Zilsel's Thesis, Maritime Culture, and Iberian Science in Early Modern Europe

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This article analyzes scientific practices in the early modern Iberian world in light of what Edgar Zilsel (1891–1944) argued about the social roots of modern science and its artisanal origins. The well-known "Zilsel thesis" is a broad argument connecting the emergence of modern science in Europe to sociological and economic factors—namely, to the breakdown of social barriers between scholars and artisans. Zilsel maintained that the separation of artisans and natural philosophers into different social strata prevented the emergence of modern science before 1600. Eventually, sometime in the sixteenth century, as scholars approached the world of artisans, especially those involved in mechanical arts and applied mathematics, social barriers were reduced or even nullified. Whereas most attempts to explain the origins of scientific modernity had focused on intellectual events (theories, ideas, debates, publications, etc.), in the 1930s Zilsel proposed a decidedly sociological picture. In Zilselian terms, attention must therefore be focused on social contexts where empirical practices prevailed and technical creators were actively engaged in the making of knowledge. Zilsel insisted on the importance of disciplines hitherto considered auxiliary and on the need to see artisanal culture not as peripheral but central to early modern European societies.

We follow recent scholars who have used Zilsel's idea to explain the origin of modern science, but we suggest that the use of this idea requires considerable care. In particular, we will put forward some criticism directed

both toward Zilsel's original formulation and toward the way it has sometimes been employed. We further claim that using these concepts in the context of early modern Europe forces one to consider the wider European maritime world—by far Europe's largest, most complex, and most crucial artisanal enterprise of the period. This in turn forces one to examine events in Iberia, one of the major players in this maritime world. The expansionist movement initiated by Portugal and Spain in the fifteenth century was soon followed by other European nations—Britain, the Low Countries, France, and others. This turned out to be the most massive expansionist enterprise in the history of Europe, giving rise to various European colonial empires. The arrival of Europeans in many regions of the "new world" and the establishment of wide-ranging maritime empires created new and exceptional conditions for the production of artisanal knowledge. In this sense, it seems particularly apt to inspect the Iberian situation following Zilsel's ideas—bearing in mind, however, that a continuity with a broader European situation followed.

EDGAR ZILSEL AND THE SOCIAL ROOTS OF SCIENCE

During the 1920s and 1930s a group of scholars considered the influence that mechanical arts and craft practices may have had in shaping the mechanistic worldview of the seventeenth century. This return to the roots of modern science sought explanations for the emergence of the Scientific Revolution as an identity-creating period for Western culture.[1] These new historiographical approaches had a distinctly sociological tone and some of them were supported by a Marxist vision of history. In fact, the emergence of sociological approaches by Marxist scholars such as Boris Hessen, Franz Borkenau, Henryk Grossman, and Edgar Zilsel, but also by non-Marxist scholars such as Robert Merton, called the attention of historians to the social and economic aspects of scientific development. Although Zilsel himself adhered to the basic tenets of a Marxist vision of history—namely, historical determinism—his thesis does not require adopting such a perspective. Indeed, as Merton first showed, and many others after him have confirmed, the consideration of social and economic aspects is perfectly compatible with an analysis of science without Marxist connotations.

[1] See Diederick Raven, "What Needs to Be Explained about Modern Science?," *British Journal for the History of Science* 44, no. 3 (2011): 449–54.

Edgar Zilsel was an Austrian philosopher and historian of science of Jewish descent connected to members of the so-called Vienna Circle, whose ideas were influenced by Max Adler's Austro-Marxism, and especially by Otto Bauer. It was Bauer who got Zilsel to leave his work on the concept of "genius" and inspired his interest in the role of the artisan in the emergence of science.[2] As a result of Nazi repression, Zilsel fled to the United States in 1939, where he lived in exile until his death. Between 1940 and 1945—the date of the posthumous publication of his article on "the genesis of the concept of scientific progress"—Zilsel was a regular contributor to the *Journal of the History of Ideas*, which he considered the most appropriate outlet for his proposals. It was in this journal that he published three of his best-known articles and in which he received some of the first responses to his ideas.[3]

At the Fifth International Congress for the Unity of Science, held at Harvard University in September 1939, Zilsel presented a paper entitled "The Social Roots of Science." This was his first public pronouncement on a theme that had already occupied him for some years and that would eventually become his greatest intellectual contribution. He stated that "real science is born when, with the progress of technology, the experimental method of the craftsmen overcomes the prejudice against manual work and is adopted by rationally trained university-scholars."[4] These ideas were gradually developed in subsequent years.[5]

According to Zilsel, what we now call modern science emerged sometime in the second half of the sixteenth century, when the social barriers separating university scholars, humanistic *literati*, and what he called "superior artisans" were broken down as a result of the emergence of early

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[2] On Zilsel's life and his relationship with the Vienna Circle, see Diederick Raven, Wolfgang Krohn and Robert S. Cohen, eds., *Edgar Zilsel: The Social Origins of Modern Science* (Dordrecht: Kluwer Academic Publishers, 2000), xix–lvi; Krohn and Raven, "The 'Zilsel Thesis' in the Context of Edgar Zilsel's Research Programme," *Social Studies of Science* 30, no. 6 (2000): 925–33; Raven, "Edgar Zilsel in America," in *Logical Empiricism in North America*, eds. G. L. Hardcastle and Alan W. Richardson (Minneapolis: University of Minnesota Press, 2003), 129–48; and Raven, "Edgar Zilsel's Research Programme: Unity of Science as an Empirical Problem," in *The Vienna Circle and Logical Empiricism: Re-evaluation and Future Perspectives*, ed. Friedrich Stadler (Dordrecht: Kluwer Academic Publishers, 2003), 225–34.

[3] Zilsel, "Copernicus and Mechanics," *Journal of the History of Ideas* 1, no. 1 (1940): 113–18; Zilsel, "The Origins of William Gilbert's Scientific Method," *Journal of the History of Ideas* 2, no. 1 (1941): 1–32; and Zilsel, "The Genesis of the Concept of Scientific Progress," *Journal of the History of Ideas* 6, no. 3 (1945): 325–49.

