Science and technology in early modern Islam, c.1450-c.1850

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“Seek knowledge, even in China”. Prophet Muhammad

A contested narrative

The course of Islamic science and technology used to be portrayed as a play in four acts. From around 750 to 950 CE, translators made available the wisdom of Ancient Greece. Scholars of the 'golden age' elaborated a little on this legacy, before transmitting it to Christendom. An Islamic 'dark age' began around 1100, usually ascribed to Turko-Mongol barbarian invasions and religious fanaticism, allowing the West to pull steadily ahead. Only in the twentieth century did Muslims enter the brave new world of universal science and technology.

Almost every element of this standard tale has lately been challenged. A few aspects of Islamic scientific endeavour seemingly date back to the time of the Prophet, early in the seventh century. The role of translations has correspondingly been downgraded. At the same time, greater stress has been placed on materials obtained from India, Persia, Babylon, and Egypt. More prominence has been granted to experimentation and observation by Islamic scholars, who led Europe and East Asia for several centuries. The onset of decline has been moved to a later point, albeit without consensus as to when that might be. Revival began from the late eighteenth century, and, in part, involved a return to the wellsprings of Islamic vitality.

The greatest controversy surrounds the causes of Islamic scientific 'decline.' For Toby Huff, 'generalised and universal norms' did not emerge in Islam, especially in the legal sphere, and an 'ethos of secrecy in intellectual affairs' prevailed. The theological victory of Asha'ri determinism over Mu'tazili rationalism reduced reason to mere common sense. Speculative and experimental researchers were pushed aside by lowly dividers of inheritance and mosque timekeepers. Institutes of higher education were elitist, had no corporate staff, failed to issue standardised diplomas, and rejected the 'rational sciences,' also known as 'useful,' 'special,' 'ancient,' 'foreign,' or 'Greek.' Educational and research institutions lacked autonomy, because *waqf* trusts were subject to intrusive religious regulation. Finally, the extended family predominated over social corporations such as guilds and professional associations. (Huff 1993: 3-4, 47-8, 55, 68-70, 73-87, 112-17, 153-5, 170-4, 181-6, 212-26., 233-4)

Muzaffar Iqbal vigorously contests all this. He stresses the whiggishness of defining the Western scientific revolution as the only possible one, leading to the deduction that only Western conditions could give rise to such a revolution. The Quran calls repeatedly on people to 'reflect on nature,' and Hadiths against innovation refer only to the religious sphere. Huff's 'disinterestedness and organised scepticism' were Islamic values, and knowledge circulated freely. Joseph Schacht, the main source of Huff's views on law, is a 'thoroughly discredited' Orientalist. In reality, Islamic law was a unified and Quran-centred system, despite the existence of different schools. While some colleges did not teach the rational sciences, others did. Personal grants of an *ijaza*, a licence to teach, did not obviously work against scientific inquiry. 'Thousands of texts' attest to rights granted to guilds, merchants, cities, and other special interest groups, and that since the time of the Prophet's Constitution of Medina. Moreover, such rights were effectively protected by the *waqf* system. Tellingly, Iqbal notes that most of Huff's factors existed during both the 'golden' and the 'dark' age of Islamic science. (Iqbal 2002: 3, 140-52, 158-9)

Other authors have added to the critique. Even if Islamic law did not recognise the juridical personality of associations, it did not prohibit them, and there is much evidence for collective organisations functioning within the law. (Ihsanoglu 2004: IX, 163) Charitable trusts, providing income in perpetuity for educational purposes, worked reasonably well. (Ihsanoglu 2004: X, 46-7) When problems arose, it was not because of Huff's alleged religious interference, but rather due to poor management of funds. (Watson 1983: 142) Typically, there was 'lack of continuing financial support, or inadequate supervision.' (Azra 1992: 145)

Some elements remain subject to controversy, and require more research. Sufi mysticism may have purveyed magical and superstitious thinking, but Sufism was a complex and potentially positive phenomenon. (Qadir 1990: 131-4; Rahman 2000d: 428-32) Given the undeniable role played by 'people of the book' in advancing Islamicate knowledge, the impact of fluctuating toleration for non-Muslims requires more research. (Sayili 1960: 426-7; Ihsanoglu 2004: viii; Kumar 2003: 675-6) The wider contours of borrowing from other civilisations, or refusal to do so, need to be better demarcated. (Sayili 1960: 428-9; Ihsanoglu 2004) Political culture remained resolutely absolutist, and some tyrants feared the subversive effects of knowledge, but rulers were also patrons of learning. (Qadir 1990: 134; Mohebbi 1996: 148-9) The abundance of slaves may well have dulled the need for labour saving mechanical inventions. (Mohebbi 1996: 207) More widely, servitude created a 'stifling acceptance of the division of society into free men and un-free men.' (Rosenthal 1960: 122) However, slavery could also free the Muslim elite for research and writing. (Shepherd 1980: 86-7)

Most controversial is the rejection of Greek philosophy by Abu Hamid Muhammad al-Ghazali [Algazel, 1058-1111]. To be sure, al-Ghazali did not repudiate the rational sciences out of hand, nor indeed reason itself. Nevertheless, he considered that materialists tended to drift into atheism, naturalists were prone to deny life after death, and mathematics, natural sciences and medicine could all lead to unbelief. Above all, al-Ghazali elaborated on the Asha'ri position that there was no necessary link between cause and effect, since God perpetually recreated the universe at every instant. (Iqbal 2002: 109-10; Nasr 1987: 307-12, 318-21; Qadir 1990: 124-6, 131-4)

The early modern conundrum

The timing of 'decline' has been the subject of fierce and inconclusive argument. Iqbal asserts that Islamic science deteriorated from around 1450, despite a marked upswing in Muslim political fortunes. He revives the old story of Mongol invasions destroying libraries, scattering scholars and severing traditions of learning. This was compounded by the division of the Islamic heartlands into three rival empires, with the conversion of Persia [Iran] to Shi'i beliefs as an additional complication. For good measure, Iqbal adds that early modern empires were 'almost bordering on decadence' in developing a 'pleasure-seeking high culture.' (Iqbal 2002: 160-9)

None of this hold up to a moment's scrutiny. The long-term impact of Mongol conquest is negated by Iqbal's own discussion of how Mongol converts blew a rejuvenating wind through learning, partly by strengthening connections with China. (Iqbal 2002: 164-5) Moreover, there were safe havens from Mongol invaders, notably India. (Rahman 2000d: 420-1) Architecture, poetry and painting may have diverted early modern energies, but the Abbasids of the scientific 'golden age' were just as 'pleasure-seeking,' if not more so. The caliphate was not obviously conducive to fresh thinking, and had become a hollow shell by 1258. Early modern borders certainly failed to hinder the free flow of ideas and scholars, even between Shi'i and Sunni areas. (Hodgson 1974: III, 33)

In reality, an obsession with science has served to conceal the technological vitality of early modern Islamic states, from around 1450 to 1850. Indeed, the name 'gunpowder empires,' bestowed on them by Marshall Hodgson, underlines how much they owed to a technique borrowed from China and Europe. (Hodgson 1974: III) This was reinforced by the absorption of Inner Asian cavalry methods from Turks and Mongols, and, to a lesser extent, naval skills from Europeans and Southeast Asians. There were advances in civilian technology, notably in manufacturing, as well as a continuing emphasis on education. (Ihsanoglu 2004; Mohebbi 1996; Habib 1980) Indeed, Iqbal himself praises the hospitals, schools, public parks, caravanserais, and irrigation facilities of the gunpowder empires. (Iqbal 2002: xviii)

Fusing science and technology into the single category of 'useful and reliable knowledge' leads to a rejection of the notion of an Islamic 'decline.' Even the suggestion of stagnation, advanced by A. Rahman, is unsatisfactory. (Rahman 2000d: 415) A gently rising plateau, exhibiting marked regional variations, is a better metaphor for the experience of early modern Islam. Many Muslim societies continued to innovate in practical ways, even if the intellectual brilliance of earlier generations had faded away.

The sinews of war

Although Muslims borrowed much firearms technology, initially from China and later from Europe, they were responsible for a number of innovations. One example was the *zamburak* system of swivelling light artillery, mounted on camels and fired with the animals in a kneeling position. This technique appears to have originated in Egypt, and spread from there to Iran, India and elsewhere. Indian Muslims attempted to adapt it to elephants, but the great beasts would not hold steady under fire. (Mohebbi 1996: 33; Bulliet 1975: 222-3; Khan 2004: 107-11)

Mastery of firearms was crucial to the rise of the Ottoman empire. Mehmet II, the Conqueror [r.1451-81], ordered huge siege guns to be cast by a Hungarian renegade. With these, he breached the walls of Constantinople in 1453, and made the city his capital under the name of

Istanbul. He and his successors decimated European pike men with field artillery, carried in ox-wagons, and the Janissary corps of servile musketeers. Turkish hosts reached the gates of Vienna in 1529, and again in 1683. The Ottomans procured some advanced weapons from Europe, together with relevant specialists, but they were long able to defend themselves without imports. In the eighteenth century, as the arms gap widened perilously, they made determined efforts to import, copy and adapt Western techniques. (Ihsanoglu 2004: I, 51-5; Cleveland 1994: 41-3, 61-3, 77; Hoodbhoy 1991: 147; Stavrianos 1975: 14)

Unlike other Islamic gunpowder states, the Ottoman empire became a major naval power. Mehmet the Conqueror constructed shipyards in Istanbul, and his fleet of galleys wrested control of the eastern Mediterranean and the Black Sea from the Italian city states. (Cleveland 1994: 41) During the eighteenth century, the Ottomans successfully converted their fleet from oar to sail. (Braudel 1981-4: III, 476-7) Although taken by surprise by the unexpected arrival of the Russian Baltic fleet in 1768, they subsequently set up new arsenals and modernised their naval forces. (Cleveland 1994: 51, 62)

The Safavids revived the glories of ancient Iran in a Shi'i guise. Defeat at Ottoman hands in 1514 led Shah Isma'il [r.1501-24] to develop his own artillery and musket corps, further enhanced by Shah Tahmasp I [r.1524-76]. (Mohebbi 1996: 174) Shah Abbas I [r.1587-1629] closely copied Ottoman methods of slave musketeers and artillery to bring Persia to the peak of its early modern power. (Cleveland 1994: 54; Stavrianos 1975: 12; Winter 1986: 584) The usurper Nadir Shah [r. 1736-47], developed a system to carry cannon slung between two mules, while the Qajar dynasty, in power from the 1790s, developed horsed artillery on European lines. (Mohebbi 1996: 32-3) However, Iranian production of firearms, whether cannon or muskets, was somewhat fitful, occasionally leaving the country dangerously dependent on imports. (Winter 1986: 601-2; Mohebbi 1996: 173-5) Despite the fleeting successes of Nadir

Shah, Iran also failed to become a significant naval power, in part because timber resources were scarce or poorly located. (Mohebbi 1996: 39-40, 43)

While showing no interest in naval prowess, the Mughal, or Timuri, dynasty pressed down overland almost to the southern tip of India. Self-sufficient in firearms, they only temporarily employed Western and Ottoman gunners. (Braudel 1981-4: III, 505-6; Jaffar 1936: 209) The Mughals developed their arsenal through a mixture of local innovation and borrowing from China, the Middle East and Europe. Huge bronze mortars were supplemented by light field artillery, cast in brass or made of wrought-iron. Cast-iron was introduced in the mid-eighteenth century. Metallic shot and gun carriages were copied from Europe, but caste-bronze casings round the ends of wrought-iron barrels were a local invention. For muskets, bored barrels, and wheel-lock and flint-lock mechanisms were gradually introduced, involving a mixture of local developments and appropriations from abroad. Fathullah Shirazi developed a seventeen-barrelled cannon, fired with one matchlock, albeit seemingly as a curiosity rather than a working weapon. (Khan 2004; Habib 1980: 18-20; Rahman 2000b: 248, 257) Mysore bred special fast trotting oxen in the eighteenth century, almost as speedy as horses to draw artillery, and less costly. (Deloche 1980: 245-6)

Indian military innovation was particularly striking for rockets, the best in the early modern world. Developed from Chinese models, they were provided with cheap iron tubes, had a range of up to 1,000 metres, and caused no recoil. A horsemen might carry up to eight, and 20 could be loaded on a camel. However, they were relatively costly, as they could only be used once. (Khan 2004: 29-31) Mysore's forces deployed rockets so effectively that specimens were sent back to Britain for analysis in the late eighteenth century. (Kumar 2003: 685) Tipu Sultan of Mysore [r.1782-99] sent some to the Ottoman sultan, as they were unknown there. (Rahman 2000b: 257)

