinaldini 1668, 172). Bayerische Staatsbibliothek, München, 2 Math.p. 53; urn:nbn:de:bvb:12-bsb10942366-1

idea about the process of heating dilatation but, in a sense, transformed the problem by shifting the focus from experimental observation to geometrical explication.

In spite of this, the *Saggi* is devoid of any reference to geometric demonstrations. The visual grammar does not include diagrams or mathematical representations. As mentioned, the large number of images contained in it focuses on the representation of the experimental apparatus and, at most, on the visual synthesis of the results through their collection in tables.

The absence of geometric diagrams in the Cimento's only printed work certainly cannot be attributed to a lack of interest in geometry on the part of its members. During his life, Viviani worked on the restoration of a number of ancient Greek mathematical works, from the Book V of the *Conics* of Apollonius of Perga (b. 262 BCE), through Euclid's (third century BCE) fifth book, to Aristeo's five last books (Viviani 1659, 1674, 1701). In 1658, Borelli published a compendium of Euclid's *Elements* (Borelli 1658) and from 1658 to 1661—with the help of Abraham Ecchellensis (1605–1664)—he prepared an edited Latin translation of an Arabic manuscript of Books V–VII of the *Conics* in Florence (Borelli 1661).

The suppression of geometrical reasoning and diagrams in the *Saggi* rather falls in line with its emphasis on pure empiricism and the exclusion of larger theoretical speculations. Even the preface to the work seems to suggest a sort of retraction from the mathematization of nature, too close to what had brought the case of Galilei:

> Now this is exactly what the soul is trying to do in the investigation of natural things. Here it must be confessed that nothing is better for this than geometry, which at once opens the way to truth and frees us in a moment from every other more uncertain and fatiguing investigation. The fact is that geometry leads us a little way along the road of philosophical speculation, but then abandons us when we least expect it. This is not because it does not cover infinite spaces and traverse all the universal works of nature in the sense that they all obey the mathematical laws by which the eternal Understanding governs and direct them; but because we ourselves have not as yet taken more than our faith in experiments. (Magalotti 1667, 36–37; Middleton 1971, 90)

These words, written by Lorenzo Magalotti, recall the objections raised by Rinaldini to Viviani after receiving his geometrical demonstration. However, the *De resolutione et compositione mathematica* does not show the same caution. The nature of the two works was profoundly different. In the first place, while relating some of the experiments performed in the Cimento, Rinaldini's book was primarily a work of pure mathematics. The inclusion in it of an experimental physics section may have mainly been due to Rinaldini's desire to claim his contribution within the Cimento (Baldini 2011, 197). Second, it is the work of a single author, and it was published when Rinaldini had already left the Medici court for Padua.

7.5 Conclusive Remarks

The use of images within the work of the Cimento reflects the institutional nature of the group. On the one hand, the collective character of the Accademia's work gave it a dialogic character. The need to devise experiments together and to offer a shared interpretation led different styles of reasoning to intertwine and influence each other. Sketches of experimental apparatus, drawings of experiments, tables and geometric representations—aiming to explain the experimental results—populate the unofficial papers of the Academy. These images aim to capture, model, explain and provide an overview of the various experiments conducted within the Cimento. Their purpose is to contribute to the design and interpretation of the experimental work.

On the other hand, the group worked and published on behalf of the Medici family, who had to manage and balance the difficult Galilean heritage in Tuscany. The images included in the only official publication must conform to the general style of the text, they have to provide credibility to the experiments and an image as "neutral" as possible of the academic work.

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