[4] Zilsel, "The Social Roots of Science," in Raven, Krohn, and Cohen, *Edgar Zilsel*, 3–6, at 5.

[5] Zilsel, "Problems of Empiricism," in ibid., 171–99, at 174.

European capitalism. The intellectual activity of universities, humanists, and the higher artisans was transformed in the early modern period into a "scientific" procedure. Thus was born, in Zilselian terms, modern experimental science. The most complete exposition of this thesis was presented in his essay on "The Sociological Roots of Science," published in 1942.[6]

For Zilsel, the sociological conditions for the birth of modern science were related to fundamental social progressive changes occurring in the transition from feudalism to early capitalism.[7] He emphasized in particular the role played by a group of "superior artisans" that he contrasted with the mere "plebeian workers." The "superior artisans" wrote in the vernacular and were seen as the immediate predecessors of science, a sort of prescientists.[8] This group of artisans established ties with scholars and humanists, even though the social separation between them was still important around 1550 and visible before 1600.

These proposals had a somewhat limited reception, and Zilsel always occupied a marginal position in the historiography of science. In hindsight it is not difficult to identify the causes for such relative oblivion. Zilsel's thesis did not find many adherents because of the combined effect of two factors. On the one hand, its Marxist taint became a major drawback when Marxist approaches to history started to collapse and finally went out of fashion in the decades after World War II. On the other hand, it must be recognized that Zilsel's thesis was presented in a rather schematic manner and never provided a credible explanation for its core argument: that is, an explanation of the mechanism responsible for the breakdown of class separation in capitalist societies in the seventeenth century.

Nevertheless, it cannot be said that these ideas were completely forgotten.[9] His thesis influenced the work of authors as eminent and diverse as Joseph Needham, Paolo Rossi, John H. Randall Jr., and Richard S. Westfall, among others.[10] It can even be argued that there is a renewed interest

[6] In the abstract of this text, Zilsel anticipates the most significant ideas of his ambitious project. Zilsel, "The Sociological Roots of Science," *American Journal of Sociology* 47, no. 4 (1942): 544–62, at 544. This article was also published in Raven, Krohn, and Cohen, *Edgar Zilsel*, 7–21.

[7] Zilsel, "Sociological Roots," 545–46.

[8] Ibid., 554n9.

[9] See Jürgen Renn and Matteo Valleriani, "Galileo and the Challenge of the Arsenal," Max Planck Institute for the History of Science, *Preprint 179* (2001): 1–32, at 4. It is also worth considering "Zilsel's dilemma," as it has been termed by Nicholas Jardine: that is, the uncertainty about the point of view from which Zilsel wrote. Jardine, "Zilsel's Dilemma," *Annals of Science* 60 (2003): 85–94, at 86.

[10] Among these authors, the most influential was Paolo Rossi, *Philosophy, Technology, and the Arts in the Early Modern Era* (New York: Harper & Row, 1970). See also John H. Randall Jr., *The School of Padua and the Emergence of Modern Science* (Padua: Ante-

in Zilsel's thesis.[11] Of special mention is the recent work by Pamela H. Smith and by Pamela O. Long. Smith has argued in favor of an "artisanal epistemology," a term that refers to the modes by which artisans manipulated nature through creative practices in the European context of the Scientific Revolution, a type of knowledge of nature gained through direct observation and manipulation of objects—through physical contact and the senses and not solely through texts and mind.[12] According to Smith, artisans were new social and intellectual authorities whose knowledge acquired a new epistemological status, a change that was accelerated by the development of world trade and the flourishing of urban nobility.[13] Long has studied the influence of craftsmen's culture on the development of "new sciences" and has argued that empirical methodologies developed by artisans or practitioners were generally adopted by society through the emergence of "trading zones"—a notion originally due to Peter Galison: mines, arsenals, and other places where craft skills were communicated and exchanged. Long has identified places and provided empirical evidence of social contexts in which groups of artisans and scholars came into contact and interacted.[14]

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nore, 1961); Richard S. Westfall, "Science and Technology during the Scientific Revolution: An Empirical Approach," in *Renaissance and Revolution: Humanists, Scholars, Craftsmen and Natural Philosophers in Early Modern Europe*, eds. J. V. Field and Frank A. J. L. James (Cambridge: Cambridge University Press, 1993), 63–72. See also Dana B. Durand, "Tradition and Innovation in Fifteenth Century Italy," *Journal of the History of Ideas* 4, no. 1 (1943): 1–20; Alexandre Koyré, "Galileo and Plato," *Journal of the History of Ideas* 4, no. 4 (1943): 400–428, see 401n6.

[11] John Henry, "Animism and Empiricism: Copernican Physics and the Origins of William Gilbert's Experimental Method," *Journal of the History of Ideas* 62, no. 1 (2001): 99–119. In some places Zilsel's ideas acquired enough gravitas to be taught to undergraduates; see Steven Shapin, "A Course in the Social History of Science," *Social Studies of Science* 10 (1980): 231–58, at 233–34. More recent scholars have recognized the importance of Zilsel's work: see especially William Eamon, *Science and the Secrets of Nature: Books of Secrets in Medieval and Early Modern Culture* (Princeton: Princeton University Press, 1994); and Eamon, "From the Secrets of Nature to Public Knowledge," in *Reappraisals of the Scientific Revolution*, ed. David C. Lindberg and Robert S. Westman (Cambridge: Cambridge University Press, 1990), 333–65, at 346. And, to give one final and telling example, Mario Biagioli in his influential and controversial *Galileo Courtier* acknowledged his debt to Zilsel. See Biagioli, *Galileo Courtier: The Practice of Science in the Culture of Absolutism* (Chicago: University of Chicago Press, 1993), 1.

[12] C. D. Conner, *A People's History of Science* (New York: Nation Books, 2005), 282.