Firearms brought success beyond the frontiers of the three great empires. Crimean Tatars sacked Moscow outside the Kremlin walls in 1571, and 'harvested' Christians from steppe and forest. Uzbek khans of Turkistan held Russia, Persia and China in check. Southeast Asian rulers restricted Dutch penetration, and nearly turned the tables on enfeebled Europeans in the late eighteenth century. A Yunnanese sultanate broke away from China between 1855 and 1873. On the other side of the world, Ahmad al-Mansur of Morocco [r.1578-1603] destroyed the flower of Portuguese chivalry at Alcazarquivir, and crossed the Sahara to take the middle Niger. Ahmad 'the left-handed' came close to swamping the Ethiopian Christian bastion in the sixteenth century. At a later stage, the Sokoto Caliphate nearly 'dipped the Quran in the sea' at the Niger's mouth. Swahili-Arab power lay athwart the Congo by the 1860s, poised to break through to the Atlantic. (Clarence-Smith, forthcoming)

Lesser Islamic states also distinguished themselves at sea. Ensconced from Tripoli to Sale in the Maghrib, Barbary corsairs mounted lightning raids as far as Iceland and the Newfoundland Banks in the seventeenth century. They remained undefeated and defiant until the 1810s. Omani sultans drove the Portuguese back in the western Indian Ocean from the seventeenth century, and successfully adopted European ships. The Moros of the southern Philippines raided from Luzon to Sumatra and from Borneo to New Guinea. Their light sailing ships, dismantled outside the raiding season, were only contained by Europeans with the advent of steamers in the 1840s. (Clarence-Smith, forthcoming)

Transport

Rulers generally envisaged communications from a military angle, although improvements implied civilian gains. Roads and bridges were to the fore, but canals and harbours also received attention. The notion that the Islamic world regressed by losing the use of wheeled vehicles is misleading. An improved camel saddle, adopted before the rise of Islam, favoured pack transport in the arid zone, but wheeled vehicles continued in use elsewhere, notably in the Ottoman and Mughal domains, and even in Tunisia. (Bulliet 1975: 9, 87, 202)

Mehmet the Conqueror ordered the repair of roads and bridges after seizing Constantinople in 1453, and Ottoman miniatures accurately depict carts and wagons. (Bulliet 1975: 235) Koja Mi'mar Sinan threw a long bridge over the Danube in a sixteenth century campaign, and became a famous architect. (Hodgson 1974: III, 124-5) A lighthouse on the Bosphorus was described in 1550 as being far in advance on anything in Europe, with its 120 steps, leaded glass windows and twenty wicks in a pan of oil. (Jones 1981: 175) The Ottomans planned canals from the Mediterranean to the Red Sea, and from the Don to the Volga, although neither project was followed through. (Hodgson 1974: III, 48-9)

Abbas I [r.1587-1629] was the greatest Persian road builder, ordering the construction or reconstruction of three great military arteries. They had a sand or gravel base and stone paving, and were thus more expensive to maintain than the light surfaces developed in late eighteenth century Europe. Wheeled vehicles were scarce in much of Iran, but roads extended the season in which caravans of pack animals could function without getting bogged down in mud. The Safavids also built combined bridges and dams over some rivers. (Mohebbi 1996: 23-4, 87-8)

The Mughals launched an 'ambitious policy of road building,' especially on the great trunk road from Kabul to Bengal. Close to densely populated areas and large cities, surfaces of broken brick paving, or even stone, were supplied. More common were slightly convex laterite surfaces with lateral drains, regularly repaired by corvée labour. Major roads were supplied with shade trees and rest houses. Permanent bridges, mainly made of brick rather than stone, were typically encountered close to religious centres. There were combined bridges and dams, but boats lashed together to form pontoon bridges were more common in North India, where the flow of water varied enormously according to the monsoon. The ox-cart was the typical wheeled vehicle, although pack animals remained more common. (Deloche 1980: 99-200, 231-85)

Agriculture

In the early centuries of the faith, Muslims probably engendered an 'agricultural revolution' across Eurasia. They perfected existing irrigation techniques, as well as spreading crops from one area to another. Andrew Watson considers that the potential for further improvements was almost exhausted by 1100, and he paints a bleak picture of decay thereafter. He blames salination, climate change, decreasing fertility of marginal lands, high transport costs in zones of discontinuous settlement, crude techniques of invaders, insecurity, crushing tax and rent, the 'dead hand' of *waqf* trusts, the decline of Islamic science, and competition from the New World. (Watson 1983: 139-46) Deterioration in Iraq, the heartland of the old caliphate, was certainly clear, in part due to invasions from the steppe and a long struggles between Ottomans and Safavids for mastery over this buffer zone. (Hasan and Hill 1986: 282)

Iraq was far from typical, however, and Watson's equation of the Islamic world with the Arab world is unacceptable. Early modern agriculture was dynamic to the north and south of the arid zone, in part because of the adoption of New World crops such as maize and tobacco, as Watson himself acknowledges. (Watson 1983: 146) Irrigation methods remained impressive. (Iqbal 2002: xviii) 'Persian wheels' were still spreading slowly, whether the *saqiya* turned by animals or the *na'ura* worked by water, both with wooden gearing. (Hasan and Hill 1986: 38-52, 279-81) In Egypt, eighteenth century beys encouraged the cultivation of new crops. (Hodgson 1974: III, 141)

Early modern European travellers in Iran were impressed by the number of water wheels, the complex system of underground irrigation channels (*qanat*), and efficient breast-straps for oxen. (Winter 1986: 583, 599-600) The Safavids encouraged irrigation, placing a novel emphasis on building dual purpose dams and bridges on large water courses. Official attempts from the fourteenth century to spread the heavy wheeled plough of the western Caucasus were unsuccessful, but this may have reflected thinner soils in Iran. (Mohebbi 1996: 33, 80-1, 87-8, 97-8, 108)

India probably witnessed the most impressive agricultural growth, accompanied by intensified commercialisation. Lands were reclaimed from the forests of the Himalayan foothills, and from jungles in the Deccan. New World crops spread widely, notably maize, tobacco, chilli pepper and groundnuts, while existing cultivation of wheat and cotton expanded. Superior Gujarati methods of rice cultivation raised yields and saved seed. Coffee was introduced from Yemen in the seventeenth century, and indigo became a major export crop. Europeans were impressed by South Indian drill ploughs. Hindu prejudices against human ordure limited manuring, but canals were repaired and extended in the Indus valley, especially by Shah Jahan [r.1628-58]. Babur [r.1526-30], founder of the Mughal dynasty, gave a detailed description of irrigation wheels. (Gopal 2000) Mainly powered by camels or oxen, these wheels appeared in Mughal miniatures, but not in those of earlier periods. (Mohebbi 1996: 108-10; Jones 1981: 199)

The growth of cash cropping for export was apparent on the Islamic periphery, notably in Southeast Asia. Although the Dutch were able to establish a monopsony over cloves, nutmeg and mace in the seventeenth century, black pepper remained out of their effective control. The profits drawn from this product remained a potent source of resistance to further European encroachment. (Andaya 1993)

From proto-industry to modern industry

Innovation persisted in Islam's early modern craft industries. Techniques altered in situ, moved across the Islamic world, or were borrowed from beyond its limits. Skilled urban artisans produced a diversified range of products in well developed Islamic towns. (Stavrianos 1975: 16)

Purchases of European manufactures did not destroy Ottoman proto-industry, contrary to Landes' assertion. (Landes 1998: 401-2) Textile workshops, especially important in Chios and Bursa, disposed of export markets around the Black Sea in the late eighteenth century. (Braudel 1981-84: III, 468-74, 477; Inalcik 1979) The eighteenth century also witnessed a boom in cotton textile production in Greece and Bulgaria, including at least one large unit in eastern Thessaly. (Jones 1981: 189-91; Crampton 1987: 10-11)

The Ottoman authorities contributed significantly to eighteenth century growth. After 1709, the state withdrew from civilian direct production. Entrepreneurs, often non-Muslim, risked their capital to produce woollens, cottons, silk, porcelain, paper and leather. Sultans offered no protectionist quotas and tariffs, for they had a duty to make goods as available and cheap as possible, but they provided cheap credit, secured raw material supplies, located and settled workers, and granted generous tax exemptions. Small scale production was left to guilds. (Ihsanoglu 2004: X, 57-9)

In Egypt, Napoleon Bonaparte was impressed by the mills that he saw in 1798, presumably water mills, and he ordered four of his scientists to examine them. (Gran 1979: 172) These may have been the 'automated flour mills' that Thomas Jefferson noted as having been described by a traveller to Egypt and North Africa. (Jones 1981: 176)

Maghribi crafts were well developed, especially the production of woollen fez caps in Tunis, with output reaching around the million mark by the early nineteenth century. They were exported to the Ottoman empire, Morocco, and below the Sahara. Other Tunisian woollens were centred in Jeri and Jerba, while silk belts came from Algiers, and leather was an ancient and famous Moroccan speciality. These proto-industries exported all over the Middle East in the eighteenth century, and even to Europe. (Valensi 1969: 54-7)

Iran built on a great legacy. Hafez el-Esfahani was a fertile inventor of the early sixteenth century, who assembled a mechanical clock by studying a European example. He also invented two new kinds of water mill, and machines to smooth paper, card wool, and make ink. (Mohebbi 1996: 10, 191-200) Persians discovered how to fabricate true porcelain of the Chinese type in the seventeenth century, before Europeans cracked the problem in 1708. (Hodgson 1974: III, 40) Carpets and silk were famous specialities in the textile sector, which also included cottons and linens in the late seventeenth century. (Spuhler 1986) Western travellers praised the production of silk, leather, 'thin steel plate' for armour, 'exquisite astrolabes,' and enamel tiles. (Winter 1986: 583, 602)

There was considerable reliance on water mills in Iran, together with a lesser use of mills powered by animals and wind. Despite rather poor hydraulic resources, Persians ingeniously exploited limited streams, including the famous *qanat* underground irrigation system. Mills were mainly employed to ground grain, but also to crush sugar cane, extract vegetable oil, polish rice, work bellows, and make paper and gunpowder. Although the evidence is scanty, there are indications of improvements in water technology in early modern times, notably through a greater use of cam-shafts (Mohebbi 1996: 113-90)

India boasted Islamdom's largest and most varied proto-industrial sector, with an urban population that may have reached 20 million in the seventeenth century. The subcontinent was the world's chief exporter of cotton textiles, and a great producer of silk goods. (Braudel 1981-84: III, 503, 506-9) In Mughal times, crank-handles were fitted to spinning wheels and cotton gins, while new weaving techniques probably originated in Iran. Block-printing of cottons spread widely. (Habib 1980: 6-10; Rahman 2000b: 255) Paper making diffused from the fifteenth century, with Gujarat, the largest producer, exporting to the Ottomans and Arabia. (Rahman 2000c: 264-6) High quality steel impressed Europeans, although Chinese hydraulic bellows were only adopted in Assam, and the exploitation of charcoal was depleting forest reserves. Output of iron and steel in the late eighteenth century stood at around 200,000 tons a year. Techniques for smelting zinc by the reduction-distillation process were developed in the Hindu principality of Udaipur, Rajasthan, and were copied in Britain prior to 1730. However, the lack of pumps left mines at the mercy of flooding. (Biswas 2000) A 'shipping revolution' from around 1650 led to creative adaptations of European techniques, exploiting the local advantage of teak, the best wood in the world for naval construction. (Habib 1980: 15-16)

There were drawbacks. Indian production of instruments was restricted. A family of Lahore artisans specialised in making astrolabes from the mid-sixteenth century, but without changing the design for 150 years. (Kochhar 2000: 190) Jahangir [r.1605-27] was offered a clock by a Portuguese embassy, but showed no interest in it. (Rahman 2000c: 261) Another limitation was India's exploitation of inanimate sources of energy, notably wind and water. (Kumar 2003: 684) However, water mills existed, especially in Kashmir, and were at times used to gin cotton, crush ores and drive bellows. Attempts to introduce windmills of the East Persian type failed, allegedly because winds were inconstant and wooden cogs ineffective. (Habib 1980: 21-2; Biswas 2000: 294, 299) A two roller vertically mounted press-mill for sugar-cane, first mentioned in 1657, was worked with a crankshaft, apparently by hand. (Rahman 2000b: 254-5) Some workers in textiles, metals, wood and leather were concentrated in large halls, but still used muscle power. (Jaffar 1936: 20912)

Craft production flourished elsewhere in Islamdom, albeit often based on servile labour. The emirate of Bukhara had some 100,000 wooden looms in the early nineteenth century, 12,000 of them in the capital city. (Khan 1998: 54) The Hausa city states exported their cotton textiles far and wide in West Africa. In Kano alone, there were some 15,000 dye pits by the late nineteenth century, employing about 50,000 people. (Lovejoy 1983: 196-7) Somali coastal city states played a similar role in East Africa. (Cattelani 1897: 67) Southeast Asia's flourishing ship-building industry was revolutionised in the late eighteenth century by a growing fusion of local techniques, already influenced by China, with those of Europe. (Clarence-Smith 2002:, 230-1; Knaap 1996)

Egypt under Muhammad 'Ali [r.1805-48] provided the most celebrated example of an early attempt to emulate the Western Industrial Revolution. He built factories, including textile mills and arsenals, but most of this effort had come to naught by the time that he abdicated in 1848. Blame for failure has variously been placed on 'unequal treaties' imposed by the West, government monopolies, coerced labour, a lack of inanimate sources of energy, and expatriate managers and engineers. (Cleveland 1994: 68-9, 73; Hodgson 1974: III, 217-19; Landes 1998: 404-6)

Training, mobility and incentives

Free artisans were mobile, and numbers of servile craftsmen were declining, at least in the Ottoman and Indian cases. (Inalcik 1979; Lal 1994; Clarence-Smith forthcoming) The main recompense for innovating was the approval and generosity of rulers and nobles, for there was no Islamic system of registering patents. (Jaffar 1936: 205) Manuals circulated, although almost no research has been done on them, countering a tendency to seek to keep knowledge secret. However, the articulation between science and technology remained poor. (Biswas 2000: 295, 309)

Toby Huff emphasises the lack of guilds in Islamdom, but Gabriel Baer has demonstrated that they flourished in the early modern era. Neither author is much interested in the training aspect of these institutions, but Baer occasionally hints at possible negative consequences deriving from restrictive practices. (Huff 1993: 174; Baer 1970) In contrast, Muzaffar Iqbal stresses their training function up to the present day (Iqbal 2002: 122) It is thus hard to know whether guilds acted as a stimulus or a brake to innovation.

