The Social Structure of Islamicate Science

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The view that Islamicate science went into decline while European science was getting started is still commonly held among historians of science and almost universal in general history and popular presentations. Different versions of the decline thesis make it start in the 11th century with the work of Ibn al-Haytham and al-Ghazālī; in the 13th century with the sack of Baghdad, or at latest with the beginning of the "Scientific Revolution" in Europe. However, it is now increasingly apparent that Islamicate science was healthy well into the period of the Ottomans, Safavids and Mughals. There are many reasons for the continued attraction of the decline theses. In addition to the inaccessibility of sources, these include mistaking the nature of credentialing in Islamicate science, and mistaking the nature of the sources in which original science was appearing. In this paper, I will sketch a more appropriate social structure for understanding Islamicate science by describing the institutional structures for training scientists and awarding credentials, and the practices of recording and transmitting research in writing. Taking the Safavid scholar Bahāʾal-Dīn al-ʿĀmilī (1547–1621) as an example, I will suggest that these structures supported an active research community well into the early modern period, further undermining the decline thesis.

Key words: science; Islam; *ijāzah;* astronomy; Persia; decline thesis

1 The Decline Thesis

Most English language historians of science would pour scorn on the idea that history of science should be written as if anything that did not contribute to modern science was both wrong and irrelevant. But many people still cling to a vestige of this historiography in their treatment of Islamicate science. This vestige is the thesis that Islamicate science experienced a "Golden Age" followed by a decline. There is general recognition of the Islamicate contribution to the exact sciences like mathematics, astronomy and optics, and also in medicine—the first accurate description of diseases like smallpox and measles, new treatment regimes, and the development of hospitals in their modern form. But all this is supposed to have come to an end before the "Scientific Revolution" really took hold in Europe. According to A. I. Sabra, writing in 1988:

> The question is not why the efforts of Islamic scientists did not produce "the scientific revolution" (probably a meaningless question), but why their work declined and eventually ceased to develop after the impressive flowering of earlier centuries. Why, for instance, did algebra fail to make significant progress after the twelfth century? Why was the work of Ibn al-Haytham and Kamal al-Din in experimental optics not continued along lines already drawn by these two mathematicians? Why did the observatory, once conceived and established as a specialized scientific institution, fail to gain a permanent footing? And why did the long standing interest in astronomical observations not develop into a more sophisticated program? (Sabra 1988: 88)[1]

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Different versions of the decline thesis make it start around 1050 with the work of Ibn al-Haytham (d. 1039) followed by al-Ghazālī (d. 1111), or in 1258 with the sack of Baghdad, or at latest with the beginning of the "Scientific Revolution" in Europe, after 1543.[2] In a series of books the influential historian and current editor of *Isis*, H. Floris Cohen, endorses the decline thesis and, in the most recent version, dates it to "c. A.D. 1050."[3] However, it is now increasingly apparent that Islamicate science was healthy well into the period of the Ottomans, Safavids, and Mughals—in other words the 1500s, 1600s, and 1700s.[4]

There are many reasons for the continued attraction of the decline thesis. We are still struggling to deal with a vast quantity of uncatalogued and unread sources.[5] But a continuing problem, I will suggest, is that we have not recognized our commitments to models of scientific research and social life that apply in Western culture, but not elsewhere. In this paper, I will sketch a more appropriate social structure for understanding Islamicate science, as part of a continuing effort to close the door on the decline thesis, by arguing that historians of science have mistaken the nature of education and credentialing in Islamicate science, and mistaken the nature of the written record and hence the sources in which original scientific work appeared.

2 Education

In Europe and later America, universities have always played a central role in scientific education.[6] During the early modern period this was significantly augmented by colleges[7] and scientific societies.[8] These were almost exclusively limited to men, until the late 1800s, however women and some men could learn science from private tutors, and in other venues.[9] One pattern that is almost wholly absent in the West, however, is scientific apprenticeship, that is receiving all one's training from a single established scientist.[10] However, what I have just called "apprenticeship" was the single most important pattern of scientific training in the Islamic world from the beginning of their mature scientific tradition (in the 800s) to well into the early modern period (and indeed this pattern of training is alive today in more traditional subjects). Islamic scientists studied with individuals.