[13] Pamela H. Smith, *The Body of the Artisan: Art and Experience in the Scientific Revolution* (Chicago: University of Chicago Press, 2004), 238. In her recent historiographical revision, Pamela O. Long noted that authors such as William Newman, Lawrence Principe, Tara Nummedal, and Deborah Harkness have also used the artisanal epistemology theory. Long, *Artisan/Practitioners and the Rise of the New Sciences, 1400–1600* (Corvallis: Oregon State University Press, 2011), 28.

[14] Long, *Artisan/Practitioners*, 9. See also Lissa L. Roberts, Simon Schaffer, and Peter

Not surprisingly, the thesis put forward by Zilsel was also directly criticized by several authors. Some criticized its Marxist origin and its externalist tone.[15] Others questioned the basic Zilselian notion according to which artisans gradually approached the scholarly and humanistic world.[16] But in our view the main obstacle to a broader and more decisive acceptance of Zilsel's thesis lies in the fact that its core explanatory scheme was never convincingly grounded in an appropriate historical setting. His apparently simple intuition requires very peculiar historical circumstances and these have never been convincingly provided. As H. Floris Cohen has put it:

> One obvious drawback is that he fails to tell us how the decisive change came about. How is it that between 1550 and 1600 the social barrier between the skilled artisan and the Latin-writing intellectual suddenly began to break down? Was this part of a more general shift in the social history of Western Europe? Or was it just a singular event? If so, how did it come about? From Zilsel we hear no more about it.[17]

Despite the current revival of interest in Zilsel's thesis as an explanatory argument for the onset of modern science, something seems to be missing in the way this very fruitful idea has been used by historians. As Floris Cohen remarked, Zilsel did no more than enunciate his thesis in very broad terms, invoking "the onset of capitalism" and other expressions to the same effect. When he needed to be more specific, he provided only isolated examples of collaboration between an artisan and a scholar (for example, Robert

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Dear, eds., *The Mindful Hand: Inquiry and Invention from the Late Renaissance to Early Industrialisation* (Amsterdam: Knaw, 2007). Long adopts the term "trading zones" from Peter Galison. See Galison, *Image and Logic: A Material Culture of Microphysics* (Chicago: University of Chicago Press, 1997).

[15] A. Rupert Hall, "The Scholar and the Craftsman in the Scientific Revolution," in *Critical Problems in the History of Science*, ed. Marshall Clagett (Madison: University of Wisconsin Press, 1962), 3–23; H. Floris Cohen, *The Scientific Revolution: A Historiographical Inquiry* (Chicago: University of Chicago Press, 1994), 341–42.

[16] See A. C. Keller, "Zilsel, the Artisans, and the Idea of Progress in the Renaissance," *Journal of the History of Ideas* 11, no. 2 (1950): 235–40, at 236. See also Walter E. Houghton Jr., "The History of Trades: Its Relation to Seventeenth-Century Thought," *Journal of the History of Ideas* 2, no. 1 (1941): 33–60. More recently: Eamon, *Science and the Secrets of Nature*; Smith, *The Business of Alchemy: Science and Culture in the Holy Roman Empire* (Princeton: Princeton University Press, 1994); Eric H. Ash, *Power, Knowledge, and Expertise in Elizabethan England* (Baltimore: Johns Hopkins University Press, 2004); David Woodward, "Cartography and the Renaissance: Continuity and Change," in *The History of Cartography: Cartography in the European Renaissance*, vol. 3, pt. 1, ed. Woodward (Chicago: University of Chicago Press, 2007), 3–24.

[17] H. Floris Cohen, *Scientific Revolution*, 340.

Norman and William Gilbert). Other historians proceeded along similar lines when invoking Zilsel's ideas. Empirical confirmation for the contact between scholars and artisans is often provided in the form of small-scale or very local events—Galileo at the Venice arsenal, or Jan Swammerdam and his drugstore at the Amsterdam dockyards.[18] Much excellent scholarship has been produced along these lines, greatly enlightening us on the ways artisans and scholars sometimes collaborated in early modern Europe, but it is doubtful that these studies can be considered illustrations of Zilsel's thesis. The problem is that substantiating Zilsel's thesis with focused situations or personal events is a somewhat self-defeating move, if not an altogether contradictory one. To locate scientific change at the level of the individual, of a narrow group, of specific professional settings or short-lived events, and not as the result of collective, broad, temporally stable social behavior, is contrary to what Zilsel proposed. One will then almost imperceptibly be led to describe the onset of scientific modernity as the result of Galileo's "genius" or Gilbert's "acumen"—and once again artisans will become mere sidekicks in a story in which the exceptionality of the "great names" is the true driving force.

Of course, one might argue that these limited or individual cases are simply specific examples of broader social and economic situations. Perhaps this is what historians have had in mind. But in that case it is impossible to avoid the question: why not face the issue head-on and characterize the overall situation instead of trying to illustrate it through particular instances? Why not identify the large-scale social, economic, or political situation that allowed scholars and artisans to interact—if such a situation existed—and then characterize it in detail? In our opinion, this is the only acceptable way to proceed according to the sociological picture sketched by Zilsel.

To use Zilsel's ideas, one needs to look for extended large-scale events or social settings in early modern Europe whose structure made possible—or perhaps even forced—sustained collaboration, discussion, and interaction between scholars and artisans. One needs to provide historical evidence that these interactions occurred not as isolated or local events but as collective processes involving hundreds or thousands of people for at least several decades. Thus one needs to identify institutions, sites, circles of sociability, etc., where this took place. One also needs to identify the strains

[18] See Renn and Valleriani, "Galileo and the Challenge of the Arsenal"; and Harold J. Cook, "The Cutting Edge of a Revolution? Medicine and Natural History Near the Shores of the North Sea," in Field and James, *Renaissance and Revolution*, 45–62.

in society that forced a narrowing of social distances; that is, one must show that there were strong dynamic factors that challenged social barriers. And one needs to show that this situation was demographically relevant and temporally stable. Finally, one needs to identify new forms of scientific practice and concepts that resulted as a direct consequence of these circumstances. In this paper, we not only argue that these conditions are crucial for a correct use of Zilsel's ideas, but also show that they took place in a notable manner in the early modern European maritime world, and that they first formed in sixteenth-century Iberia.