The first known Ottoman Turkish guild was that of tanners in the fifteenth century, and by the early seventeenth century an 'all-embracing system' had emerged. There were 1,001 guilds in Istanbul alone, divided into 57 groups. Non-Muslims were included, sometimes in separate organisations, and sometimes mixed with Muslims. Recognised and overseen by the state, but with a considerable degree of internal autonomy, guilds exercised monopolies in different branches of production and services. They issued licenses for the right to engage in a trade or craft. Information on Syria and Egypt reveals a similar situation in the Arab provinces. (Baer 1970: 16-26)

In addition, the Ottomans systematically invited infidel specialists of various kinds, many of whom embraced Islam. (Jones 1981: 178-9) Under the early sultans, a technical department in the palace, the Taife-i Efrenciyan, gathered technology and developed it. Jews came as early as 1394, after their expulsion from France, and great numbers flowed in from Iberia after 1492. (Ihsanoglu 2004: I, 52, 64) One sultan professed astonishment that European rulers should expel such useful people as Jews and Moriscos. (Stavrianos 1975: 17-18)

Foreign artisans, including Muslims, provided the Ottomans with 'a great deal of new scientific and technical information.' Among Christians were Saxon mining experts in the silver mines of Serbia, who seem to have obtained pumps from Europe. Genoese clock-makers had their own guild in Galata from 1630, and partly replaced imports from Europe. (Ihsanoglu 2004: I, 50-2, 55-7, and III, 28; Savage-Smith 2003: 655) Among immigrant Muslim artisans were 32 master craftsmen from Tunis, brought over in the early 1830s to develop the production of fez hats in Istanbul. (Ihsanoglu 2004: X, 59) Reliance on skilled foreigners probably increased from around 1700. (Shaw 1976-77: I, 237)

The number of servile artisans in the Ottoman empire declined after the sixteenth century, even if skilled slaves continued to be much sought after, and unskilled slaves could be compelled to learn a trade over a long period. Slave workers in the great proto-industrial centre of Bursa were regularly freed under contractual arrangements, increasing their productivity and lowering supervisory costs. (Inalcik 1979)

The Ottomans made an explicit connection between science and technology in 1838. The Board of Useful Affairs, set up by Mahmud II, declared that, 'all arts and trades are products of science.' The report lauded steam power as a major fruit of scientific enquiry, and pointed out the utility of astronomy for navigation, and of mathematics for war. (Rahman 1982: 48)

Parviz Mohebbi is sceptical as to the impact of Persian guilds on innovation, for apprenticeship and monopoly perpetuated a routine maintenance of existing knowledge. Guilds also tended to be subservient to despotic rulers, for whom many artisans worked directly in workshops, Moreover, a fair number of artisans were slaves. However, Mohebbi indicates that some forms of technology did improve in Safavid times, and notes that Shah Tahmasp I abolished the soap monopoly in 1573. Moreover, sixteenth century Iran produced a detailed explanation of three inventions, a primer for artisans, and a treatise on agriculture. (Mohebbi 1996: 10-11, 149-50, 167, 221-3)

Foreigners and religious minorities played their part in Iran. Shah Abbas I [r.1587-1629] deported large numbers of Armenians to his new

Persian capital of Isfahan, where they flourished. (Baghdiantz McCabe 1999) Europeans were scarcer in Persia than in the Ottoman domains, but a Genevan did good business mending clocks in Isfahan in 1707. (Winter 1986: 602)

Artisanal knowledge in the Mughal empire was simultaneously propagated and protected through the intertwined structures of guild and caste. Boys were apprenticed young and learned on the job. They were often the sons or relatives of artisans, within caste structures that persisted even among converts to Islam. Guilds occasionally 'maintained their own schools' to train their children, providing instruction in 'arts and crafts' that were not included in the curriculum of mainstream establishments. Innovation was encouraged, for 'those who invented new things, as well as those who made important mechanical works, were encouraged by liberal bonuses and munificent allowances.' (Jaffar 1936: 12-13, 20, 202-12) Servile artisans received training, but most artisans were free by Mughal times, and moved about as they pleased. (Jaffar 1936: 206; Lal 1994: 83-9, 96-104; Biswas 2000: 304-5; Braudel 1981-84: III, 504) The Mughal public works department inspected halls where large concentrations worked. (Jaffar 1936: 201)

There was technical interchange between civilisations. Muslims brought to India right-angle gearing, the spinning wheel, distillation, paper manufacture, lime and gypsum mortar, and the lateral rolling of iron. In India they learned about parallel worms, double rolling, bowing and printing cloth. Surprisingly, they took relatively little from China, despite proximity to Yunnan. (Biswas 2000: 307-8)

Mughal manuals have been little studied. Some gave directions for making instruments, including astrolabes. Amanullah Khan Husaini, son of a noble at the court of Jahangir [r.1605-27], wrote an agricultural manual in Persian covering crops, seed selection, preparing land, manures, protecting plants, diseases, and climates. Similar manuals in Sanskrit and regional languages circulated, providing additional information on grafting and irrigation. (Rahman 2000a: 22-3; Rahman 2000b: 245; Gopal 2000: 315)

In West Africa, a boy might gain 'training in some of the available crafts and professions' alongside his regular education. (Reichmuth 2000: 424) In Ilorin, Nigeria, they learned to be weavers, tailors and traders. Moreover, slaves and their children were schooled. (Reichmuth 1998: 104, 115)

Primary education

The teacher in the village or quarter school [*maktab*] was usually a mosque official. He taught boys, and sometimes girls, to memorise the passages of the Qur'an necessary for reciting prayers, explaining the meaning of the classical Arabic. Such schools commonly trained children to read and write the Arabic script, which could be applied to whatever language they spoke. Some basic arithmetic might also be dispensed. There were no clear mechanisms for feeding pupils into the next level of education, but neither were there significant barriers. (Rahman 1982: 35; Jaffar 1936: 11; Sraïeb 1995: 13; Kahumbi 1995: 323; Reichmuth 1998: 102-9)

Even in the furthest Islamic marches, primary schools were common. In the southern Philippines, American colonial officials noted in 1900 that 'nearly every village of any size had a "pandita" school where boys were taught passages of the Qur'an, Arabic writing, and a little arithmetic.' (Gowing 1983: 63) Graduation in West Africa 'came to be celebrated as an initiation ceremony firmly embedded in Muslim communal life.' Marriage generally followed soon after, although a period of further instruction was possible. (Reichmuth 2000: 419-20, 424) A majority of children probably went through primary school in nineteenth century Kano, Nigeria, although the proportion was lower elsewhere. Yoruba girls were especially likely to be schooled. (Reichmuth 1998: 102-

4) Educating girls at this level had almost ceased in Algeria by the 1850s, however, and 'poverty prevents many parents from affording the meagre stipend to the maâllem.' (Morell 1984: 386)

Rulers rarely interfered with primary education, so that little is known as to how it evolved. In particular, rates of literacy and numeracy remain obscure. However, Abulfazl 'Allami [1551-1602], Akbar's celebrated chief minister, reformed the curriculum of Indian primary schools. He introduced a new and faster way of learning to read and write. (Jaffar 1936: 87-8)

Madrasas

At the upper level of education, a madrasa, or college, trained future judges, teachers and mosque officials. Patterned on the famous Baghdad institution set up in 1067, madrasas spread through much of Islamdom. Typically, a madrasa would have a mosque and boarding facilities, and would be financed by one or more charitable trusts [sing. waqf *khayri*.]. Education was generally free, and famous scholars housed advanced pupils to serve them and imbibe their learning. Girls, from a scholarly family, were likely to be educated at this level at home, as most madrasas only took male pupils. Europeans called some famous madrasas 'universities,' but there was no formal distinction between secondary and tertiary education. The renown of individual teachers was the key, and they delivered teaching licences to individual pupils. (*NEB* 1993: XVIII, 16, 23; Nasr 1987: 71-2; Jaffar 1936: 11; Law 1916; Reichmuth 2000: 420)

The ulama who taught in madrasas were not inherently hostile to the rational sciences. At the very least, logic was a useful tool for the religious sciences, while mathematics, geography and astronomy served to compile the religious calendar, fix times for prayer, determine the direction of prayer towards Mecca, assess the religious tax, and divide estates on inheritance. Moreover, as astrology became increasingly divorced from astronomy, madrasas became more welcoming to this science. (Turner 1997: 205; Rahman 2000a: 20)

Upstart Ottoman Turks, facing dangerous European and Islamic adversaries, were particularly keen to embrace the rational sciences. Orhan Bey, the second sultan [r.1326-62], founded the first madrasa in Iznik [Nicaea] in 1331. Various members of the elite followed suit, providing financial security through *waqf* trusts. By the end of the sixteenth century, there were 324 madrasas scattered across the empire, with particular concentrations in Istanbul, Bursa and Edirne. Prestigious madrasas were generously endowed, and great interest was demonstrated by Mehmet the Conqueror [r.1451-81] and Süleyman the Lawgiver [or the Magnificent, r.1520-66]. Sciences were to be taught in higher level madrasas, where all teachers were to have some knowledge of arithmetic, geometry, astronomy, logic, and philosophy. (Ihsanoglu 2004: I, 46, and III, 14, 16-17) Textbooks initially came from Persia and Turkistan, notably for astronomy, logic and mathematics, and some Western materials filtered in, especially for geography. (Shaw 1976-77: I, 143-4, 147-8; Hodgson 1974: 120-2)

Ottoman studies of the rational sciences swung to and fro. Scientific studies 'rather rapidly withered' when reactionary ulama and Sufis got the upper hand, as in parts of the seventeenth century. Madrasas then exhibited 'a certain intolerance of experiment.' Indeed, a scholar was executed in 1601, for taking a position of natural law determinism. This was an isolated case, however, and others were known to hold similar beliefs. (Hodgson 1974: III, 121-3) Katip Chelebi [1609-57] complained of the 'exclusion of rational sciences and mathematics from the curriculum.' However, Count Marsigli reported that madrasas were teaching logic, 'alchemy,' botanics, geometry, astronomy, ethics, geography, and medicine in the late seventeenth century, albeit with traditional texts. (Ihsanoglu 2004: I, 46-8)

In the reformist Lale Devri [tulip age] of Ahmet III [r.1703-30], scholars were encouraged 'to inquire broadly,' and some took an interest in 'Occidental learning.' Reform peaked under Grand Vizier Nevshehirli Damat Ibrahim Pasha, from 1718 to 1730. (Hodgson 1974: III, 121-2, 139; Ihsanoglu 2004: III, 28) Translations from Western works flourished, and two missions were sent abroad, to Paris and Vienna. (Shaw 1976-77: I, 232-5) European botanical information, including discoveries made in the New World, seeped in. (Savage-Smith 2003: 661) Despite the violent overthrow of Ahmet and his vizier in 1730, Father Toderini, in Istanbul from 1781-86, commented on the considerable learning exhibited in madrasas. He also noted that the *waqf* system provided colleges with more 'scientific autonomy' than their counterparts in Europe. (Ihsanoglu 2004: I, 49)