When a European scientist, any time from the middle ages forward, trained at a university, his education was the responsibility of a group of scholars who made up a corporate entity. The well-known basic courses of European universities, the *trivium* and *quadrivium*, as well as the advanced courses, would be taught by different instructors. The degree that a student earned was bestowed by the corporate entity, not by a single individual. Correspondingly, the MA was originally a license to teach the liberal arts—all the subjects in the curriculum.[11]

By contrast, the default pattern in the Islamicate world was personal instruction from an individual expert. This pattern applied to education not only in the sciences but across the whole range of disciplines including theology and law. An individual student might study with several different teachers—often traveling long distances to find them, and individual teachers might have more than one student at a time. But, the central connection, the credentialing, was between an individual student and an individual teacher. And unlike Europe, both men and women participated as both student and teachers.[12]

At the end of their training Islamic students received a license to teach called an *ijāzah*, issued by their personal teacher. The *ijāzah* differs from a European university degree in several ways. First, as already indicated, it is issued by an individual, even if the teacher is based at an institution, for example a college or *madrasa*. The name of the place or institution does not figure in the *ijāzah*, except incidentally. Second, from the beginning both men and women participated as both teachers and students. Third the *ijāzah* connects the student, though the teacher, to a chain of authorities, going back in time through the people who gave the

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teacher permission to teach this material, to their own teachers, and so on. In the case of religious (and legal) subjects, these chains terminate with the Prophet or his Companions (who lived in the middle and late 600s), or God. For scientific subjects a common endpoint is Ibn Sīnā (Avicenna, 980-1037), as you can see in Figure 1.[13]

FIGURE 1

Ibn Sīnā d. 1037
↓
Abu al-ʿAbbās al-Lawkari d. c.1123
↓
Afdal al-Dīn al-Ghīlānī
↓
Al-Sayyid Sadr al-Dīn al-Sarakhsī
↓
Farīd al-Dīn Dāmād al-Nīshāpūrī
↓
Nasīr al-Dīn al-Tūsī d. 1274
↓
Shihāb al-Dīn Abū Bakr
↓
Tāj al-Dīn al-Qirtāsī
↓
ʿAlāʾ al-Dīn al-Qirtāsī
↓
Mazhar al-Dīn al-Kāzarūnī
↓
Jalāl al-Dīn Dawānī d. 1502
↓
Muʾayyadzāda d. 1516

Reconstructed chain of authorities linking the recipient through his teacher to Tūsī and Ibn Sīnā, in the ijāzah granted to Muʾayyadzāda by Jalāl al-Dīn Dawānī in 1483. Redrawn from Judith Pfeiffer, "Teaching the Learned," in Pomerantz & Shahin (eds.), *Heritage of Arabo-Islamic Learning*. Leiden: Brill, 2015, p. 318.

Here you see a schematic of the authorities listed in an *ijāzah* granted in 1482 by the famous Persian scholar al-Dawānī, to a younger Ottoman scholar, Mu'ayyadzāda to teach, among other things, some works on science. Note that at the top you can see Ibn Sīnā, and in the middle Naṣīr al-Dīn al-Ṭūsī (d. 1274), the director of the Marāgha observatory in Persia.[14] Fourth, the *ijāzah* is not a general license to teach a group of subjects, but is restricted to specific texts by specific authors that the teacher himself has been licensed to pass on. Another difference between a degree and an *ijāzah* is size; a degree certificate is usually a single sheet, while an *ijāzah* may be a booklet that runs to twenty pages or more!

An important corollary of the apprenticeship system leading to the *ijāzah* is that scientific education had no set curriculum. Although there are generally recognized sequences in advanced education (for example, you are expected to study geometry before you study astronomy) the exact contents of any given student's training are determined by the training and personal interests of their teacher. This will be true even if the teacher is attached to an institution like a *madrasa* or college. These institutions are neither supported nor governed by the people who worked in them, unlike European universities. Rather they are religious bequests.[15] The founder (who may be a man or a woman) provides the funds to build the institution, and specifies what staff to hire. They also supply ongoing salaries for staff (and sometimes students).[16] The

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founder may have specified the hiring of a teacher with particular skills or the teaching of particular subjects, but these will most probably be theology or law. Scientific subjects were studied independently of theology and law, and would depend on teachers with separate qualifications in these subjects. As the only thing determining what subjects were taught at the outset would be any wishes expressed by the donor or founder, as well as the individual training of the teacher, there need be no uniformity in curriculum, even for the primary areas of theology and law.[17] What sciences were taught would depend even more on the qualifications of the teacher. In any subject, a teacher might choose any set of recognized texts to teach to students, without considering whether anyone else was using the same sequence, although the teacher's primary curriculum would cover those texts for which they themselves had received *ijāzahs*.[18]

3 Research

Like European universities in the medieval and early modern periods, there was no specific training in research, or expectation that the recipient of an *ijāzah* would produce novelties as the result of research. Rather, what we now recognize as research is primarily the result of writing new books for use by beginners, writing new books for more advanced readers, and especially commenting on existing books. Except for the books for beginners, all these genres may include trying to resolve outstanding problems. Sometimes this leads to a completely new book, which introduces new problems and a new round of commentaries. Examples are Ibn al-Haytham's *Doubts about Ptolemy* and al-Ṭūsī's commentary on Ptolemy's *Almagest*.[19] And *anyone* can do this—it does not require special equipment, like a printing press, although, in practice, popular books were mass copied by factories of scribes.