A ZILSELIAN LOOK AT IBERIAN SCIENCE

Iberian scientific and technological activities in the early modern period have traditionally been ignored in the great narratives of Western science. Several reasons may explain this neglect. A significant part can be attributed to seventeenth-century Protestant and eighteenth-century Enlightenment narratives, always quick to depict in the most unfavorable tones the role played by Catholic Iberia. The "leyenda negra" (black legend) cast a long shadow that has not completely disappeared yet.[19] But Spanish and Portuguese historians are also partially responsible for this lack of attention: by transporting to the historiographical field the deep political and ideological struggles that divided their own countries in the twentieth century, they have proposed depictions that oscillate uncritically between the nationalistic encomium and the bitter jeremiad.[20]

This situation, however, has changed considerably in recent years. In 2001 Juan Pimentel argued for a specific "Iberian vision," and, in 2004, in a more emphatic way, Jorge Cañizares-Esguerra denounced the neglect of Iberian science by historians of the Scientific Revolution, and wondered pointedly how much longer Iberian science of the Renaissance would be

[19] The topic has generated an immense literature. For important recent studies, see Ruth MacKay, *"Lazy, Improvident People": Myth and Reality in the Writing of Spanish History* (Ithaca: Cornell University Press, 2006); Philip Wayne Powell, *Tree of Hate: Propaganda and Prejudices Affecting United States Relations with the Hispanic World* (Albuquerque: University of New Mexico Press, 2008 [1971]).

[20] See especially the very perceptive study by Eamon, " 'Nuestros males no son constitucionales, sino circunstanciales': The Black Legend and the History of Early Modern Spanish Science," *Colorado Review of Hispanic Studies* 7 (2009): 13–30; and also Jorge Cañizares-Esguerra, *Nature, Empire, and Nation: Explorations of the History of Science in the Iberian World* (Stanford: Stanford University Press, 2006), 4, 23.

ignored.[21] A new generation of historians, equipped with new historiographical and conceptual tools, seems to be successfully overcoming these obstacles. Early modern Iberian scientific activity—mostly related to maritime expansion, geographical discoveries, and colonization—has recently attracted the interest of a large group of historians of science on both sides of the Atlantic. Authors such as William Eamon, Antonio Barrera, María Portuondo, and Alison Sandman, to name but a few, have analyzed in detail the specificities of Spanish science, underlining in particular the processes of accumulation of empirical knowledge and their associated administrative practices.[22] Other recent works have extended these arguments to claim that an accurate picture of modern science cannot be formed if the Iberian contribution is neglected.[23]

Zilsel himself had noted the importance of maritime voyages and discoveries and, implicitly, of the Iberian role in early modern science.[24] In several of his publications he referred to the sciences that allowed geographical discoveries, such as cartography and navigation, and to the "superior artisans" who cultivated these sciences, such as Gerard Mercator, Pedro Nunes, Pedro de Medina, and Francisco Faleiro. However, he never fully exploited this direction of thought and never truly considered Iberian science.

An important clarification is required. With the term "Iberian science"

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[21] Juan Pimentel, "The Iberian Vision: Science and Empire in the Framework of a Universal Monarchy, 1500–1800," *Osiris* 15 (2001): 17–30; Cañizares-Esguerra, "Iberian Science in the Renaissance: Ignored How Much Longer?," *Perspectives on Science* 12 (2004): 86–124.

[22] The literature on this topic is quite considerable. See, for example, Alison D. Sandman, "Mirroring the World: Sea Charts, Navigation, and Territorial Claims in Sixteenth-Century Spain," in *Merchants and Marvels: Commerce, Science, and Art in Early Modern Europe*, ed. Pamela H. Smith and Paula Findlen (New York: Routledge, 2002), 83–108; Antonio Barrera-Osorio, *Experiencing Nature: The Spanish American Empire and the Early Scientific Revolution* (Austin: University of Texas Press, 2006); Cañizares-Esguerra, *Puritan Conquistadors: Iberianizing the Atlantic, 1550–1700* (Stanford: Stanford University Press, 2006); María M. Portuondo, *Secret Science: Spanish Cosmography and the New World* (Chicago: University of Chicago Press, 2009); Eamon, "Nuestros males." One of the most novel and penetrating analyses is Arndt Brendecke, *Imperio e información: Funciones del saber en el dominio colonial español* (Madrid: Iberoamericana, 2012). See also Antonio Sánchez and Henrique Leitão, "Introduction: Revisiting Early Modern Iberian Science, from the Fifteenth to the Seventeenth Centuries," *Early Science and Medicine* 21, no. 2–3 (2016): 107–12.

[23] Víctor Navarro and William Eamon, *Más allá de la Leyenda Negra: Beyond the Black Legend* (Valencia: Instituto de Historia de la Ciencia y Documentatión López Piñero, Universidad de Valencia, CSIC, 2007); Daniela Bleichmar et al., eds., *Science in the Spanish and Portuguese Empires, 1500–1800* (Stanford: Stanford University Press, 2009).

[24] Zilsel, "Problems of Empiricism," 172.

we are not suggesting a nationalistic or epic narrative of Spanish and Portuguese achievements in science. In modern historiography, the term "Iberian" is still frequently associated with propagandistic or at least highly self-conscious modes of historical discourse, but this is not at all our intention. Quite the contrary: we do not accept such types of discourse and we flatly refuse any essentialist interpretation.