Cairo contained an 'infinity of colleges of fine construction and marvellous grandeur' in the sixteenth century, of which al-Azhar was the most famous. The position of Shaykh al-Azhar, created in the late seventeenth century, indicated growing administrative autonomy. The buildings were considerably enlarged through pious donations from 1715. Students came from far beyond the frontiers of Egypt, and were grouped by region of origin, with separate endowments. In 1798, the teaching staff numbered between 40 and 60, of whom half a dozen were particularly sought after. (Dodge 1961: 80, 82-3, 86-93, 100)

Philosophy, mathematics and natural science were on the curriculum, but many teachers at al-Azhar could not afford to buy instruments. Ahmet Pasha therefore donated a sundial in 1748, 'to arouse an interest in astronomy.' Moreover, scientific subjects were optional extras, often studied privately. Ahmad b. al-Mun'im al-Damanhurri [d.1778], Shaykh al-Azhar from 1768 to 1778, took private lessons to master arithmetic, computation, algebra, trapeziums, geometry, astronomy, anatomy and medicine, as well as the animal, vegetable and mineral realms, and techniques for finding water. Shaykh Hasan al-Jabarti [d.1774], of Ethiopian origins, studied the rational sciences with an Indian scholar, including some medicine and engineering. His son, 'Abd al-Rahman al-Jabarti, became a famous historian, but also had an interest in astronomy. (Dodge 1961: 73, 92-5; Winter 1992: 114-15) Eighteenth century Egyptians keen on the rational sciences generally travelled to Istanbul to complete their studies. (Gran 1979: 169)

The French invasion of Egypt in 1798 provoked an intellectual storm. The French were keen to impress Arabs with their technical as well as their military achievements. In the short period before their capitulation in 1801, 'scholars like 'Abd al-Rahman al-Jabarti learned a great deal about European science.' Nevertheless, logic, arithmetic, algebra, equations and astronomy, listed in 1864 as part of al-Azhar's curriculum, remained supplementary courses. (Dodge 1961: 110, 114) Numbers of scholars studying science were small. (Lane 1986: 227-30) Mathematics and science at al-Azhar were optional till 1908. (Rahman 1982: 36-7)

Scholars from far and wide came to the madrasas of Iran, especially to those of Isfahan [Esfahan], the new Safavid capital from 1598. Rulers took a keen interest in colleges, and subsidised them. (Rahman 1982: 35) Madrasas spread across the empire, with Shiraz and Meshed [Mashhad containing major clusters. Philosophy, more or less banished from the Sunni world, flourished in Iran, together with natural sciences, mathematics, astronomy and medicine. Mathematics covered geometry, trigonometry, algebra, and optics, while chemistry was among the natural sciences. (Nasr 1987: 57-8, 71-3, 174, 218; Winter 1986: 585) Despite their Shi'i orientation, Iranian works were read widely through the Sunni world, helping to keep the study of speculative philosophy alive.

(Hodgson 1974: III, 33) However, some 'religiously aberrant' teachers were executed. (Hodgson 1974: III, 41; Winter 1986: 608)

Notable among Iranian scholars of this age was Mir Damad [d.1631], interested in natural science and inspired by Aristotle and Ibn Sina. He came to be known as the 'third teacher,' after Aristotle and al-Farabi. His principal disciple was Mulla Sadra [d.1640] of Shiraz. (Hodgson 1974: III, 42-54; Iqbal 2002: 94-8) Meshed, on the borders of Turkistan, was another centre for the rational sciences (Nasr 1987: 57-8; Iqbal 2002: 57) For all this, the religious sciences predominated in Iran, and alchemy and astrology retained a considerable following. The death of numerous scholars in the 1722 siege of Isfahan, followed by the emigration of many survivors to India as the Safavid dynasty collapsed, worsened the situation. (Winter 1986: 608-9) Prominent for Shi'i religious scholarship were Najaf and Karbala in Iraq, containing major shrines and often subject to Ottoman rule. (Litvak 1998)

The Mughal emperors were great patrons of learning in India, with Humayun [r.1530-36] already stressing geography and astronomy, and attracting many Persian scholars. (Jaffar 1936: 78; Winter 1986: 582) The central Gangetic plain contained the most prestigious schools, especially in the old capital of Delhi and around the new capitals in the Agra area. However, madrasas were scattered throughout the empire, and beyond, founded or restored by members of the elite, including some women. (Jaffar 1936: 131-44) Despite resistance by some ulama and brahmins, Mughal rulers generally encouraged the reciprocal borrowing of scientific ideas, imparting a particular dynamism to this empire. (Rahman 2000a: 23-9; Abdi 2000: 57-8, 65)

Akbar [r.1556-1605], the greatest Mughal ruler, manifested a strong interest in philosophy, natural science, and even in the scientific method. (Hodgson 1974: III: 7, 77) He 'richly endowed' madrasas throughout his realm, and famously allowed non-Muslims to study there. He attracted Persian professors from Shiraz, and founded the Ibadat

Khana in 1578, in his capital of Fatehpur Sikri, as a place for intellectuals to debate. (Jaffar 1936: 82-3, 86, 89; Law 1916: 160-8) He had major works translated from Sanskrit, including the *Lilivati*, Bhaskaracharya II's great twelfth century work of mathematics, which anticipated on modern calculus. Among the Iranians who came to Akbar's court was Fathullah Shirazi, a brilliant polymath, gifted in mechanical engineering, mathematics, astronomy, medicine, philosophy and the arts. (Rahman 2000a: 18, 23)

In on of his decrees, Akbar proclaimed that 'every boy ought to read books on morals, arithmetic, the notation peculiar to arithmetic, agriculture, mensuration, astronomy, physiognomy, logic, higher mathematics, science and history, all of which may gradually be acquired.' (Abdi 2000: 57) He wished to emphasise mathematics, medicine, agriculture and geography in the curricula of madrasas, although the religious sciences remained predominant. (Kumar 2003: 678-9; Metcalf 1982: 18-19)

Abulfazl 'Allami [1551-1602], Akbar's chief minister, reformed the curriculum of madrasas. He recommended that the sciences be taught in this order: ethics, arithmetic, accountancy, agriculture, geometry, 'longimetry,' astronomy, geometry, economics, administration, physics, logic, natural philosophy, abstract mathematics, divinity, and history. He insisted that 'none should be allowed to neglect those things which the present time requires.' (Jaffar 1936: 88-9; Law 1916: 161-2) Mathematics became compulsory in Indian madrasas under Akbar, a rare situation in the Islamic world of his time, and textbooks in Arabic and Persian proliferated. However, the ulama generally succeeded in excluding translations of Hindu works. (Abdi 2000: 57-8, 65)

Akbar's successors kept up the momentum, especially by patronising madrasas and individual scholars. Jahangir [r.1605-27] was a noted bibliophile and restorer of schools, and he patronised Mirza Ghiyas

Beg, 'the best arithmetician' of the time. (Jaffar 1936: 92-5) Shah Jahan [r.1628-58] continued the work of endowing colleges and encouraging the learned. (Law 1916: 183-4) Mahmud Jaunpuri [1585-1651] wrote about matter, form, and motion in a fresh and original manner. (Rahman 2000a: 23)

Eric Jones says disparagingly of Awrangzib [r.1658-1707] that he 'went out of his way to suppress original thought as determinedly as any Ottoman sultan.' (Jones 1081: 196) Indeed, this emperor has often been portrayed as a narrow bigot, whose decision to cease tolerating Hindus caused the empire to collapse and entrenched communalism in the sub-continent. Hindus ceased studying in madrasas, and some temples were destroyed. (Law 1916: 187)

Awrangzib did not oppose education as such, however, for he 'founded numberless colleges and schools.' (Law 1916: 187-9) He reproached his former tutor for forcing him to memorise words and terms that he did not understand, and for not teaching him about European geography. Awrangzib insisted on the need to know about the products, military capacities, policies, methods of government, languages and customs of foreign lands. According to a French resident, the emperor desired an 'adequate conception of the universe, and of the order and regular motion of its parts.' (Jaffar 1936: 176-81) His successor, Bahadur Shah [r.1707-12] established yet more madrasas. (Law 1916: 194-5)

Among Awrangzib's well endowed foundations was the celebrated Farangi Mahall madrasa, established in Lucknow in an old Dutch building. (Law 1916: 187-9) In this great college, Mulla Nizam al-Din [d.1747] developed a nine to ten year programme of studies, the Nizami curriculum. Of the 83 works to be studied, 4 were on medicine, 4 on philosophy, 2 on astronomy and 1 on geometry. This study plan was widely copied by a network of madrasas linked to Farangi Mahall, although the science and philosophy content tended to be reduced. (Rahman 1982: 40) Farangi Mahall also became famous for taking both

Sunni and Shi'i students, as the Nawab of Awadh [Oudh] was of the Shi'i persuasion. (Metcalf 1982: 30-3)

The Mughal empire fragmented under Hindu and Christian pressure from 1707, but the impact on Islamicate learning remains uncertain. Al-Tahanavi, author of a famous dictionary of technical terms, alleged in the eighteenth century that he could not find a single place in the sub-continent to study science. (Hoodbhoy 1991: 37) The immensely influential Deoband madrasa, founded in 1867, turned its face resolutely against the rational sciences, apart from medicine and a little logic and philosophy. (Metcalf 1982: 99-104) However, the rational sciences were compulsory in the madrasas of eighteenth century Awadh and Bihar. To the west, they remained optional, but were often privately studied. Moreover, an influx of Persian scholars, fleeing the chaos of the collapsing Safavid realm, provided new teachers. (Kumar 2003: 670, 679-80) Ghulam Husain Jaunpuri's *Encyclopaedia of mathematical sciences*, published in 1835, was a thorough and competent recapitulation of classical knowledge. (Rizvi 2000: 203)

The madrasas of Mecca and Medina became increasingly significant centres of learning from the fifteenth century, at a time when many colleges in the Arab world came to be in difficulty. Upstart Ottoman sultans, seeking to underpin their Islamic legitimacy, provided generous endowments to Hijazi colleges. Students came from all over Islamdom, combining the pilgrimage with a period of study, to the particular benefit of Southeast Asian and Sub-Saharan African Muslims. (Azra 1992: 151-5; Reichmuth 2000: 427) The influence of Hijazi madrasas probably peaked in the eighteenth century. (Iqbal 2002: 207-8)

There were other Middle Eastern clusters of colleges. Damascus was an ancient centre of learning, allegedly containing 159 madrasas in the fifteenth century. (Azra 1992: 151; Huff 1993: 73-4) In Yemen, Zaydi Muslims ensconced in the highlands provided a refuge for Mu'tazili rationalism. (Crone and Cook 1977: 134) Bayt al-Faqi and Zabid were

Sunni centres of Yemeni learning, the latter with over twenty madrasas in the fifteenth century. (Azra 1992: 151) Tarim, in Hadhramaut, had an ancient reputation. (Stark 1946: 188)

In the Turkic world, Bukhara was an educational focal point, drawing students from half of Asia. (Hodgson 1974: III, 156, 320) In the early nineteenth century, the city had 180 madrasas, with some 15,000 students. Logic, natural history, arithmetic, geometry, geography, and medicine figured on the curriculum of some establishments, if in a clearly subordinate role. Textbooks were ancient, and there was no apparent awareness of Western ideas. (Khan 1998: 61, 64, 70-3, 113)

The Volga Tatars were much more open to the West, perhaps because they had been conquered by Russia in the sixteenth century. As Russian repression increasingly gave way to tolerance in the eighteenth century, the Tatars built up trade and manufacturing, and turned Kazan into a new centre of learning. (Hodgson 1974: III, 221-2, 318-9) Orenburg became another centre. (Rorlich 1986: 59-61)

From the early seventeenth century, and especially in eastern China, some Islamic scholars accepted Confucianism and Daoism [Taoism] as philosophies, rather than religions. This enabled savants such as Wang Daiyu and Ma Zhu to drink deeply at the well of Chinese knowledge. A Confucianised gentry emerged in the eighteenth century, many of whom had come through the Chinese examination system. However, it remains uncertain how much science and technology was imbibed by Chinese Muslims who followed this line. (Lipman 1997: 75-80; Wang 1996: 169-70, 229) There were also 'little Meccas' to propagate Islamic learning, such as Hezhou in the northwestern province of Gansu, and Kunming, Dali and Shadian in the southwestern province of Yunnan. Madrasa education developed strongly in such centres from at least the sixteenth century, with some teachers drawn from Turkistan and India. (Wang 1996: 151-4, 158-61; Dillon 1999: 51, 55;)