Another important difference in research production depended on the form of written communication, which was by manuscript not printed books. We are so used to the idea that printing was a positive influence on the scientific revolution that we have forgotten what we lost when we stopped producing manuscripts.[20] In a manuscript-based culture, commentaries and glosses begin as notes literally written in the margins of the original work. When the work is next copied these may be incorporated into the main manuscript, creating a new book with additional, original content. This process can go on as long as anyone is interested in the book. In other words, a manuscript book is a wiki, but a print book is only a text.[21] This is an important source of the undervaluation of Islamicate science.

It is easy to recognize a new treatment of a scientific subject when it takes up a whole book. Examples from the accepted history of Islamicate science are Ibn Sīnā's *Canon of Medicine* (composed around 1025) and Ibn al-Haytham's *Optics* (composed before 1040). Using this standard, we look for later books improving on the earlier ones. Thus al-Ṭūsī's *Tadkhira*, composed before 1274, replies to Ibn al-Haytham's *Doubts*, and later writers, like Niẓām al-Dīn al-Nīsābūrī (died c. 1329) and ʻAlī Qūshjī (d. 1472), criticize and expand on al-Ṭūsī. In the case of al-Nīsābūrī, for example,[22] several of his most important books take the form of commentaries or glosses, which incorporate the marginal notes added to manuscripts by the process we described above. Commentaries or glosses have often been dismissed, mistakenly, as "derivative" or a tool for teaching rather than an original contribution to research.[23] But in the Islamicate sciences, this is one of the main places where you find original work.[24]

As an example, consider the astronomical research tradition started by Bahāʾ al-Dīn al-ʿĀmilī (1547–1621) a polymath who lived and worked in Persia, and whose astronomical work began a major research tradition based almost entirely on glosses and commentaries. His first book on astronomy, the *Tashrīḥ al-aflāk* (*Dissection of the Heavens*), was an introduction for non-experts, written before 1576, and dedicated and rededicated to four successive rulers of Persia. It lacks calculations or detailed models. It even lacks definitions for many key terms. So, it has been seen as evidence for the decline of Islamicate science. In fact,

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it was not a bad technical text; it was a patronage gift, and more likely to be read if it was non-technical. As a patronage gift it was very successful, ultimately gaining al-ʿĀmilī the support of Shah ʿAbbās I ("The Great") in 1587. Al-ʿĀmilī then wrote a gloss on his own book that he finished no later than 1599. The gloss is many times longer than the original. It supplies all the technical details missing in the first, non-technical book, for example definitions of concepts, and also refers to his original research, including new models for the moon and Mercury. Other scholars immediately began to write commentaries on the gloss, a process that continued for at least two hundred years. In these commentaries, they introduced new topics like discussions of the Copernican system. Hence the existence of an active tradition of glosses and commentaries is as much an indication of an active research tradition as the appearance of new stand-alone books.[25]

The short discussion of a topic, in one section of a gloss or commentary, provides the same kind of short form publication that scientific articles came to offer in the West, and with much the same results. As long ago as 1962, Thomas Kuhn noted that the appearance of this form of publication was a marker for the maturity of a scientific field. The publication of "big books" ceases when there is no longer any need to explain all the fundamentals of a field to defend the author's view from its competitors.[26] Al-ʿĀmilī refers to earlier authors like ʿAlī Qūshjī and Quṭb al-Dīn Shīrāzī (1236–1311), who in turn refer back to al-Ṭūsī and the first non-Ptolemaic models in the Islamicate tradition. The pattern of writing commentaries and glosses is well established by his time, although his followers begin a separate branch stemming from the *Tashrīḥ al-aflāk*.[27]

4 Reconsidering Decline

H. J. J. Winter's survey article "Persian Science in Safavid Times" illustrates many of the problems that still recur in appraisals of Islamicate science. These include the refusal to accept as significant any work that did not contribute to Western science after the European "Scientific Revolution"; failing to recognize glosses and commentaries as original contributions, and hence failure to recognize an ongoing active scientific tradition; privileging theoretical science over the material aspects of science (instruments and special purpose buildings) as well as technology, and failing to apply the same standards to appraising Islamicate scientists that are applied to Western science. Hence, Winter failed to recognize either the normal state of Islamicate science before al-ʿĀmilī or its continuation for centuries after him.

Winter begins his survey by saying that during the Safavid period "[...] there is little doubt that both Iran and Turkey were gradually coming under the influence of Western science and technology[...]."[28] This is not only historically false, it is contradicted by evidence Winter himself brings forward, but discounts because of his failure to address Safavid science in its own terms. He identifies al-ʿĀmilī, and even names his most well-known book on astronomy:[29] "[T]here were many writers of *astronomical manuals* in Persia: [...] One of the best known of these writers was Bahāʾ al-Dīn al-ʿĀmilī [...] author of *Tashrīḥ al-aflāk*, a work on astronomy in Arabic which was followed by Persian commentaries."[30]