By "Iberian science" we refer to the specific characteristics that scientific practice acquired under the peculiar conditions (economic, political, and social) prevalent during the first phase of European maritime expansion. The complex set of events associated with the fifteenth- and sixteenth-century maritime expansion of Portugal and Spain was an epoch-making moment in the history of Europe. The onset of long-distance oceanic navigation, the first arrival of Europeans to new lands and continents, the establishment of novel worldwide commercial routes, and the massive movement of colonization that ensued were events that radically changed the history of Europe and affected the history of all continents. The suddenness, the scale, and the lasting effects of these changes should be noted: in a few decades, from the mid-fifteenth to the early sixteenth century, local, agrarian, and medieval-structured kingdoms became the rulers of gigantic sea empires with trade routes traversing oceans and operating on different continents. This was first achieved by Iberian maritime expansion, but was soon followed by the expansionist maritime enterprises of other European nations. It is obvious that such deep changes (for example, oceanic navigation, or the arrival into wholly new natural environments) were associated with specific technological and scientific practices—broadly termed "Iberian science."

Our objective, therefore, is to focus on the first phase of this expansionist movement: that is, to characterize the scientific scene and practices prevalent in Iberia from the mid-fifteenth to mid-sixteenth century. Some specific modes in the study of nature can be identified: the establishment of new empirical practices; a vast critique of ancient authorities; the participation of people from all walks of life in the construction of knowledge about nature; the creation of new artisanal and industrial complexes; the dissemination of scientific concepts among the less-educated strata of society; the growth of technical and scientific literature in the vernacular; the emergence of new professionals, intermediate between scholars and artisans; the appearance of institutions of technical education and institutions for the accumulation and management of information; the invention of novel cognitive devices such as cartographic models, nautical instructions for pilots,

and geographical questionnaires for explorers; and proto-experiments with nature—such as "trying out" or replicating recipes—using reports on drugs and other commercial products.[25]

Of course, we are not the first to introduce these topics. Before us other historians—mostly, but not exclusively, Iberians—have conducted intense historical work analyzing, for example, technical developments related to ocean voyages, the growth of geographical knowledge, and developments in natural history as a consequence of contact with the "New World." But despite the value and dimension of these works, we must recognize that our predecessors were not really interested in the social picture, and much less in a Zilselian point of view.

"Iberian science" refers not only to the new facts of nature discovered —new lands, new oceans, and new natural environments—but also to the emergence of new modes of studying and describing the natural world and new social settings. To put it more epigrammatically, "Iberian science" means that Europeans' first confrontation with new worlds ushered in a new way of doing science. This new interest in nature quickly spread throughout the whole of society. It was fostered by the surprise of incessant novelties; it gave rise to an unprecedented openness to the new and to an optimistic confidence in the abilities of the human mind. Most of all, it was not a passing interest of just a few. It was grounded in the strategic importance of long-distance travel, in the institutions that managed voyages, and in their imperial control; it was cultivated by those professionals who for different reasons (commercial, administrative, political) had to make sense of the endless novelties of the "new world"; it was discussed, circulated, and exchanged in the regulated environment designed by the Portuguese and Spanish crowns.

It is difficult to understand the scientific history of modern Europe without considering the transformations that took place in the Iberian Peninsula during the sixteenth century. This is especially true because these transformations were quickly transferred to many other places in Europe: the Iberian Peninsula was visited by many foreigners—Italian, French, German, English, and other nationalities—who closely followed the dramatic

[25] This last topic is underlined by Barrera-Osorio, *Experiencing Nature*, 101ff. Besides medical practices, as noted by Barrera-Osorio, there were other, less-explored paths to the study of nature, such as colors and dyes. A recent issue of the *Journal of Interdisciplinary History* addresses these topics, specifically in relation to the Spanish Empire. See the thematic issue: "Art and Trade in the Age of Global Encounters, 1492–1800," *Journal of Interdisciplinary History* 45, no. 3 (2015). We thank William Eamon for calling our attention to these articles.

transformations going on in the Iberian world and recognized the many opportunities to be pursued.[26]

INSTITUTIONS AND MECHANISMS OF CONTROL

Iberian maritime expansion has sometimes been characterized as adventurous, reckless, disorganized, violent, and driven mostly by greed and religious zealotry. Although all of these elements were surely present, historians should not be carried away to the point of missing crucial facts. One central fact is that in the building of the Iberian empires there was an enormous effort of preparation, planning, and control. This was put into action in different ways, but most of all by an ample and comprehensive legislative effort and, perhaps even more important, by the creation of specific institutions, such as the Armazéns da Guiné e Índia (Storehouse of Guinea and the Indies) in Lisbon in the second half of the fifteenth century, and the Casa de la Contratación (House of Trade) in Seville, created in 1503.

The Armazéns and the Casa were the agencies that monitored the nautical network of the Portuguese overseas empire from Lisbon to Timor and the Spanish empire from Seville to La Española, respectively. These institutions were the focal point of the commercial, administrative, and logistical management of the voyages; they controlled great flows of products and information—technical, geographical, cartographical, zoological, and botanical—about the natural world, and thus, in a sense, became scientific institutions. They were indeed the first institutions in Western Europe dedicated to such ends and to operate on such a scale: knowledge from all over the world was systematically collected, classified, regulated, standardized, and distributed.[27]

Within the administrative machinery of the Iberian empires, the Armazéns and the Casa acted as centers of calculation and control of nautical and cosmographic knowledge. They were the central nodes in long-distance networks of knowledge creation and circulation.[28] Their novelty lies in how

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[26] Leitão, ed., *360 Ciência Descoberta* (catalogue) (Lisbon: Fundação Calouste Gulbenkian, 2013), 11–13. See also Sánchez, *La espada, la cruz y el Padrón: Soberanía, fe y representación cartográfica en el mundo ibérico bajo la Monarquía Hispánica, 1503–1598* (Madrid: CSIC, 2013).

[27] David Turnbull, "Cartography and Science in Early Modern Europe: Mapping the Construction of Knowledge Spaces," *Imago Mundi* 48 (1996): 5–24, at 7.