In North Africa, the Zaytuna madrasa of Tunis stood out. Ahmad Bey [r.1837-55] reformed the institution in 1842, paying the thirty professors, equally divided between the Hanafi school of law, that of the court, and the Maliki school, followed by the majority of the population. However, it was not till 1875 that the rational sciences were made compulsory. (Sraïeb 1995: 13-15, 34) The main concentration of madrasas in Algeria was in Constantine [Blad el-Hawa], notably al-Salahiyya with a renowned library. Some logic, astronomy, arithmetic and medicine were taught. (Morell 1984: 386-7; Clancy-Smith 1994: 63) The great Qarawiyyin madrasa of Fez was 'the pinnacle of learning in north-west Africa,' and Marrakech also contained madrasas. Algebra and astronomy were on the curriculum, albeit in a minor position. (Pennell 2000: 17)

South of the Sahara, Timbuktu was to the fore, with astronomy, meteorology, mathematics, medicine and logic on the fringes of the regular curriculum. (Saad 1979: 98-9, 107-9, 137) The *'ilm* schools of Ilorin, on the Yoruba southern fringes of West African Islam, taught arithmetic and astronomy within a heavily magico-mystical framework. (Reichmuth 1998: 125, 137-40) Bornu's capital Ngazargamu [Gazagarmo], southwest of Lake Chad, was almost as reputed as Timbuktu, attracting students from far and wide in the eighteenth century. On the other side of the continent, the colleges of Harar, in the eastern Ethiopian highlands, were reputed. (Reichmuth 2000: 426-7, 429) South of the Horn, the Comoro Islands were the main centre of Islamic learning. (Shepherd 1980: 87) Habib Saleh, a Hadhrami Sayyid from these islands, founded the first major madrasa on the mainland, at Lamu in the 1880s. (Zein 1974)

The madrasa system is often said not to have reached Southeast Asia, but this reflects semantic confusion. A *pesantren*, meaning a place where pious Muslims learn, was classified as a Sufi establishment, because the 'mystical sciences' were taught there. However, the relation between a *pesantren* and a *pengajian*, or elementary school, was the same as that between a madrasa and a *maktab*. From the sixteenth century at least, the best *pesantren* were 'centres of Islamic education.' (Dhofier 1999: 2-15) The hubs of scholarship were Aceh and Palembang in Sumatra, Banten and Surakarta in Java, and Patani in northern Malaya under Thai rule. Increasing numbers of students also went overseas to obtain madrasa training in Arabia from the sixteenth century. (Azra 1992: 2-6, 160, 346-566; Riddell 2001: 101-92)

Sufi lodges

The Mongol destruction of the caliphate in 1258 allowed Sufi mystics to move to the centre of the Islamic stage, with consequences that continue to be hotly debated. Sufi brotherhoods played an educational role, but stand accused of 'fostering a spiritualizing and anti-rationalist approach to Islam,' even possibly of contributing to a 'lack of mechanical inventiveness.' (Ruthven 2000: 285) Intellectual stagnation, or even regression, allegedly stemmed from an emphasis on ceremonies, amulets, incantations, blind obedience to a shaykh, self-denial, and other-worldliness. (Qadir 1990: 131-4) Sufi 'emotional abandon and mystical rapture' allegedly stood in the way of technical change. (Gopal 2000: 316)

However, Sufism has been appraised more positively, for example as a refuge for 'speculative philosophy.' (Huff 1993: 115) The tenth century *Epistle of the brothers of purity*, sometimes taken as a founding text of Sufism, was an encyclopaedic work that covered all the sciences. As in Europe, many mystics were fascinated by God's handiwork in the natural world. Moreover, 'natural mysticism' was often connected with an urge to 'serve their fellow human beings.' (Rahman 2000d: 428-32) As a more worldly and reformist 'Neo-Sufism' emerged from the seventeenth century, it is possible that attitudes towards scientific and technical endeavour became more positive. (O'Fahey and Radtke 1993)

Sufi lodges could be found in a town, but they were typically rural institutions. A lodge was known in different parts of the Islamic world as a *ribat*, *zawiya*, *khalwa*, *tekke*, *khanqa*, *pesantren*, or *pondok*. Many were endowed as charitable trusts, constructed around the tomb of a 'friend of God,' and self-supporting through fields and flocks. Disciples were not expected to take vows of chastity, and usually stayed for a limited period, taking part in devotional, mystical, educational, and practical tasks. Lodges usually provided some teaching, at least at primary level. (Ruthven 2000: 219-81; Jaffar 1936: 18-19, 32) Unlike a madrasa, a lodge would house women, and some might take only women. (Azra 1992: 149) Sufi education was of especial significance in Southeast Asia and Sub-Saharan Africa. (Rahman 1982: 45-6; Azra 1992; Dhofier 1999; Riddell 2001; Reichmuth 2000: 423-4)

The distinction between lodges and colleges grew increasingly blurred in early modern times, as Sufi establishments 'became in an ever more outward manner institutions of learning.' They now taught 'branches of the arts and sciences' that had earlier been confined to madrasas. (Nasr 1987: 90-1) The eastern Algerian Rahmani *zawiya* of Tulqa, near Biskra, had a library of some 3,000 manuscripts in the 1820s. Lodges of this order taught hundreds of pupils. (Clancy-Smith 1994: 53-4, 63, 223) Another form of rapprochement occurred because teachers in madrasas belonged to Sufi orders, as in Tunisia. (Sraïeb 1995: 14) This appears to have been the case elsewhere in North Africa, as well as in the Hijaz, Egypt, and the Sudan. (Azra 1992: 148-50; Reichmuth 2000: 428; Morell 1984: 387)

Some Ottoman Sufis promoted philosophy and science. Jalal al-Din Dawwani [1427-1502] wrote some 70 books, including a famous text on ethics. He looked favourably upon philosophy, even if in a subordinate position to mysticism. (Qadir 1990: 140-1) Ibrahim Hakki of Erzurum published a famous work in 1757, the *Marifetname*, often copied and later printed and reprinted. In this curious book, superstitious legends and scientific explanations lay cheek by jowl. There were fairly accurate world maps, together with scientific explanations of the spherical shape of the earth, the heliocentric planetary system, the magnetic compass, and earthquakes. Hakki explained at one point that the faithful only needed to accept God's creation, ascertaining the details through their own labour. (Ihsanoglu 2004: II, 22-30; Savage-Smith 2003: 654)

Early modern Iran was initially suffused with mystical thought, for Shah Isma'il rose to power as the head of the Safavid Sufi order. 'Abd al-Rahman Jami [d.1492], poet, scholar, and mystic, prayed, 'O God ... show us the nature of things as they really are.' (Iqbal 2002: 79-80) One fervent Sufi scientist was Baha' al-Din al-Amili [1546-1621], a Lebanese who came to study in Isfahan at the age of 13. He taught and died in Meshed, writing learned works on mathematics and astronomy, which did more than summarise old masters. (Nasr 1987: 57-8) His students continued his work. (Iqbal 2002: 57)

The approximation of college and lodge could also be seen in India. Mahmud Shah Musafir, active in Aurangabad in the early seventeenth century, not only founded a madrasa, but also built an ingenious water mill. (Rahman 2000d: 432) A Sufi directed the celebrated Bidar madrasa, of the Deccan. (Jaffar 1936: 121-5) The Farangi Mahall network of madrasas, discussed above, was deeply imbued with Sufism. (Metcalf 1982: 30-3) Mysticism also acted as a bridge between Muslim and Hindu scholars in the sub-continent. (Rahman 2000a: 27-8)

That said, some Indian Sufis opposed the rational sciences. Sayyid Ahmad Sirhindi [1564-1624], a particularly influential shaykh, issued a fatwa against mathematics and the 'secular sciences,' proclaiming that education should be purely religious. (Hoodbhoy 1991: 65) Shah 'Abdu'l-'Aziz Waliyullah [1702-62], an equally famous Chishti Sufi of Delhi, also rejected the rational sciences, even though he accepted reason and interpretation. (Metcalf 1982: 37-43) He did include some mathematics, astronomy and medicine in his 'private curriculum.' (Hoodbhoy 1991: 152)

Observatories and other public institutions

Many observatories were more than centres to study the stars, for they functioned as scientific and mathematical research centres. (Sayili 1960) An influential model was Maragha, in southern Azerbaijan, with its heyday around 1300. This observatory probably influenced Copernicus and Kepler. (Huff 1993: 179-81; Nasr 1987: 80-1; Ruthven 2000: 203) Another exemplar was the observatory of Samarqand in Turkistan, dubbed 'the astronomical and mathematical "capital of the world"' in the 1420s and 1430s. (Iqbal 2002: 132-3; Nasr 1987: 81, 175)

An Ottoman observatory, completed in 1575, was equipped with the 'best instruments of the time.' Enjoying the favours of Murad III [r.1574-95], Taqi al-Din, chief astronomer, disposed of fifteen assistants and a fine library. He constructed a mechanical clock, with a dial indicating seconds, to make some remarkably accurate observations. However, 'false religious assertions by envious statesmen' caused the observatory to be pulled down in 1580. (Ihsanoglu 2004: III, 19-20; Sayili 1960: 289-305; Winter 1986: 589-91) One pretext for the destruction was that 'astronomical observations were actually the cause of the plague.' (Jones 1981: 182) The Shaykh al-Islam, or grand mufti of the empire at the time, argued that it was wrong to pry into the secrets of nature, and that it brought misfortune to those who did so. (Sayili 1960: 292-3)

Although this observatory was not replaced, the Ottoman elite gradually absorbed new views of the cosmos. Indeed, it was another Shaykh al-Islam, Feyzullah Efendi, who wanted to convert the Galata Tower into an observatory on European lines in 1703. The plan was aborted by his untimely demise. (Sayili 1960: 305) A Hungarian translator and convert, Ibrahim Müteferrika, had been captured and enslaved in

1692, and had subsequently converted from Protestantism to Islam. (Shaw 1976-77: I, 236-7) In the 1730s, Müteferrika argued in favour of heliocentricity, on the grounds that religion only demanded recognition that God had made the universe, whereas human beings were charged with the task of figuring out the details of Allah's creation through reason. That said, it was only in the mid-nineteenth century that the Copernican universe officially became compatible with Islam. (Ihsanoglu 2004: II, 2, 16)

The Ottomans kept abreast of developments in the West, through immigrants, envoys to Europe, and translations. In the eighteenth century, some 331 works on astronomy were published around the empire, including a few printed books. The chief astronomer, occupying a position probably created in the late fifteenth century, produced calendars, timetables for praying and fasting, forecasts of natural phenomena, horoscopes for the elite, and lists of auspicious days. Copernican ideas were divulged in Istanbul from at least 1660, and astronomers gradually divided into geocentric and heliocentric camps, the latter officially embraced by the public educational system in the 1830s. (Ihsanoglu 2004: I, 68-71, II, and III, 18-19, 25-7, 43)

Both Shah Isma'il, founder of the Safavid dynasty [r.1501-24], and his successor Tahmasp I, intended to build observatories, but neither carried out his plans. However, the astrolabe was perfected in this period, and large numbers of these instruments were locally made. A Hindu astronomical treatise, composed around 1150, was translated into Persian. The French astronomer R. Du Mans was 'held in high regard' in the late seventeenth century, when astronomy was considered to be the most developed exact science in Iran. (Winter 1986: 582, 586-8, 593, 602) However Du Mans' gift of a telescope to the Shah provoked little interest. (Mohebbi 1996: 219)

The Mughals saw themselves as the heirs of Samarqand's astronomical glory, and a steady stream of works in the classic Islamic tradition was produced under the dynasty. (Winter 1986: 593; Rizvi 2000: 202-3, 213-14) In Akbar's reign, attempts were made to incorporate the Siddhantic astronomical system into the classical Arabic-Greek corpus, and the interchange persisted into the eighteenth century. (Kumar 2003: 674-5; Rahman 2000a: 22-3) Shah Jahan [r.1628-58] planned an observatory, but the funds were allegedly diverted to construct the Taj Mahal as a monument to his deceased wife. Islamic astronomers long remained uninterested by the telescope, despite its systematic and productive use by French Jesuits in Pondicherry from 1689. (Kochhar 2000: 191, 193-4)

