4.1.1 Science and Technological Change in Early Modern History (ca. 1500–1800)

Jan Hansen, Jiří Janáč, Lilla Krász, and Marco Mostert

Introduction

In Europe, the early modern period was a time of societal transition, from the traditional towards the modern. Framed by the global expansion of European settlement, driven by the rivalry between the great powers on the continent, and by their efforts to discover and control new lands and resources at home and overseas, the era witnessed the gradual formation of Europe. It provided the conceptual and material base for European global dominance in the nineteenth century. Scientific and technological change played a central, if often overlooked part in this process, which is usually described in terms of the expansion of capitalism and the related development of institutions and innovation cultures. The invention, development, and dissemination of the printing press from the fifteenth century onwards, as well as other early modern technologies, reveal how science and technological change went hand-in-hand, and how knowledge (about mathematics, optics, astronomy, chemistry, and medicine) and the media used to convey it, were evolving in tandem. Arguably, new knowledge cultures and associated technologies were an achievement from which large parts of the enlightened eighteenth-century elites derived their self-conception, embodying progress and modernity.

This chapter discusses some aspects of this transformation by exploring the emerging written culture and other infrastructures of knowledge, technological networking across Europe, the diffusion of innovations through migrant knowledge, and industrialisation. First, we will look at the ways in which the printing press changed the infrastructure of knowledge. Next, we will discuss technological change and the role of migrating craftsmen in the diffusion of innovations. Finally, we will see how industrialisation was helped by inventions that were developed by craftsmen, experimenting tinkers, and

 https://doi.org/10.11647/OBP.0323.40

self-taught mechanics rather than by scientists. This holds true both for the fifteenth-century printing press and for the eighteenth-century steam engine. These inventions were among those that spread wherever Europeans set foot. Ingenious devices were developed in the colonies as well, and they contributed considerably to the global expansion of Europe.

Fig. 1: Philip Galle, "Boekdrukkunst" ("Printing art") (ca. 1589–1593), Rijksmuseum.org, http://hdl.handle.net/10934/RM0001.COLLECT.115331. Printworks at the end of the sixteenth century, showing typesetting, the act of printing itself, and printed sheets hanging to dry.

The Infrastructure of Knowledge

During the early modern period, the ways in which people learnt about the world and their place in it were transformed through changes in the infrastructure of knowledge: in the use of speech or making visual images to convey information, the proliferating uses of the written word, and the invention and development of the printing press.

Orality was still important in early modern Europe, and much technical knowledge relied on learning one's trade or art in practice. However, the development of writing, which had gradually taken root since antiquity, became an increasingly important medium for transmitting messages. Written texts could be read and listened to when they were read aloud. They could also be copied and kept for later use. The use of writing led to the formation of institutions such as the archive, meant to keep documents, and the library, for keeping written texts in book form. Schools were developed, in which knowledge was imparted about the various ways of dealing efficiently with

written texts. Writing began to form part of social reality. 'Literate mentalities' developed, which allowed those who could read and write to form a different view of the world.

In the thirteenth century, the numbers of documents that were produced increased dramatically, as did school texts. Books began to resemble the books we use today. Catalogues and inventories were made to help visitors find texts in libraries and archives. Earlier oral legal practices were put into writing, and trust in the written word increased. It became necessary to learn to write correctly in order to study at a university and embark on a career in law or medicine, or to be trained as a notary public. 'Knowledge' and 'applied knowledge' became separated from one another, and teaching was shifting its attention towards society's new demands for literacy. A flywheel was set in motion and started to gather speed. This was fed by formal schooling in the arts of the written word. Schooling imbued knowledge which might be applied as a technique—as 'technology'. The development of technology deepened the complexity of society. This increased complexity, in turn, increased demand for schooling, and so on. All this made the thirteenth century into a key period in the history of European literacy. An audience developed for the products of the movable-type printing press, developed by Johannes Gutenberg (c. 1400–1468) around 1440. This happened especially in the towns, where formal schooling took place, where universities developed, and where the demand for consulting books shaped new forms of written texts.

The introduction of the printing press was momentous. The medieval millennium produced some 11,000,000 manuscript books; but in only the first half-century of its existence, until around 1500, the printing press had already produced several millions of books. Not all printed books contained texts that modern-day Europeans would consider as 'knowledge'. But some books did, and the printing press generated a written culture that over the early modern centuries saw the rise of forms of scholarship and science with which we are still familiar today. An intellectual community of scholars, the so-called Republic of Letters, corresponded by letter and published the results of their research in printed books. Printed scholarly journals first appeared in the seventeenth century. From the fifteenth century, scholars housed their libraries in studies at their private homes. These small rooms could also house collections of curiosities. The first European museums also appeared in the fifteenth century, as did the first public libraries. Meanwhile, small laboratories came into existence for alchemy and medicine. Places for research in teams were to develop only in the nineteenth century; until then, pure scientific research and scholarship required considerable investments of time and money.