[28] Bruno Latour, *Science in Action* (Cambridge, Mass.: Harvard University Press, 1987), 215ff; John Law, "On the Methods of Long-Distance Control: Vessels, Navigation and the Portuguese Route to India," *Sociological Review Monograph* 32 (1986): 234–63.

they were directly sponsored by the Crown and how they addressed not local needs but a worldwide network. The Armazéns and the Casa were also dedicated to the teaching and the technical improvement of hydrographical knowledge, nautical and shipbuilding techniques, and the development of instruments and charts.[29] Both institutions were crucial in the effort to map new regions and in the progressive definition of an official image of the world. Standardized procedures and new cognitive devices were explicitly developed to this end, such as the *padrões d'el-Rei* (the King's standard charts, in the Armazéns) and the *Padrón Real* (Royal Pattern Chart, in the Casa).[30]

INTERMEDIATE PROFESSIONALS AND THE SOCIAL ASCENSION OF TECHNICAL PERSONNEL

One feature that characterizes the deep social and administrative changes taking place in Iberia was the appearance and subsequent development of institutional positions intermediate between the scholar and the craftsman. These positions were intermediary in the sense that their holders were trained at the higher level (university) but their obligations—explicitly defined by Crown legislation—were toward lower-level personnel: pilots, sailors, and craftsmen. Thus they enjoyed the social recognition and the scientific competence of the scholar but had to work with the artisan. Between the mid-fifteenth and the late sixteenth century in Portugal and Spain, many dozens (perhaps hundreds) of such men can be identified. The Iberian world therefore provides a striking example of a stable and durable institutional basis that allowed—or at least facilitated—the bridging of the social distance between artisans and scholars.

The most prominent of these intermediate positions were the *piloto mayor* (pilot major), cosmographer (royal cosmographer or chief cosmographer), and professor of cosmography, created by the Spanish and Portuguese crowns in court and in institutions such as the Casa de la Contratación or the Armazéns da Guiné e Índia. In contrast to what "cosmographer" meant in central Europe, in Iberia a cosmographer was a university-trained man who was obliged to interact with practical seamen

[29] Avelino Teixeira da Mota, "Some Notes on the Organization of Hydrographical Services in Portugal before the Beginning of the Nineteenth Century," *Imago Mundi* 28 (1976): 51–60, at 51. "Nautical science" is a traditional generic label to refer to oceanic navigation and shipbuilding.

[30] Sánchez, *La espada, la cruz y el Padrón*, 136–49.

and cartographers. He had to teach and examine pilots, cartographers, and instrument makers and certify the quality of their maps and instruments. A cosmographer in sixteenth-century Portugal or Spain fulfilled a complex set of tasks: teacher, examiner, quality controller, technical consultant, and scientific advisor at court. Of crucial importance is the fact that he moved socially between very different strata and *loci*: the royal court, the university, the artisan's workshop, the cartographer's home, the harbor, and the shipbuilding yard.

The creation of these posts is a direct consequence of the specific needs posed by oceanic voyages and long-distance navigation. Of special urgency was the need to train, supervise, and advise nautical personnel, as well as to control flows of information (cartographic, technical, and more) in matters of political and economic importance. Some of the names associated with these intermediate posts are well known—Amerigo Vespucci, Juan Díaz de Solís, Pedro Nunes, Sebastian Cabot, Alonso de Chaves, Rodrigo Zamorano, João Baptista Lavanha, Andrés García de Céspedes, and Manuel de Figueiredo, among others—but the novelty of these posts and their obvious Zilselian relevance has not been sufficiently underlined. Most of all, it has not been adequately noted that these are just the most prominent names within a new and well-defined social group that took shape in sixteenth-century Iberia, a social group that played a crucial role in maritime activities and in the interchanges between scholars and artisans.

Another important aspect of Zilsel's thesis has to do with the social status of craftsmen, and again the Iberian world lends ample support to Zilsel's vision. In Spain and Portugal in the early sixteenth century, social mobility was driven not only by the influx of sudden wealth and the creation of a commercial bourgeoisie; technical personnel also experienced a marked raise in social standing. Long-distance pilots and cartographers, in particular, enjoyed special social recognition as people with specific professional skills, even though in most cases they were poorly educated.[31] Pilots from Lisbon and Seville had their own fraternities and even their own Universidad de Mareantes (a corporation of pilots) in Seville. Cartographers seem to have enjoyed even higher social standing, probably due to the fact that they often worked with sensitive, even confidential, materials.

[31] A. J. R. Russell-Wood, "Seamen Ashore and Afloat: The Social Environment of the *Carreira da India*, 1550–1750," reprinted in *The Globe Encircled and the World Revealed (Expanding World: The European Impact on World History, 1450–1800)*, ed. Ursula Lamb (Aldershot: Ashgate, 1995), 93–110.

THE RISE OF THE VERNACULAR, NEW STYLE, AND NEW TEXTS

Besides being associated with new institutions and new types of (intermediate) professionals, maritime technical activities fostered the use of the vernacular and the production of texts in the vernacular. Cosmographers taught and wrote books in Portuguese and Spanish addressing the specific technical problems of pilots, seamen, and cartographers.

The use of the vernacular in the teaching of scientific matters in Iberia became so widespread that even religious orders, which in general maintained a rigorous adherence to Latin in educational activities, resorted to it when teaching technical matters.[32] The Mathematical Academy (Academia de Matemáticas) in Madrid—where classes were taught in Spanish—became the focal point for a movement to translate scientific texts into the vernacular: teachers of mathematics such as Jerónimo de Chaves, Jerónimo Girava, Rodrigo Zamorano, and Pedro Ambrosio de Ondériz translated into Spanish the Latin texts of Sacrobosco, Euclid, Finé, Apianus, and Frisius.[33] The widespread use of the vernacular in technical and scientific matters was not the result of a scholar's taste or a group's interests; it was a national imperative, needed to provide scientific and technological knowledge to groups of men who had not benefited from university education. This is a clear indication that low level, non-university-educated layers of society were engaging in technical and scientific activities on a much larger scale than ever before.