Winter goes on to mention al-ʿĀmilī's contributions to other scientific fields including two works on the astrolabe and a book on arithmetic that he notes, "[...] inspired commentaries in both Persia and India [...] and was later printed [...] (Tehran 1316/1898–99)."[31] Had he followed his own note about the Persian commentaries on the *Tashrīḥ al-aflāk,* he would have discovered al-ʿĀmilī's massive *Gloss* on his own work, together with commentaries on the *Gloss* written by al-ʿĀmilī's students beginning in the same year.[32] Here we might ask, why would anyone write one commentary, let alone two, on a gloss that had only just appeared? But, the educational system described above did not provide the large audience of undergraduates that attracted printers to produce cheap astronomy texts for European universities in the same period, and, unless there was a huge market, evidently these were not *handbooks*. The correct explanation is that each of these

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works, the *Gloss* and the commentaries, contained original work and constituted the extension of an active research tradition. The *Tashrīḥ al-aflāk* itself might reasonably be described as a handbook, or at least a non-technical introduction to astronomy. It achieved such importance as the founding work in al-ʿĀmilī's tradition that it continued to circulate in manuscript until it was printed in the nineteenth century, and, ironically, became a vehicle for European astronomy to enter the intellectual life of the Safavids' arch enemies, the Ottomans.[33]

Winter is slightly more generous about practical astronomy. He describes a vigorous industry producing astrolabes of unusual beauty, without sacrificing accuracy for decoration. Like al-ʿĀmilī, the principal makers served ʿAbbās I (r. 1588–1629). Winter notes that production of these instruments peaked after peak production in Europe, around 1700 as opposed to 1580.[34] He also describes the visit to Isfahan of a European mathematician, Père Raphaël du Mans (Jacques Dutertre, 1613–96) sometime in the late 1660s. Père du Mans compared Persian texts on the astrolabe with European counterparts by Stoeffler and Regiomontanus, and concluded that the Persian works were "better and more accurate, being neater geometrically."[35] In fact, according to Winter, "The Muslim tradition in astronomy, reaching its peak at Samarqand, was perpetuated by the Mughal emperors, and came to its close with observatories erected at Delhi, Jaipur, Mathura (Muttra), Benares and Ujjain [...]" in the 18th century.[36] But even the explosion of new observatories in Mughal India, and the huge output of superb astrolabes that he documents, are not enough to counter the thesis of decline for Winter. The unspoken criticism is that none of these observatories adopted telescopes, and hence were inconsequential in comparison to contemporary European sites. Al-ʿĀmilī worked in the research tradition that began with al-Ṭūsī and the observatory at Marāgha he directed, and included ʿAlī Qūshjī who worked at the observatory in Samarkand. The construction of five observatories by the Mughals between 1724 and 1737 should be seen as a continuation of this vigorous research tradition, which was evidently still satisfying the needs of its scientists, its patrons and their audiences.

According to Winter al-ʿĀmilī is an example of "The encyclopaedic mind, characteristic of the medieval world [...]." which prevailed in Safavid Iran.[37] This is an interesting form of denigration. Al-ʿĀmilī, we are being told, is the wrong kind of person to be doing science, or at least to be doing *worthwhile* science. Al-ʿĀmilī was a polymath. His main career was in religious law, leading to his appointment as the most senior *shaykh al-islām* (jurisconsult) in the Safavid empire. But he also made major contributions to both theoretical and practical astronomy, pure mathematics and other sciences. In Italy, at the same moment in time, this scope of achievement would merit the label "Renaissance man."

5 Conclusion

I said at the outset that the decline thesis was an instance of what might be labeled Whig or teleological history, claiming that "anything that didn't contribute to modern science was both wrong and irrelevant," that is, not properly part of the history of science. Of course, Islamicate science during the fifteenth, sixteenth and seventeenth centuries fits this rubric almost perfectly. But the scientific activity in fields like astronomy is a continuation of the research traditions founded in the "Golden Age." So, if we acknowledge the activities of the "Golden Age" as science, we should accept their continuation in the sixteenth and seventeenth centuries as science too. Part of the difficulty here is that we need to recognize how these research traditions operated. Islamicate scientists were trained by individuals, not institutions, and credentialed by acquiring *ijāzahs* that entitled them to teach very specific items. They continued the research traditions in which they trained, usually, by writing glosses, commentaries or supercommentaries, rather than providing new, book length treatments of their subject. Their commentaries provided relatively short explanations, analyses, and improvements of particular points in the text they addressed (which were often themselves commentaries,

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glosses, etc.). Each of these short discussions may be seen as the equivalent of a later European journal article. Any commentary may contain several items that reach a noteworthy level of novelty and importance. These patterns of education and scholarship were in place between the ninth and eleventh centuries and persisted, with minor changes, into the present. The entire social structure of Islamicate science, the training and credentialing of scientists as well as the written form in which research circulated, differed from later Western paradigms. This does not mean that early modern Islamicate science was not science, or that it was declining or stagnant. It continued to expand, continued to generate and incorporate original research, and, most important, continued to be successful in fulfilling the needs of its home cultures.[38] These were not the needs of European science, nor were its accomplishments organized, transmitted or stored in formats that Europeans came to regard as canonical. Islamicate science did not decline during or after the early modern period,[39] it just continued in a different way from Western science.[40]

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1 A. I. Sabra, "Science, Islamic," in *Dictionary of the Middle Ages*, ed. J. R. Strayer (New York: Scribners, 1988 Vol. 11, 81–89). Sabra's talk of "progress," "permanent footings," and "sophisticated programs" clearly takes European science as its standard. For a partial reply to Sabra's historical claims, see note 4.