Jai Singh [1688-1743], a Hindu vassal of Muhammad Shah [r.1719-48], straddled the old and the new. He built or restored five observatories between about 1721 and 1734, including one in Delhi and one in his own capital of Jaipur. His astronomers wrote mainly in Persian, using observations with improved instruments to revise Islamic astronomical tables. One of his associates, Khairullah Khan Muhandis, deduced the elliptical orbits of planets. Jai Singh attracted European Jesuits, sent a mission to Portugal, and had some Western works translated into Persian. However, the writings of Copernicus, Kepler and Galileo seem to have been considered too unorthodox for translation. Moreover, Jai Singh made no known observational use of a European telescope that he obtained. Aware of heliocentric notions, he apparently clung to geocentricity. After his death, the observatories decayed, and the one in Delhi was vandalised by a Maratha army in 1764. (Kumar 2003: 675-6, 686; Kochhar 2000: 191-3; Rizvi 2000: 209-10, 214, 216-18)

The Muslim marches of Russia witnessed openness to new ideas. Kudsi of Baku [1794-1826], an Azeri scholar trained in the classical Islamic manner, settled in Kuba, Azerbaijan, after wandering widely. Working with Russian sources, he presented a Copernican vision of the universe, arguing that this conformed more with the Quran than Ptolemy's ideas. In 1846, shortly before his death, he presented a copy of his work, written in Persian, to the Ottoman sultan. (Ihsanoglu 2004: II, 36-8)

Astronomy provided a refuge for the rational sciences elsewhere in the Islamic world, for example in Morocco. (Nasr 1987: 174; Pennell 2000: 17) The Samarqand observatory soon fell into ruins after 1449, but neighbouring Bukhara continued to have a famous one. (Winter 1986: 588; Hodgson 1974: III, 145) China's Muslim Bureau of Astronomy, formally instituted in 1368, still functioned in the sixteenth century. (Huff 1993: 241) Pattingalloang, vizier of Makassar in South Sulawesi, obtained a telescope from an English merchant in 1652. (Pyenson 1998: 41) There were telescopes in early nineteenth century Egypt, albeit few in number. (Lane 1986: 228)

More humble public institutions provided practical education. Most Ottoman mosques had an official timekeeper (*muvakkit*), 'responsible for keeping track of the correct prayer hours.' Under the supervision of the chief astronomer, and funded through a *waqf*, the timekeeper had a collection of instruments to carry out his task. His public buildings 'might also function as centers where mathematics and astronomy were taught.' (Ihsanoglu 2004: III, 17-19) After primary school in eighteenth century Egypt, boys studied higher forms of arithmetic with the public weigher or the official land measurer, prior to entering a madrasa. (Dodge 1961: 97)

Hospitals and medicine

The traditional format for medical training was apprenticeship, with practical experience gained in the hospitals of major cities. An Ottoman Chief Physician was appointed in the fifteenth century. He watched over the health of the denizens of the palace, and oversaw the empire's medical practitioners, including pharmacists. (Ihsanoglu 2004: I, 64, and III, 17-18)

The great Ottoman sultan Süleyman the Lawgiver [r.1520-66] was unusual in founding a specifically medical madrasa, drawing to some extent on Western knowledge. However, this long remained an exception to the usual learning through doing in hospitals. (Ihsanoglu 2004: I, 64, and III, 17, 30-1; Hodgson 1974: III, 121) Jewish physicians were an important conduit for European medicine, with 41 of them recognised in Istanbul in the early seventeenth century. Local Greek Christians, trained in Italian universities, then became increasingly significant. (Ihsanoglu 2004: I, 64-6)

European medical notions filtered into the Ottoman empire with a time-lag. The sixteenth century chemical treatments of Paracelsus gained a following a century later, notably in the work of Salih b. Nasrullah [d.1669]. (Ihsanoglu 2004: I, 66, and III, 25; Savage-Smith 2003: 661-2; Dölen 1998: 160). A 1548 Italian treatise on botany and materia medica was translated in 1770. Anatomical sketches were copied, but the circulation of the blood was not mentioned till the late eighteenth century. (Savage-Smith 2003: 661) A 1632 treatise on anatomy by Shemseddin Itaki included material from sixteenth century European authors. (Dölen 1998: 160)

Western remedies long continued to be explained in terms of Ibn Sina [Avicenna] or Ancient Greek authors. (Ihsanoglu 2004: I, 47; Savage-Smith 2003: 661-2) A complete Turkish translation of Ibn Sina's *Canon of medicine* appeared in the eighteenth century. (Savage-Smith 2003: 663) The same century witnessed a juxtaposition of 'practical medical knowledge taken from Europe alongside old concepts, such as the concept of the four bodily humors.' In 1806, a new school of medicine was set up in the imperial maritime arsenal, with European textbooks and courses in French and Italian. It closed two years later, but was revived in

1827 for the needs of the army. (Ihsanoglu 2004: I, 67, and III, 31-2, 41) In 1820, Shanizade Ataullah Mehmed Efendi described the body as a machine, drawing on the 1762-72 *Encyclopédie* of Diderot and d'Alembert, albeit without acknowledgement. (Savage-Smith 2003: 667-8; Ihsanoglu 2004: I 67)

The Ottomans took measures to ensure public health, contrary to Eric Jones' alleged fatalism in response to repeated visitations of the plague from the 1720s. (Jones 1981: 181-2) In reality, a sultan ordered the translation of two Dutch medical treatises to deal with the problem. The task, completed in 1768, made available Western notions about more than this particular disease. (Savage-Smith 2003: 662) Ottoman techniques of inoculation for smallpox, developed through trial and error by Greeks, were described by a Greek doctor in 1715. They were copied in Britain in the 1720s, where they were employed till the 1790s. (Jones 1981: 182)

A European description of Aleppo, Syria, from 1742 to 1753 indicated that doctors were mainly Christians, together with a few Jews. Ibn Sina and Greek authors were their chief sources, little chemical medicine was employed, and knowledge of the structure of the human body was hazy. Inoculation against smallpox was only practised by some Christians. (Savage-Smith 2003: 663-4)

Hasan al-'Attar, an Egyptian enthused by French scientists among the occupation forces in 1798-1801, brought out a large medical text in Syria in 1814. He returned to Egypt and brought out another work in 1830. He was the first Arab author to discuss anatomy in European terms, but he insisted that closer attention to the works of al-Razi, rather than to those of Ibn Sina, yielded a positive view of dissection. (Gran 1979: 169-71) Al-'Attar then became Shaykh al-Azhar, from 1831 till his death in 1835. (Sraïeb 1995: 24) However, many of Cairo's medical practitioners in the 1830s were still 'miserably ignorant' barbers. (Lane 1986: 227-8)

The Safavids encouraged a renaissance in Iranian medical studies, and the Persian diaspora in India absorbed Hindu ideas. Muhammad Husaini Nurbakhshi Baha' al-Din [d.1507] probably identified syphilis, whooping cough and hay fever, the latter not recognised in Europe till 1819. 'Imad al-Din b. Ma'sud b. Mamhud, of Shiraz, published an important work on syphilis in 1569. The sixteenth century was also a golden age of pharmacology. (Winter 1986: 582, 586, 603-9; Nasr 1987: 218)

European influences grew in Iran from the late seventeenth century. Anonymous manuscripts contained ink sketches of skeletal and muscular figures, and some organs, drawn from a Latin treatise of 1543. The eighteenth century witnessed both the full translation of Ibn Sina's *Canon* into Persian and a growing interest in Western doctors. (Savage-Smith 2003: 661-3) Catholic missionaries spread some Western knowledge, but the chemical remedies of Paracelsus did not catch on. (Winter 1986: 607-9)

Persian immigrants stimulated the study of medicine in India from the sixteenth century. (Nasr 1987: 218-19; Winter 1986: 603) This was at a time when Hindu studies of cures based on minerals were progressing markedly. (Deshpande 2000: 160-4) Indeed, India witnessed an interchange between Muslim, Hindu and Christian medicine, with the translation of numerous Sanskrit texts into Persian, and influences from sea-borne Europeans from 1500. Large hospitals were also built in Mughal India, for example in Hyderabad in 1595 and in Delhi in 1719-48. (Kumar 2003: 681-2)

In the seventeenth century, interest in Western medicine grew stronger, notably at court. (Hodgson 1974: III, 144) A Muslim aristocrat employed François Bernier in the middle of the century, who did translations, and dissected a sheep to illustrate the circulation of the blood. A Hindu text from 1787 mentioned cowpox inoculation for smallpox.. (Kumar 2003: 671, 682)

Secular schools

The emergence of specifically secular schools was slow, even though Muslim rulers were entitled to act in the public interest [*maslaha*]. Colleges within a palace complex often dispensed the rational sciences, and were among the few that taught girls, but for centuries they were not clearly distinguished from madrasas (*NEB* 1993: XVIII, 16; Turner 1997: 203; Jaffar 1936: 190; Ihsanoglu 2004: X, 46)

The Ottomans were pioneers in setting up specialised military schools, following foreign models to some degree, but retaining many links with madrasas. In response to ever more pressing threats from Austria and Russia, a school for 'bombardiers' was founded in 1734-35, to improve the quality of Ottoman artillery. Headed by a French count and general, a convert to Islam, the school employed both Ottoman and European texts and teachers. However, it did not long outlive the death of its first head in 1747. (Ihsanoglu 2004: III, 28-9)

Efforts were revived in 1773, when a French officer advised on the establishment of a 'naval school of engineering' in Istanbul. (Savage-Smith 2003: 654) The Hendesehane [House of Geometry] opened its doors in the Imperial Maritime Arsenal in 1775, teaching a restricted number of students the skills required for artillery, navigation and fortification. Also known as the École de Théorie et de Mathémathiques, and from 1781 as the Mühendishane [House of Engineers], the school was first headed by a French officer and baron of Hungarian origin. However, he was replaced by a Turk in 1776, and Ottomans took over all teaching positions in 1788, when the French became enemy aliens. (Ihsanoglu 2004: III, 29)

Selim III [r.1789-1807] gave a new impetus to Ottoman schools. In 1793, the Mühendishane split into two schools, one for artillerymen and sappers, and the other for naval personnel. They mixed European and

Ottoman methods and teachers, and used both French and Turkish as languages of instruction. After a reactionary interval, Murad II [r.1808-39] obtained Prussian and French instructors for the army, and British ones for the navy. He opened a medical school in 1827, a military school modelled on Saint Cyr in 1834, and two institutions to train officials in 1838. (Ihsanoglu 2004: II, 33-6, III, 30-4; Cleveland 1994: 61-3, 76-8) Teachers in these schools published textbooks based on European works, for example Dervish Pasha [1817-79], who published the first book of modern chemistry in 1848. (Dölen 1998: 168-9)

The poor results of many early students in special schools were blamed on inadequate prior education, leading the government to overhaul the entire Ottoman educational system. Secular secondary schools were set up after 1839. (Rahman 1982: 48) The first Islamic university on European lines, the Darülfünum, was planned in 1846, although it did not open till 1863, and only functioned satisfactorily from 1900. (Ihsanoglu 2004: III, 36-9)

The Ottoman model was copied in Egypt and North Africa. The Egyptian *mamluk* officer Ali Bey al-Kabir [r.1760-73] made Egypt virtually independent from Istanbul, hiring Westerners as military advisors. (Cleveland 1994: 64) Muhammad 'Ali [r.1805-48], having secured his rule in 1811, founded a school for officers in Aswan. From the early 1820s, he set up others for doctors, veterinary surgeons, engineers, chemists and translators. (Cleveland 1994: 65-7; Hodgson 1974: III, 218) In Tunisia, Ahmad Bey [r.1837-55] created the Bardo polytechnic school in 1838, run by a European till 1862, when a Tunisian took over. The school mixed traditional religious sciences with mathematics, topography, modern languages, and military history. In Morocco, Mawlay Muhammad set up the al-Muhandisin madrasa in 1844 as a military school, teaching some mathematics. (Sraïeb 1995: 14-15, 21)

The East India Company initially stepped into the shoes of the declining Mughals. In 1780-81, Warren Hastings founded the 'Aliya madrasa in Calcutta, teaching astronomy, mathematics and philosophy as traditional Islamic sciences, under the direction of a graduate of Farangi Mahall. (Rahman 1982: 73; Metcalf 1982: 31) The Delhi College, which flourished from 1825 to 1857, used Urdu as the medium of instruction and was endowed with a *waqf*, but the majority of students were non-Muslims. One branch taught modern Western science. This establishment was popular with progressive Muslims, training many future modernists, including Sayyid Ahmad Khan. (Metcalf 1982: 72-5)

Discussion groups and the circulation of scholars

Informal study groups were common from early times. (Ihsanoglu 2004: III, 39) 'Study circles' among mosque congregations were probably the first to emerge. At a later date, bookshops and coffee houses hosted many intellectual discussions. (*NEB* 1993: XVIII, 16; Shaw 1976-77: I, 234) Monarchs and ulama made occasional attempts to ban coffee houses, alleged to be centres of irreligion and subversion, but to little avail. (Hattox 1985)

The Ottoman transition to more formal learned societies was gradual, and hard to pinpoint accurately. Informal gatherings of scholars were 'part of Ottoman cultural life.' The grand vizier of the 'tulip era' introduced a degree of formalisation by treating translators as a collective entity in the 1720s, albeit without specific juridical status. From 1815 to 1826, a kind of *salon* assembled in a wealthy suburb of Istanbul, including eminent scientists. However, many were exiled after 1826, denounced as Bektashi sectarians. The Encümeni Danish, founded in 1851, was the first incontrovertible formal learned society in the Islamic world. (Ihsanoglu 2004: III, 39, VIII, 87-96, and IX, 164-5)

Muslims travelled widely and freely through the lands of Islam, even across the Sunni-Shi'i divide, seeking patrons, teachers, pupils and intellectual stimulus. Scholars sought to perfect not only their learning but also their moral character. Arabic, as a 'common language of discourse,' facilitated this interchange. (Iqbal 2002: 159-60) Farsi [Persian] was almost as important a lingua franca as Arabic, and Turkish raised its profile in the early modern era. (Ihsanoglu 2004: III, 20-1) Other widespread languages easing dialogue were Urdu, Mandarin Chinese, Malay, Javanese, Swahili, and Hausa.