There is quite a lot more to be said about nautical books than simply noting that they were written in the vernacular. Nautical books were truly hybrid cultural artifacts: although their language and mode of expression were clearly drawn from artisan's manuals, their contents did not originate in the artisan's world. Cosmography, the rudiments of astronomy and mathematics, the use of instruments—all these topics were presented in the explanatory and sequential style of the artisans' "how to" manuals and books of rules. Examples include the *Guias náuticos* (Nautical guides), *Regimentos*, and the very rich nautical literature of Iberia in the sixteenth century: books such as the *Tratado del esphera y del arte de marear* (Seville,

[32] An Italian traveler in Portugal noted with surprise that mathematical courses were taught by the Jesuits in Portuguese. See Mota, "Os Regimentos do Cosmógrafo-Mor de 1559 e 1592 e as origens do ensino náutico em Portugal," *Memórias da Academia das Ciências de Lisboa: Classe de ciências* 8 (1969): 1–69, at 35.

[33] María Isabel Vicente and Mariano Esteban, *Aspectos de la ciencia aplicada en la España del Siglo de Oro* (Salamanca: Junta de Castilla y León, 2006).

1535) by Francisco Faleiro, *Arte de navegar* (Valladolid, 1545) by Pedro de Medina, *Breve compendio de la sphera y de la arte de navegar* (Seville, 1551) by Martín Cortés, *Compendio de la arte de navegar* (Seville, 1582) by Rodrigo de Zamorano, etc. These works enjoyed remarkable success and were greatly influential in Iberia and throughout Europe, having been translated into different languages.[34]

These books embody very pragmatic goals; they are designed to instruct and perfect seamen, pilots, and other seafaring personnel. Basic theoretical principles are presented, generally based on Sacrobosco's *Treatise on the Sphere*, but the overall tone is decidedly practical, almost like that of manuals of a trade. Information is usually presented not as in a textbook or a compendium, but in structured sets of rules and instructions, ready for practical use.[35] Indeed, these books introduced a new style: by combining topics previously taught at the university (mathematics, astronomy, and cosmography) with the "how to" approach typical of artisans' manuals, these books manifest in a striking manner the blending of the scholar's and the artisan's world that is at the heart of Zilsel's thesis. This technical literature to support the maritime enterprise rapidly spread throughout Europe, with England and the Low Countries becoming major centers for the production of these texts.[36]

QUESTIONING AUTHORITIES AND THE SPIRIT OF PROGRESS

The acute and sometimes dramatic questioning of received authorities is a key element in Zilsel's depiction of the birth of modern science. He did not

[34] For example, Medina's *Breve compendio de la sphera* went through at least fifteen French editions, five Dutch editions, three Italian, and two English editions. There is an abundant literature on the subject. See especially J. M. López Piñero, *El arte de navegar en la España del Renacimiento* (Barcelona: Labor, 1979; 2nd ed., 1982).

[35] This is very clear in Francisco Faleiro, *Tratado del esphera y del arte de marear: Con el regimiento de las alturas: Con algunas reglas nuevamente escritas muy necessarias* (Sevilla: Cromberger, 1535), sig. dii.

[36] Across Europe this literature has a similar tone. Such is the case for the English production through the mid-sixteenth century: *The Rutter of the Sea* (1528), the works of Robert Recorde, the *Cosmographical Glasse* (1559) of William Cunningham, the English translation (by Richard Eden) of Martin Cortes's book, or the books of William Bourne, to name just the most prominent. See David W. Waters, *The Art of Navigation in England in Elizabethan and Early Stuart Times* (London: Hollis and Carter, 1958), and also the books by E. G. R. Taylor, *The Haven-Finding Art: A History of Navigation from Odysseus to Captain Cook* (London: Hollis and Carter, 1971 [1956]); Taylor, *Tudor Geography, 1485–1583* (New York: Octagon Books, 1968). More recently, Ash, *Power, Knowledge, and Expertise* (see n16).

suggest, however, the rejection of ancient authority per se. More specifically, Zilsel believed that new social conditions forced a renegotiation of the authoritative role attributed to ancient texts and older authors.[37] This phenomenon became central during the Iberian maritime expansion because the continuous observation of new natural events, new animals, new plants, and new lands ignited a large-scale critique of ancient authorities. It is well known that the "new world" showed the limits of ancient natural descriptions; as Barrera put it elegantly, "there were no avocados in Pliny's *Natural History*."[38] But the phenomenon was much more consequential. Ancient authors were not only shown to be incomplete; they were many times demonstrated to be incorrect. One lasting consequence of the continual arrival of overseas novelties to Lisbon or Seville was thus a direct challenge to much that had constituted traditional knowledge.

A few examples suffice to show how outspoken Iberian authors were and how generalized was the critique of ancient knowledge. In 1498, the Spanish scholar and humanist Antonio de Nebrija (1441–1522) stated that "nothing certain has been handed down from our ancestors" about the Western hemisphere.[39] In roughly the same years, similar statements were coming from people of very different backgrounds. Thus, around 1505, the Portuguese sailor and soldier Duarte Pacheco Pereira (ca. 1460–1533) declared: "Experience has disabused us of the errors and fictions of which some of the ancient cosmographers were guilty in their description of land and sea; for they declared that all equatorial country was uninhabitable on account of the heat of the sun. We have proved this to be false."[40] Two ideas became canonical in Iberian texts of this period and must be put in evidence: the fact that ancient knowledge contains many errors, fictions, and falsities; and that it was the direct experience of new situations and places that proved this. Cosmographer Martín Fernández de Enciso (ca. 1470–1528) also declared in 1519 that "experience is the mother of all things."[41] In 1563, the medical doctor Garcia de Orta (ca. 1500–68) was merely echoing common feelings among the Portuguese and Spanish when

[37] Zilsel, "Social Roots," 3.
[38] Barrera-Osorio, *Experiencing Nature*, 2.
[39] Antonio de Nebrija, *Introductorium Cosmographicum*, in *La ciencia de la tierra: Cosmografía y cosmógrafos salmantinos del Renacimiento*, Cirilo Flórez, Pablo García and Roberto Alvares (Salamanca: Caja de Ahorros y Monte de Piedad de Salamanca, 1990 [ca. 1498]), 243.
[40] Duarte Pacheco Pereira, *Esmeraldo de situ orbis* (Lisbon: Imprensa Nacional, 1892 [1505]), book 2, chap. 11, 77. Authors' translation.
[41] Martín Fernández de Enciso, *Suma de geographia* (Seville, 1519), last page (at the close of the book).

he warned against the errors of the ancient authorities: "Because the lands . . . are now discovered and better known, the errors of the past are rectified."[42] Decades later, the naturalists Gonzalo Fernández de Oviedo (1478–1557) and José de Acosta (1539–1600) continued to claim that no ancient writer, either Greek or Latin, knew the multitude of different species that existed in the New World.[43] All Iberian literature connected to maritime discoveries in this period exhibits a vigorous and self-conscious departure from ancient authorities.