2 However, specialists have very different views. See George Saliba, *Islamic Science and the Making of the European Renaissance* (Boston, MA: MIT Press, 2007) 233–56, quoted below note 40. See also Sonja Brentjes and Robert Morrison, "The Sciences in Islamic Societies, 750–1800," in *The New Cambridge History of Islam. Volume 4: Islamic Cultures and Societies to the End of the Eighteenth Century,* ed. Robert Irwin (Cambridge: Cambridge University Press, 2010) 564–639: "For almost five hundred years Islamic scholarly cultures have been mostly downplayed, or their existence has been flatly denied" (*ibid*.: 633). They carry their account of Ottoman science and technology into the nineteenth century, by which time Ottoman rulers had appropriated European military technologies and European patterns of education to support them, but only mention the Safavids and Mughals in passing, most notably as patrons of astrology (*ibid*.: 630). Similarly, F. Jamil Ragep, "Islamic Culture and Natural Sciences," in *The Cambridge History of Science, Vol 2: Medieval Science,* ed. D. Lindberg, and M. Shank Cambridge: Cambridge University Press, 2013), 27-61 (doi:10.1017/CHO9780511974007.003), describes scientific traditions that continue into the Ottoman and Safavid periods: "The two rival empires—the former Sunni, the latter Shīʿī —attained magnificence in literature and the arts, but their attainments in scientific and philosophical matters are still not sufficiently known or appreciated. Recent historical work has shown that a number of intellectual traditions continued, perhaps even flourished, during this time." (2013: 33). See also Steven J. Livesey, and Sonja Brentjes, "Science in the Medieval Christian and Islamic Worlds," in *The Oxford Illustrated History of Science*, ed. Iwan Rhys Morus (Oxford: Oxford University Press, 2016), 72–107. See below for a discussion of H. J. J. Winter, "Persian Science in Safavid Times," in *The Cambridge History of Iran, Vol. 6: The Timurid and Safavid Periods,* ed. Peter Jackson, and Laurence Lockhart (Cambridge, Cambridge University Press, 1986), 581-609 (doi:10.1017/CHOL9780521200943), reprinted unchanged in 2008, with identical pagination. Hereafter cited as Winter (1986/2008).

3 H. Floris Cohen, *The Scientific Revolution: A Historiographical Inquiry* (Chicago: University of Chicago Press, 1994), 384–417; H. Floris Cohen, *How Modern Science Came Into The World: Four Civilizations, One 17th-Century Breakthrough* (Amsterdam: Amsterdam University Press, 2010), 64–75, and H. Floris Cohen, *The Rise of Modern Science Explained: A Comparative History* (Cambridge: Cambridge University

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Press, 2015), 1–72. Note especially the table on p. 66 which dates the decline from "c. A.D. 1050." This book is an updated version of a Dutch publication from 2007.

4 Recent English language studies include: Miri Shefer-Mossensohn, *Science among the Ottomans: the Cultural Creation and Exchange of Knowledge* (Austin: University of Texas Press, 2015); Sonja Brentjes, *Travellers from Europe in the Ottoman and Safavid Empires, 16th–17th Centuries: Seeking, Transforming, Discarding Knowledge* (Burlington, VT: Ashgate/Variorum, 2010); on Mughal astronomy see Denis Savoie, "Les cadrans solaires écliptiques de l'observatoire de Jaipur," in *Recherches sur les cadrans solaires,* ed. Denis Savoie (Turnhout, Belgium: Brepols, 2014), 161–74, which describes the unusually accurate instruments built for one of five non-European observatories constructed in Northern India during the first half of the eighteenth century. On the entry of the telescope, Copernicus and Newton see, Simon Schaffer, "The Asiatic Enlightenments of British Astronomy," in *The Brokered World: Go-Betweens and Global Intelligence, 1770–1820*, ed. Simon Schaffer, *et al.* (Sagamore Beach, MA: Science History Publications/USA, 2009), 49–104.

5 "[…] the full record of the Islamic achievement in the sciences is now to be found in manuscripts that, despite the hazards of history, have been preserved in large numbers in libraries scattered over the Middle east, Asia, Europe, and the United States, where the great majority of them await study" Sabra (1988: 81), cited n.1. Although the situation has improved since Sabra wrote this, a large proportion of manuscripts remain unexamined, and a fortiori unexamined by readers equipped with modern historiographical approaches. On modern historiography of science, see Pamela H. Smith, "Science," in *A Concise Companion to History,* ed. Ulinka Rublak (Oxford: Oxford University Press, 2012), 269–97 and Sonja Brentjes, A. Fidora, and M. M. Tischler, "Towards a new approach to medieval cross-cultural exchanges," *Journal of Transcultural Medieval Studies* 1, no. 1(2014), 9–50.