From the sixteenth century, the holy cities of Mecca and Medina assumed a heightened importance as 'clearing-houses' of knowledge for the Islamic world. This owed much to support from the Ottoman sultans after their conquest of Egypt in 1517, in conjunction with the ceaseless flow of pilgrims from all corners of Islamdom. Scholars from remote parts of Africa, South India, China, Russia and Southeast Asia thereby kept in touch with developments in the great gunpowder empires. Many scholar-pilgrims made extended educational stop-overs on their way to the Hijaz, as with Southeast Asians seeking out renowned teachers in India and southern Arabia. (Azra 1992: 141-55) That said, it not clear how much the rational sciences benefited from this process.

Some Western science and technology entered Dar al-Islam with European visitors. Thus, the Ottomans derived much information from diplomats, travellers, merchants, seamen and slaves. (Ihsanoglu 2004: I, 50) The Safavids became aware of Europe's scientific revolution through visitors, including envoys from Western monarchs. (Winter 1986: 581) Shah Abbas I sent a mission to Europe, which brought back news of Saxon mining techniques and water-driven sawmills. (Mohebbi 1996: 146) The Mughals were generally quite open to obtaining knowledge from European traders and envoys. The emperor Akbar [r.1556-1605] and his chief minister showed particular interest in stimulating and diffusing new techniques in metallurgy and distillation, but also for glass, pumps and ships. (Kumar 2003: 671) Awrangzib [r.1658-1707] stressed his desire for 'useful knowledge.' (Jaffar 1936: 183) However, from the

1750s, contact increasingly came to be the fruit of European conquest. (Kumar 2003)

Muslims travelled infrequently in Europe, and the few exceptions made no more than fleeting visits until the early nineteenth century. An Ottoman mission went to France in 1720-1, ostensibly to discuss churches in Jerusalem. In reality, Yirmisekiz Çelebi Efendi demonstrated a serious and informed interest in technical matters, and prepared detailed reports on canals, locks, bridges and tunnels. He also gave accounts of visits to an observatory, a mirror factory, an establishment making anatomical models, a greenhouse, and the royal library. (Savage-Smith 2003: 650-1)

The 'French knowers' of Istanbul only really became significant after 1793, when the Ottomans opened permanent embassies in the West. Closed in 1806, they were soon re-opened. From 1830, the Ottomans also sent selected students to Europe, with France as the preferred destination. Increasing numbers of non-Muslims took part in these study tours from 1839. (Cleveland 1994: 62-3, 77-8; Ihsanoglu 2004: III, 35-6) Muhammad 'Ali and his successors similarly sent groups of Egyptian students to be educated in Europe, mainly in France. (Delanoue 1982; Hourani 1970)

Libraries and bookshops

Collections of written materials were available all over Islamdom, as there were booksellers and libraries in all cities of note. The arts relating to book production were highly valued, from making paper, inks, decorative covers and bookmarks, to copying, gluing and binding. There was also a 'vast network of public libraries that could be consulted anywhere in the Muslim world.' Every madrasa had a library attached to it, as did some Sufi lodges. Moreover, 'there were thousands of private libraries.' (Pedersen 1984; Iqbal 2002: 161)

Libraries were seen as necessary adjuncts of scientific endeavour in sixteenth century Istanbul. (Ihsanoglu 2004: III, 19) Early nineteenth century Cairo contained 'many large libraries, most of which are attached to mosques.' However, the city only had eight booksellers, and their wares were technically of rather poor quality. Moreover, 'books on medicine, chemistry, the mathematics, algebra and various other sciences, etc., are comparatively very few. (Lane 1986: 219-20) In late seventeenth century Iran, libraries were small, for ' none exceeded four hundred volumes.' (Winter 1986: 586-7)

In Mughal India, Humayun [r.1530-36] founded a new imperial library, 'collecting a vast number of books.' (Jaffar 1936: 78) Akbar [r.1556-1605] enriched this library with scientific books, and had many texts translated into Persian, including from Sanskrit and European tongues. (Hodgson 1974: III: 76; Jaffar 1936: 83-5) His son Jahangir expanded the imperial library, and many private collections also existed at this time. (Jaffar 1936: 92-5, 131-44)

The vizier of early seventeenth century Makassar, South Sulawesi, was an avid student of European science. He obtained globes and maps, and had many texts translated into Makassarese, including a Spanish work on gunnery. These were later rendered into the Bugis tongue of neighbouring Islamic states. (Pyenson 1998: 41)

In West Africa, 'extensive private libraries' were crucial in the dissemination of information. Manuscripts circulated widely, written in Arabic, and either imported from across the Sahara or copied on paper obtained from the Maghrib and Egypt. (Saad 1979: 107-9)

Cosmographies

Cosmographies, in effect encyclopaedias, informed the reading public from the twelfth century. These voluminous tomes treated a variety of topics, such as astronomy, mineralogy, botany, zoology, anthropology, geography and history. Information and ideas drawn from other cultures percolated into them, including, over time, elements from Western sources. (Nasr 1987: 97, 102-3)

Ottoman cosmographies and maps incorporated information drawn from European discoveries, and demonstrated knowledge of magnetic declination in compasses. (Ihsanoglu 2004: I, 57-63, and III, 24-5) Katip Chelebi [Haji Halife, 1609-57], included gleanings from sea captains in his famous work, and deplored the widening scientific gap with Europe. (Hodgson 1974: III, 121-2; Ihsanoglu 2004: III, 25-6)

Annotated Ottoman translations of Western works became increasingly common from the late seventeenth century. The Dutch *Cosmographia*, or *Atlas Major*, of Janszoon Blaeu appeared in 1685. Abu Bakr al-Dimashqi, the translator, baldly summarised the heliocentric view of the planetary system. He claimed that the study of the rational sciences, especially astronomy and geometry, was alive and well in Islamdom, while conceding that knowledge of geography had enabled Europeans to 'excel in disturbing Muslims.' Osman b. Abdülmennan, translating Berhnard Varenius' *Geographia generalis* in 1751, opted for heliocentricity, resorting to the homely analogy of roasting a kebab. (Ihsanoglu 2004: II, 10-15, 20-1) Ottoman military maps were prepared on European lines from 1711. (Savage-Smith 2003: 654) Growing openness to European ideas culminated in a bout of hectic translating by Ishak Efendi [1774-1836]. A convert from Judaism, he attempted to present the whole of Western scientific learning to the early nineteenth century Ottoman public. (Ihsanoglu 2004: III, 32-3, and IV)

Encyclopaedic works were also common in India, allowing information and ideas to seep in from Hindu sources, and later from Europe. In the reign of Humayun [r.1530-56], Muhammad Fadil al-Miskini al-Samarqandi published the *Pearls of sciences* , with information on geography, minerals, zoology anatomy, disease, drugs, foods, astronomy, mathematics, accounts, optics and alchemy. He included snippets on African animals, and demonstrated that the Earth was spherical. Fathullah Farooqi wrote a similar tome a little later, in simple language for lay people, defining terms in Persian, Arabic and Sanskrit. (Rahman 2000a: 22) A Sanskrit encyclopaedia of 1709 covered meteorology, among a variety of subjects. (Gopal 2000: 315) This tradition persisted into the early nineteenth century, by which time Western influence was becoming apparent, for example with logarithmic tables. (Abdi 2000: 58-9, 65)

Printing

Islamic opposition to printing probably hampered a wider diffusion of science and technology, but the reasons for such objections remain to be clearly established. Francis Robinson argues that Islamic scholars disapproved of printing because religious materials should be transmitted orally. This allowed the ulama a vital role in interpreting texts, given that they possessed neither sacramental nor esoteric functions. However, he undermines his argument by noting that written versions were acceptable as an 'aid to memory.' (Robinson 1993: 234-9, 245-6) Even less convincing are Huff's arguments, seemingly derived from Christian analogies, that the ulama believed that printing profaned the word of God, while simultaneously permitting holy writ to fall into the hands of the untutored populace. (Huff 1993: 224-6) It is hard to conceive how the word of God could be desecrated by printing in Islamic terms, and the ulama never had a monopoly over sacred texts. (Iqbal 2002: 261)

Other alleged barriers to printing are equally dubious. It was more difficult to type-set Arabic characters than other scripts, for consonants took four different forms, according to their place in the word, and there was a complicated system of pointing for vowels and inflections. However, these technical problems were quickly resolved by Italian printers producing materials in Arabic characters, including a Quran printed in Venice in 1530. Christian Arabs in Syria also adopted the technique. (Pedersen 1984: 131-3; Savage-Smith 2003: 659; Robinson 1993: 233) It is further suggested that copyists, organised in guilds, stood to lose their livelihood. (Robinson 1993: 233; Iqbal 2002: 261) This could have affected 90,000 scribes in Istanbul in 1679. (Ihsanoglu 2004: I, 47) However, new employment was generated for printers, and the introduction of printing did not immediately throw all copyists out of work. (Lane 1986: 220) Moreover, some copyists in Muslim lands were slaves, and thus little able to protest. (Hodgson 1974: II, 445)

A more significant stumbling-block was the loss of treasured calligraphic effects in the process of type-setting. (Savage-Smith 2003: 659) Given the almost complete prohibition on pictorial representation in Islam, 'the art of writing became the most respected art, and no alphabet in the world has been the object of such intense artistic labor as the Arabic.' (Pedersen 1984: 81)

The problem with this argument is that block-printing, a Chinese procedure, overcame the loss of calligraphic effects. (Savage-Smith 2003: 659) Block-printing already existed in Egypt and Iran in the thirteenth century, if only to produce paper money and similar objects. (Huff 1993: 224-5) The technique existed for early modern Indian textiles. (Rahman 2000b: 246) And yet, at best, only short texts may have been produced in this way, such as official notices. (Pedersen 1984: 139) Catherine II, who sought support from her Muslim Tatar subjects, had a Quran block-printed in Russia in 1787. (Carter 1955: 151)

Ottoman reactions to movable type were not entirely hostile. Jews established presses in Istanbul, shortly after the technique began to spread in Europe after 1455. They were joined by Armenians from 1567, and Greeks from 1627. A decree of 1485, repeated in 1515, banned Muslims from printing, and prohibited people of all faiths from printing or owning materials in the Arabic script. However, a 1588 decree permitted the importation of materials in Arabic script from the West, and an Arabic bible was printed in Aleppo [Halab] in Syria, in 1716. (Savage-Smith 2003: 656)

The Rubicon was crossed in 1712, when an Ottoman decree authorised the printing of all but religious texts. This was because the reformist sultan, Ahmet III, had been persuaded of the utility of printing by Muhammad Efendi Chelebi, and his son Sa'id Efendi, who had spent some time in Paris and had learned about printing. The Shaykh al-Islam, 'Abdallah Efendi, issued a fatwa to proclaim the 'unconditional' Islamic legitimacy of the decree. Sa'id then teamed up with the Hungarian convert discussed earlier, Ibrahim Müteferrika, to set up a printing press in Istanbul. (Pedersen 1984: 134) However, Ahmet III's 1727 decree, authorising this venture, stipulated that not religious books could be printed, and that materials had to be submitted for vetting to a board of four ulama. The press began publication in 1729, and survived Ahmet III's violent overthrow the following year. Many maps were produced, but only seventeen books up to 1743, when Ibrahim fell ill. His heirs were allowed to continue in business, but only published another seven works up to 1797, when the business closed down. (Savage-Smith 2003: 657-8, 660)