The new knowledge was not acquired by logical syllogisms and deductive reasoning, but by experience—i.e., by direct empirical evidence. This allowed even poorly educated persons to challenge the most respected texts. Sailors, missionaries, soldiers, merchants, and travelers of every kind became sources and bearers of novel information about nature. In the process not only were ancient texts questioned, but the very hierarchy of authority on the natural world was deeply altered. Whereas traditionally knowledge about nature came from scholars and was materialized in classical texts, now it came from the direct experience of men who often had no formal training.

All of these aspects are well known by historians of early modern maritime expansion; their Zilselian relevance, however, has never been put in evidence. Actually, revolt against authorities implicitly entails the notion of progress—a very Zilselian idea. As A. C. Keller has pointed out perceptively, Zilsel considered the belief in progress one of the most important features of scientific thought.[44] He connected the notion of progress in the Renaissance with the ebullient nature of European capitalist societies. Fascination with the new and the expansion of horizons, however, were also traits that characterized Iberian societies in the aftermath of the great voyages of discovery.

The discovery of new geographic realities introduced an unmistakable, sometimes very explicit idea of progress. In 1537 the mathematician and cosmographer Pedro Nunes used almost hyperbolic language to describe the success of Portuguese sea voyages, a success that he explicitly linked to scientific progress: the Portuguese pilots and cosmographers knew more geometry and astronomy, had better instruments, and better maps than

[42] Garcia de Orta, *Colloquies on the Simples & Drugs of Índia* (London: Henry Sotheran and Co., 1913 [1563]), seventeenth colloquy, 153.
[43] Gonzalo Fernández de Oviedo, *Sumario de la natural historia de las Indias* (1526); José de Acosta, *Historia natural y moral de las Indias* (1590).
[44] Keller, "Zilsel, the Artisans, and the Idea of Progress in the Renaissance," 235.

their European counterparts.[45] Nunes was one of the most influential cosmographers in Iberia in the sixteenth century, and his work was based upon the belief that progress is achieved through the practice of science and mathematics. Despite the epic tone of his pronouncement concerning the scientific and technological progress of the Portuguese, Nunes was hardly an exception and hardly the most emphatic. Garcia de Orta also continually insisted on the great progress brought about by new knowledge of the natural world. Orta did not mince words when expressing this point: "I declare that one can get more knowledge from the Portuguese in one single day than from the Romans after a hundred years."[46] Examples could easily be multiplied. The notion of scientific progress through knowledge and the mastery of nature was pervasive and deep in sixteenth-century Iberia. It became part of Portuguese and Spanish imperial rhetoric, both written and visual, and was displayed in a most conspicuous manner when the Portuguese king chose the armillary sphere—a scientific instrument used in cosmography—as symbol of the royal arms.

The examples briefly described in the previous paragraphs—new institutions, control mechanisms, intermediate professionals, the creation of large artisanal complexes, the social ascension of technical personnel, the growth of vernacular literature, the notion of progress, etc.—are far from a haphazard set of unrelated events. Rather, they are the direct consequence of a global phenomenon that involved extended strata of society over long periods of time, a premise that is at the heart of the Zilsel thesis. The phenomenon in question, of course, was the onset of oceanic navigation and the creation of enormous maritime empires, first by the Iberians and afterward by other nations in Europe.

CONCLUSION

The debate over the origins of modern science seems to be as lively as ever, and Zilselian ideas are still relevant today. Some of these ideas seem to predate important current historiographical tendencies directing the historian's gaze away from the topoi of traditional narratives (the "great names," scholars, and universities) and toward the activities of the lower strata of society (craftsmen, uneducated personnel, popular culture, vernacular texts).

[45] Pedro Nunes, *Tratado da sphera* (1537). See the modern edition, Nunes, *Obras*, vol. 1 (Academia das Ciências de Lisboa and Fundação Calouste Gulbenkian, 2002), 120–21.
[46] Garcia de Orta, *Colloquies on the Simples*, fifteenth colloquy, 127–28.

But Zilsel was a man of his times and contemporary historiographical currents and prejudices influenced him more than he could know. Not only was he to a considerable extent tied to a Marxist, deterministic view of history; perhaps more gravely, he seems to have been caught up in the same historiographical constraints he criticized. Somewhat paradoxically, despite the novelty of his thesis, Zilsel substantiated it in an essentially conservative manner. Although he claimed artisanal culture and "experimental science" (but what this meant was never clearly defined) were key sources of modern science, he still located its main driving stimulus in traditional intellectual "great names" such as Galileo, Bacon, or Newton.

One of our main contentions in this essay is that Zilsel's insight has not yet been fully substantiated—neither by Zilsel himself nor by later historians. Credible empirical evidence for his thesis would need to include large-scale phenomena that were temporally durable and driven by sufficiently strong social forces. To this end, we have demonstrated how, by locating the birth of scientific modernity in broad social events firmly grounded in artisanal practices, Zilsel's thesis forces one to look for specific historical scenarios. Local or small-scale events are, in this context, neither convincing nor sufficiently probatory. More to the point, they seem to contradict Zilsel's intentions. One is thus led to look at the epoch-making changes associated with European maritime expansion, changes that completely reshaped the political and economic landscape of Europe and launched the West's colonial enterprise. In such a scenario, the Iberian context emerges naturally—perhaps unexpectedly, but, in our opinion, impossible to overlook.

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