6 On the role of early modern universities in scientific education see, e.g. Mordechai Feingold, *The Mathematicians' Apprenticeship: Science, Universities and Society in England, 1560–1640* (Cambridge: Cambridge University Press, 1984) and Mordechai Feingold and Victor Navarro-Brotons, *Universities and Science in the Early Modern Period* (Dordrecht: Springer Netherlands, 2006). On European universities' debt to other cultures see Christopher I. Beckwith, *Warriors of the Cloisters: The Central Asian Origins of Science in the Medieval World* (Princeton NJ: Princeton University Press, 2012) and George Makdisi, *The Rise of Colleges: Institutions of Learning in Islam and the West* (Edinburgh: Edinburgh University Press, 1981) esp. 224–80. On the corresponding Islamicate institutions see Makdisi (1981: 27–34), Jonathan Berkey, *The Transmission of Knowledge in Medieval Cairo: A Social History of Islamic Education* (Princeton, NJ: Princeton University Press, 1992) esp. 6–85; Michael Chamberlain, *Knowledge and Social Practice in Medieval Damascus*, 1190–1350 (Cambridge: Cambridge University Press, 1994) esp. 69–90. Note that these sources depict very different times and places. Also, Makdisi supports a cultural form of the decline thesis (1981: 289–91).

7 Universities were supplemented in the early modern period by new colleges like Gresham College, London, founded 1597, the 39 Jesuit colleges founded in France before 1610 (*Catholic Encyclopedia*) and numerous Lutheran *gymnasia*. See Anthony Grafton, "Libraries and Lecture Halls," and Bruce Moran, "Courts and Academies" in *The Cambridge History of Science, eds.* Katherine Park and Lorraine Daston (Cambridge: Cambridge University Press, 2006), 238–50 and 251–71 (doi:10.1017/CHOL9780521572446.011 and doi:10.1017/CHOL9780521572446.012).

8 For example: The Royal Society, London, founded in 1663, and the *Académie des sciences,* Paris, founded in 1666. See e.g. E. N. da Costa Andrade, *A Brief History of the Royal Society* (London: Royal Society, 1961); Roger Hahn, *The Anatomy of a Scientific Institution: The Paris Academy of Sciences*, *1666-1803* (Berkeley, University of California Press, 1971).

9 Park and Daston (2006), cited n. 7, offers the following alternative venues for education in science: markets, piazzas and villages, homes and households, libraries and lecture halls, anatomy theaters, botanical gardens, and natural history collections, laboratories, sites of military science and technology, coffeehouses and print shops, and finally networks of travel, correspondence, and

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exchange. Almost all of these are available in one form or another in Islamicate societies up to and including the early modern period. On the limitations of the treatments by Harris, Cook, and Vogel, in this volume see Sonja Brentjes, "Relationships Between Early Modern Christian and Islamicate Societies in Eurasia and North Africa as Reflected in the History of Science and Medicine," *Confluence: Online Journal of World Philosophies* 3, (2015), 85–121.

10 There are examples of "followers" and "disciples" e.g., in the case of Galileo, but notice that all these people also received training in other venues, especially universities and learned societies; Torricelli, for example, began his education in a Jesuit college, but after being introduced to Galileo's follower Castelli continued his education under Castelli rather than at a formal institution, then serving for a long time as his secretary. Mario Gliozzi, "Torricelli, Evangelista," *Complete Dictionary of Scientific Biography,* ed. N. Koertge, 27 vols. (Detroit: Charles Scribner's Sons, 2008 Vol. 13: 433–40), esp. 433–4.

11 Steven J. Livesey, "Medieval Universities," in *A Companion to the History of Science*, ed. Bernard Lightman (Oxford: John Wiley and Sons, 2016) 181–93; Makdisi (1981: 224–25, 270–74) cited n.6.

12 On female participation see Mohammad Akram, *Al-Muḥaddithāt: The Women Scholars in Islam* (Oxford: Interface Publications, 2007); Berkey (1992: 161–81) cited n.6.

13 Mesut Idriz, "From a Local Tradition to a Universal Practice: "Ijāzah" as a Muslim Educational Tradition," *Asian Journal of Social Science* 35, (2007): 84–110; Makdisi (1981: 14–52); Chamberlain (1994: 87–90), both cited, n. 6.