Printing began again in that same year in the Imperial School of Military Engineering, which specialised in textbooks on mathematics and engineering, with short print runs of around a hundred. (Dölen 1998: 161-2) Several printed religious books also appeared in the 1800s, suggesting that the ban on such material had lapsed. (Pedersen 1984: 134) In 1831, the government published the first Turkish newspaper, an official gazette. (Cleveland 1994: 77)

Armenians printed in Persia's capital, Isfahan, from the early seventeenth century, but with ups and downs. Catholic Carmelite missionaries in that city received permission to print with Arabic font in 1629, though they never successfully produced a book. However, printed works were imported from Europe and India. Persia's first viable indigenous press began work in 1817. (Savage-Smith 2003: 658)

The Portuguese presented a printing press to Jahangir [r.1605-27]. but this Mughal monarch showed no interest in their gift. Rather than the ulama, it was the service nobility who may have opposed printing, as it threatened to elevate humble rivals. (Rahman 2000c: 261-2) South Asian Muslims developed the technique from the 1820s. From tracts, they moved to newspapers, and on to religious materials, including the Quran. An increasing volume of this material was in Urdu, or in other vernaculars, rather than in Persian or Arabic. (Robinson 1993: 232-3, 239-43)

Kazan, in Russian Tatarstan, became a centre of printing at about the same time. (Hodgson 1974: III, 222) By a decree of 1801, Tsar Paul I authorised a printing press for Russian Muslims, and a Tatar merchant financed a press in Kazan the following year. In a mere three years, it produced 11,000 textbooks and 19,000 religious works. The University of Kazan, set up in 1804, had its own press, and the two merged in 1843. (Rorlich 1986: 69-70) By 1820, there were 17 presses in operation. (Robinson 1993: 232) In contrast, Bukhara's first printing press, in 1901, was in a Russian settler community. The emir was still asking for a printing press in 1917. (Khan 1998: 61, 188)

In the Arab world, Muhammad 'Ali's 'wholehearted acceptance of the printing press' became a distinguishing feature of his drive to modernise Egypt. (Cleveland 1994: 67) A government press was established on a suburb of Cairo in 1821, and an official weekly soon followed. (Pedersen 1984: 136) Lebanon became a major centre of Arabic printing from 1834, when American Protestant missionaries brought a press from Malta. (Huff 1993: 225)

The rapid diffusion of lithography through Islamdom, after its invention in Munich in 1796, underscores the value attributed to calligraphy. (Savage-Smith 2003: 659; Pedersen 1984: 139) Only block-printing or lithography was usually employed to produce Qurans mechanically in Muslim lands. (Carter 1955: 150) Lithography proved more popular than type in India throughout the nineteenth century. (Robinson 1993: 239-40) In 1832-33, Ghulam Husain Jaunpuri's influential *Encyclopaedia of mathematical sciences* was lithographed. (Abdi 2000: 81) From that date on, the technique 'put vernacular books at the disposal of the educated at extremely low prices.' (Jaffar 1936: 226) It also played a great role in Islamic printing in Indonesia. (Azra 1997: 252)

Styles of scholarship

Few authors, whether Muslim or not, have a good word to say about the scholarly ethos of early modern Islam. Scientists of the golden age had been bold and brilliant in experiment and observation, but their early modern successors merely transmitted established knowledge. Rather than new paradigms and daring postulates, Islam experienced an 'era of manuals, commentaries and super-commentaries,' which were all too often 'unoriginal, pedantic and superficial.' (Rahman 1982: 45) Science became largely 'a matter of collecting already collected knowledge, and copying it down again and again, with minor variations.' (Turner 1997: 205) There was a 'decline in scientific spirit, in the genuine scientific interest.' (Sayili 1960: 412)

Marshall Hodgson presented a more nuanced view. While admitting that madrasa teachers frequently displayed a 'certain intolerance of experiment,' he wrote of monarchs upholding a 'mature scientific tradition, though locally not highly creative, a tradition duly aware of the significance of experimental demonstration and the like.' (Hodgson 1974: III, 122-3) Indeed, practical innovation flourished, and original thinking was by no means entirely dead.

Reluctance to learn from other civilisations was far from absolute, but may have been a hindrance to progress. Some Islamic scholars refused to admit that Western science and technology could hold any lessons for them. (Hoodbhoy 1991: 147-8) As European conquest spread, a psychological rejection of the Western scientific method, if not of its technological fruits, arose in places, for example among influential North Indian Muslims. (Metcalf 1982: 11, 99-104) Many Muslims also ignored the Prophet's famous injunction to seek knowledge 'even in China,' in relations with other non-Western civilisations surrounding the abode of Islam.

Ekmeleddin Ihsanoglu argues that Ottoman interest in scientific theory fell away from around 1600, but that there was a counterbalancing pragmatic stress on immediately useful knowledge. Astronomers turned to Europe to seek 'works necessary for timekeeping and calendar making.' There was little passion in debates over heliocentricity from the 1660s, with the old geocentric model presented as being of equal validity, for it was the accuracy of astronomical tables that really mattered. (Ihsanoglu 2004: I, 68-71, II, and III, 18-22, 25-7)

In an Ottoman book defending science, *The balance of truth*, Katip Chelebi [1609-57], maintained that the Quran untiringly invited men to think about the well-ordered form of the created universe. (Rahman 1982: 34) He urged the study of cartography, because 'the heathen, in their application to, and their esteem for, these branches of learning have discovered the New World and have over-run the markets of India.' (Jones 1981: 179) However, Katip Chelebi appears to have been a rather isolated figure.

Bayard Dodge admired the austerity and commitment shown by teachers of Egypt's al-Azhar, while considering that they 'were inclined to be imitative rather than creative, writing expositions of ancient works instead of presenting new ideas of their own.' He cited Mahmud al-Sharqawi, complaining that 'learning, investigation, instruction and recording all went in a circle around the text, with its explanations, glosses and notes, without the possibility of proceeding to a new idea or opinion, or to objective investigation.' (Dodge 1961: 82, 92-4) The 'arid intellectual atmosphere' of al-Azhar was satirised by Egyptian poets of the eighteenth century, and Michael Winter wrote of teachers that 'their erudition was limited to the traditional subjects, yet they showed little originality even in these. (Winter 1992: 114)

Nevertheless, the Egyptian Da'ud al-Antaki [d.1599] wrote a 'treasury' of Islamic science which included some fresh ideas, even if it chiefly consisted of recapitulation. (Nasr 1987: 214) Moreover, it was out of this 'arid' Egyptian milieu that Hasan al-'Attar emerged. His early nineteenth century work was characterised by a strong desire to 'arrive at a positivist philosophy of science through indigenous lines of thought.' He sought to demonstrate that it was not necessary to surrender cravenly to European science, for the roots of much that the West had achieved lay neglected in the Islamic corpus. (Gran 1979: 169-76)

H. J. T. Winter considers that, 'for two centuries, there was a dearth of creative minds' in Iran, and that the perfection of an old tradition was the best that scholars could manage, but his own text indicates that there was more. Though the dominant ethos may have been one of 'regard for the established authors,' medicine was clearly an exception. Jean Chardin [1643-1713], who lived in Iran in the 1660s and 1670s, noted that the techniques most intensively studied were those useful for construction and other practical purposes. These included mensuration, right-angle triangles, the measurement of arcs, pulleys, determining the height of distant objects, and the laws of optical reflection. (Winter 1986: 581-2, 602, 608-9) Two metal instruments from around 1700 were engraved with world maps that displayed a remarkable command of cartography and trigonometry. (Iqbal 2002: 134)

Judgements on India are mixed. 'Abdu'l-'Ali [1731-1810] was the 'Ocean of Sciences' of the great Farangi Mahall madrasa, but Muhammad Shafi', a modern scholar, considers that he merely wrote 'commentaries, glosses and super-glosses on most of the usual textbooks.' (Metcalf 1982: 30-1) In contrast, A. Rahman considers that Mahmud Jaunpuri [1585-1651] wrote books on physics that relied closely on observation and deduction. (Rahman 2000a: 23)

The open and practical nature of Islamic culture in India could be discerned in books on mathematics, written in Persian or Arabic. Some incorporated Sanskrit aspects, and even those that stuck to the Arabic corpus 'presented new methods of operations and interpretations,' especially in trigonometry and geometry. Moreover, the author of an influential madrasa textbook, Baha-ud-Din Amuli [1547-1622], illustrated his work 'throughout on the basis of inheritance, legacies, trade and commerce.' (Abdi 2000: 58, 65-6) This undermines A. Rahman's contention that there was a complete divorce between scholarship and technology, so that only 'limited and incremental advances' in production were possible, through a process of 'trial and error.' (Rahman 2000b: 246)

The peripheries of the Islamic world have been harshly judged, and yet very little is known about them. C. R. Pennell considers that Morocco's education system was 'very conservative,' for 'learning meant years of rote memorisation of ancient texts and commentaries.' He further states that the ulama were terrified of putting forward any novel ideas that might displease the sultan. (Pennell 2000: 17-18) Lewis Pyenson devotes a single brief paragraph to the Islamic period in his survey of Indonesia. (Pyenson 1998)

Mentalities

The case for a counter-productive underlying Islamic mentality has often been made. The ulama had become fatalistic, apathetic and traditionalist by early modern times, and thus opposed inquiry and innovation. Science was dangerous, because it threatened to disturb the eternal verities of revealed faith. Borrowing knowledge from infidels meant acknowledging the superiority of their religion. Despotism reigned unchallenged, thereby undermining conditions for free intellectual debate. The 'middling sort,' thin on the ground, were unable to put forward new ideas. (Jones 1981: 176, 181, 183-4, 199; Huff 1993) As late as 1886, a Moroccan named Kardudi concluded on a visit to Madrid that Europeans had only progressed due to luck and 'the spirit of darkness, ... the better to sink them in impiety.' (Sraïeb 1995: 21)

The positive aspects of Islamic civilisation have been stressed more of late. A favourable attitude towards the acquisition of *'ilm*, or knowledge, conformed to numerous passages in Quran and Hadith. Traditions held that the Prophet had encouraged the quest for knowledge from the cradle to the grave, and as far as China. (Kahumbi 1995: 324-7) The ulama were split over rational forms of *'ilm*, and did not oppose them systematically. (Ihsanoglu 2004: V) There were no social barriers to education, charitable funding for poor boys was well established, and the principle of schooling girls was accepted, as long as rules of modesty were upheld. (Jaffar 1936; *NEB* 1993: XVIII, 16, 23) Religious and racial tolerance enabled numerous renegades, scriptuaries and freed slaves to flourish, often as conduits to the wisdom of the outside world.

Reformers from the 1860s picked up on this positive legacy. They argued, in their different ways, that believers were commanded to study God's work, as part of their submission to his will. Scientific discoveries had been foreshadowed in the Quran, and the failure to maintain scientific enquiry and technological development had brought Islam to its knees. (Rahman 1982: 49-51; Iqbal 2002: xix) Jamal al-Din al-Afghani [1838/9-97], Pan-Islamic activist, used exegesis to show that a spherical Earth circulating round the sun was present in the Quran. (Dodge 1961: 118) The great Indian moderniser, Sayyid Ahmad Khan [1817-98], was more radical, for he equated natural law with God's law. (Hoodbhoy 1991: 65-7)

Conclusion

Decline seems to be the wrong word to describe the production of reliable and useful knowledge in early modern Islam. Even the notion of stagnation misses the point that slow advances occurred in different parts of Islamdom, notably the Balkans, Anatolia, the Volga basin, Iran, and North India. The absence of the Arab world from this list underscores the predominance of areas using Turkish and Persian.

As indigenous innovation lost momentum towards 1600, Muslims compensated by demonstrating a growing openness to the findings of infidel scientists and technical experts. The obligation of monarchs to act in the public interest enabled rulers to stimulate this process. In the Ottoman and Mughal cases there was an almost seamless transition, whereas other parts of Islamdom witnessed a marked trough between the impasse reached by classical knowledge and the adoption of European ideas.

The slow tempo of Islamic innovation mattered tremendously, because the West was sprinting ahead so fast. Although Muslim elites began to emulate Europe seriously from the eighteenth century, they failed to achieve an Industrial Revolution. This allowed de jure infidel tutelage to spread across most of the 'abode of Islam' in the course of the nineteenth century, with de facto control exercised in nominally independent states.

Nevertheless, the characterisation of the centuries prior to c.1850 as a scientific and technological 'dark age' has had perverse effects. Rather than situating themselves in the line of a rejuvenated indigenous tradition, Muslim scientists and managers have tended to cut themselves off from their own roots, embracing Western modernity as a total package. A recognition of Islamic strengths in the early modern production of reliable and useful knowledge might help to bridge the destabilising psychological gulf between the old and the new, the effects of which remain with us to this day.

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