14 Redrawn from Judith Pfeiffer, "Teaching the Learned: Jalāl al-Dīn al-Dawānī's *Ijāza* to Muʾayyadzāda ʿAbd al-Raḥmān Efendi and the Circulation of Knowledge between Fārs and the Ottoman Empire at the Turn of the Sixteenth Century," in *The Heritage of Arabo-Islamic Learning: Studies Presented to Wadad Kadi*, ed. Maurice Pomerantz and Aram Shahin (Leiden: Brill, 2015), 284–332, p. 318 (doi: 10.1163/9789004307469_014).

15 On the legal definition, conditions of validity, and status of participants, see Monica M. Gaudiosi, "The Influence of the Islamic Law of *Waqf* on the Development of the Trust in England: The Case of Merton College," *University of Pennsylvania Law Review* 136, (1988) 1231-61, esp. 1232-40. Cf. Makdisi (1981: 35–74); Chamberlain (1994: 51–55 & 79–80), both cited n. 6.

16 Gaudiosi (1988: 1234, 1239); Makdisi (1981: 171-86); Beckwith (2012: 42–43), both cited n. 6.

17 See Makdisi (1981: 80–98); Chamberlain (1994: 82–87), both cited n. 6. In the exact sciences, there were practical constraints; as indicated above, it was usual to study Euclid before Ptolemy, and there was also a wide consensus on the best introductions to astronomy. See F. Jamil Ragep, *Naṣīr al-Dīn al-Ṭūsī's Memoir on Astronomy (al-Tadhkira fī ʿilm al-hayʾa)*, 2 vols. (New York: Springer, 1993) 1: 56.

Ottoman *medreses* were a partial exception to the general freedom in teaching. Their curriculum was established by statute under Mehmed II and Suleiman I. See: Shahab Ahmed and Nenad Filipovic, "The Sultan's Syllabus: A Curriculum for the Ottoman Imperial *medreses* Prescribed in a *fermān* of Qānūnī I Süleymān, Dated 973 (1565)," *Studia Islamica* 98/99, (2004): 183–218.

18 Pfeiffer (2015: 312–17), cited n. 14, shows how several different intellectual lineages could appear in a single *ijāzah*.

19 Don L. Voss, *Ibn al-Haytham's Doubts About Ptolemy: A Translation and Commentary,* Ph.D. dissertation (University of Chicago, 1985); George Saliba, "The Role of *Almagest* Commentaries in Medieval Arabic Astronomy: A Preliminary Survey of Ṭūsī's Redaction of Ptolemy's *Almagest*", *Archives Internationales d'Histoire des Sciences* 37, (1987): 3–20.

20 Compare Elizabeth L. Eisenstein, *The Printing Press as an Agent of Change: Communications and Cultural Transformations in Early Modern Europe* (Cambridge, Cambridge University Press, 1979) with Danielle Jacquart and Charles Burnett, *Scientia in Margine: Etudes sur les Marginalia dans les manuscrits scientifiques du Moyen Age à la Renaissance* (Genève: Droz, 2005).

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21 Early in the print era Europeans continued to use manuscripts, and used books in the same way that they had used manuscripts. Copernicus's main book was extensively annotated and exchanged among scholars, leading to families of copied comments, but no new printed books. See, Owen Gingerich, *An Annotated Census of Copernicus'* De revolutionibus: *(Nuremberg, 1543 and Basel, 1566),* (Boston: Brill, 2002.) However, Emilie du Châtelet's printed French edition of Newton's *Principia* is really a commentary that updates the original and contains much new material. See, Emilie du Châtelet, *Principes mathématiques de la philosophie naturelle* (Paris, Desaint & Saillant, 1759).

22 For example, his commentaries on Ṭusi's presentation of the *Almagest*, Ṭusi's astronomical handbook, and Ṭusi's main astronomical work the *Tadhkira*. Robert Morrison, "Nīsābūrī," *The Biographical Encyclopedia of Astronomers,* ed. Thomas Hockey et al. (New York: Springer, 200), 837 (doi: 10.1007/978-0-387-30400-7_1016). See also Robert Morrison, *Islam and Science: the Intellectual Career of Nīẓām al-Dīn al-Nīsābūrī* (New York: Routledge, 2007).

23 For example, Cohen (2005: 56) cited n.3, which takes commentaries as a sign of decline.

24 "[C]ommentaries are by no means a rehash of the original text, to be consulted when the original becomes difficult to understand, but are sometimes a mine of their own to be exploited for the original ideas they contain. The fact that most of the literature of post-twelfth-century Islamic civilization, scientific or otherwise, was written in the form of commentaries should no longer be seen as a sign of decline in intellectual production, as is so often done, but rather the production of specialized periodical literature […]. In sum reading those commentaries from one century to the next is tantamount to surveying the periodical literature in a specific field from one year to the next." George Saliba, "Writing the History of Arabic Astronomy: Problems and Differing Perspectives," *Journal of the American Oriental Society* 116, no. 4, (1996): 709–18, 714a–b.

25 Another example of this kind of research tradition is provided by the sequels to Jaghmīnī's *Mulakhkhaṣ,* another introduction to astronomy, composed before 1246–47. "The educational tradition represented by the transmission, transformation, commentaries, and study of Jaghmīnī's text was thriving in the Ottoman period well into the 18th century (Ihsanoğlu 2002: 586–87). Indeed, the *Mulakhkhaṣ* tradition exists in thousands of extant copies of the original as well as commentaries, supercommentaries, and glosses. There were at least 15 commentators, including […] Qāḍīzāde al-Rūmī who dedicated his commentary, written in 1412, to Ulugh Begh. Qāḍīzāde's commentary then became the subject of numerous supercommentaries by such authors as Sinān Pāshā (died: 1486) and ʿAbd al-ʿAlī al-Birjandī. This continuous chain of astronomical learning represented by the *Mulakhkhaṣ* and its commentaries and supercommentaries—one that extended for a period of 500 years is a significant indication of an active, ongoing educational tradition within Islam." Sally P. Ragep, "Jaghmīnī'," *Biographical Encyclopedia of Astronomers*, ed. Thomas Hockey *et al.* (New York: Springer, 2007), 584-5, doi: 10.1007/978-0-387-30400-7_710, citing ed. Ekmeleddin İhsanoğlu, *History of the Ottoman State, Society and Civilisation*, 2 Vols. (Istanbul: IRCICA, 2002). And see now Sally P. Ragep, *Jaghmīnī's Mulakhkhaṣ: An Islamic Introduction to Ptolemaic Astronomy* (Berlin: Springer, 2016).

26 Thomas S. Kuhn, *The Structure of Scientific Revolutions* (Chicago: University of Chicago Press, 1962), Ch. 2.

27 The status of commentaries and glosses in Islamicate intellectual life is addressed at length in a recent special issue of *Oriens*, and specifically for the sciences in Asad Q. Ahmed, "Post-Classical Philosophical Commentaries/Glosses: Innovation in the Margins," *Oriens* 41, nos 3–4 (2013): 317–48 (doi: 10.1163/18778372-13413405) and Nahyan Fancy, "Medical Commentaries: A Preliminary Examination of Ibn al-Nafīs's Shurūḥ, the Mūjaz and Subsequent Commentaries on the Mūjaz," *Oriens* 41, no.'s 3–4 (2013): 525-45 (doi: 10.1163/18778372-13413412).

28 Winter (1986/2008: 587), cited n. 2.

29 But not his most important or original book on astronomy, which might be either the *Gloss on the Tashrīḥ al-aflāk* written before 1599 (see below), or his lost work presenting new models for the moon and Mercury.

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30 Winter (1986/2008: 592), emphasis added. Cited n. 2.

31 Winter (1986/2008: 592), cited n. 2.

32 Al-ʿĀmilī's *Gloss,* completed between 1595 and 1599, is known as the *Sharḥ tashrīḥ al-aflāk* or *Ḥāshiya tashrīḥ al-aflāk*. The end date is established by Muḥammad-Kāẓim Tunikābunī's commentary on the *Dissection, Qānūn al-idrāk fī Tashrīḥ al-aflāk*, definitely completed in 1599, which makes extensive use of the *Gloss*. Another important commentary was completed by Ṣadr al-Dīn Qazvīnī in 1672, entitled *Tafrīḥ al- idrāk fī tawẓīḥ tashrīḥ al-aflāk,* providing evidence of the continuation of the tradition. My sincere thanks to Younes Mahdavi for this information.

33 Robert Morrison, "The Reception of Early Modern European Astronomy by Ottoman Religious Scholars," *Archivum Ottominacum* 21 (2003): 187–95, esp. 189.

34 Winter (1986/2008: 585-7), cited n. 2.

35 Winter (1986/2008: 587), cited n. 2. For more recent studies of European travelers to Persia in the early modern period, see especially Sonja Brentjes, *Travellers from Europe in the Ottoman and Safavid Empires, 16th–17th Centuries: Seeking, Transforming, Discarding Knowledge* (Burlington, VT: Ashgate/Variorum, 2010), and Elio Brancaforte and Sonja Brentjes (guest curators and editors), *From Rhubarb to Rubies: European Travels to Safavid Iran (1550–1700); The Lands of the Sophi: Iran in Early Modern European Maps (1550–1700), Harvard Library Bulletin* 23, nos. 1–2 (2012).

36 Winter (1986/2008: 593), cited n. 2.

37 Winter (1986/2008: 606), cited n. 2.

38 These included, for algebra, determining shares under inheritance law, for spherical astronomy, determining the *qibla*, and for *hay'a*, answering the religious question of the structure of the cosmos. See Ahmad S. Dallal, *Islam, Science, and the Challenge of History* (New Haven: Yale University Press, 2010), Chapter 1, text to notes 53–57.

39 Compare George Saliba (2007, 253), cited n. 2: "[…] [T]he production of science in what is now Europe began to grow almost at a logarithmic rate […] European science began to surge on, and both of the Chinese and Islamic worlds were left behind."

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