The eighteenth-century Enlightenment saw writing as the engine of civilisation, and the prehistoric period as somehow of lesser value than periods

and cultures that knew writing. And they considered the printed word to be intrinsically better than the handwritten word. It was print culture, so it was thought, that allowed the development of public opinion: a tribunal that was independent of all powers, and that would be respected by all powers. It is certain that, building on the developing culture of literacy and the infrastructure of reading, early modern Europe experienced a boom of applied technologies that benefitted trade and communication networks. That was made possible, even if only in part, by the printing press.

Technological Change, Infrastructures, and Networking

Early modern technological change is often associated with notions of revolution (e.g., the 'military' or 'scientific' revolutions). But radical new innovations tended to appear sporadically; the steam engine and the printing press are the most often mentioned exceptions. Indeed, rather than being driven by heroic figures and major inventions, technological change developed gradually, through the expansion and improvement of networks, the growing intensity of expert exchange and the circulation of knowledge, and assisted by improvements in (transport) infrastructures. Instead of radical transformation, technological change often followed a path of gradual improvements based on trial and error and learning by doing. Science, rather than being a driving force of technological change itself, followed the knowledge and practices developed by craftsmen and engineers.

Between 1450 and 1800, European merchants expanded their trading networks on a global level, leading to their operation of regular trans-oceanic exchanges, connecting Europe through seaports with virtually every corner of the planet. Technological innovations were crucial for this expansion. The expansion of global contacts facilitated the introduction in Europe of advances in shipbuilding (such as the Asian lateen sail and leeboard), weaponry (Chinese gunpowder), and navigational instruments (compass, astrolabe), all of which originated in other parts of the world. They were skilfully combined by their new users.

Efforts of merchants, shipbuilders, and sailors active in the Dutch trade in the Baltic during the sixteenth century led to the development of the *fluyt*, a sailing vessel superior to those used by their European competitors. Designed to facilitate trans-oceanic trade with a focus on maximum cargo capacity, minimal crew, and low building costs, the *fluyt* marked a significant improvement on Mediterranean vessels such as carracks and galleons, the original vehicles of European expansion. By significantly reducing transportation costs, this new type of vessel contributed to the success of the Dutch Seaborne Empire, built on an extensive merchant fleet which by the mid-seventeenth century

represented approximately half of the total European capacity. Later on, British shipwrights adopted and improved the original design, in turn enabling the expansion of the British Atlantic trade.

Sometimes the state played a central role in infrastructural development and technological change, especially from the rise of absolute monarchies. In the mid-seventeenth century, Europe witnessed a turn from private initiative towards designs and efforts orchestrated by the state. An early example is the systematic development and standardisation of postal services, which started at the beginning of the sixteenth century. Networks of horse-riding couriers for regular diplomatic communication across the large European kingdoms and empires appeared. The Habsburg monarchy, spanning an area that stretched from the Atlantic coast to the borders of the Ottoman Empire, played a leading role, establishing the Imperial Post to connect the main centres of the empire. When this network also started to provide services to non-state customers, cities such as Venice connected themselves to it as well.

With traffic levels gradually increasing, in the eighteenth century European states started to develop an interest in improving roads and waterways, either by stimulating private investment (the British turnpike roads) or by building national road networks (on the continent).

The development in postal services (using the improving road networks) and in shipbuilding (which supplied global trade networks) significantly contributed to the intensification of communication both within Europe and between Europe and the wider world. They thereby also contributed to the formation of Europe as a self-aware cultural and economic unit.

Migrating Craftsmen and the Diffusion of Innovations

Who used the new technologies and scientific advances that appeared in early modern Europe? The question about the users and consumers of knowledge and technology is significant because the invention of a device would be meaningless without its subsequent use and further development. This is just as true for the invention of the printing press as it is for the invention of the mechanical pocket watch (1510), the microscope (1608), the steam engine (1712), and the loom (1764). The people who used these devices were scholars, artisans, craftsmen, engineers, and entrepreneurs, among others. In the early modern period, ever more people took up these professions. This mirrored an increasing social complexity between 1500 and 1800.

The boundaries between those who advanced science and technological change and those who used these achievements were fluid. A significant example to study the persona of the innovator-user is that of migrating craftsmen. It was a fundamental part of the training of every carpenter,

shoemaker, or baker to spend their apprenticeship years on the move. In several professions, migration was regarded as a prerequisite for a craftsman to become a master. Many guild regulations contained detailed provisions in this regard. Ambitious architects and engineers were expected to travel to Italian towns early on in their careers to continue their education there. The result was a trans-local, trans-regional, and trans-territorial transfer of science and technology, making the early modern period a remarkably dynamic epoch. By acquiring practical skills and knowledge and transferring it to other places, craftsmen contributed to the production and transformation of science and technology.

Many of these craftsmen kept travel diaries in which they took notes about the knowledge and skills they acquired. Some of them even published their diaries. This connects to the increasing literacy rate and the importance of the printing press in the early modern period. On a large scale, letterpress printing affected the circulation of knowledge and influenced practical skills among craftsmen, workers, and others engaged in handicraft and technical professions. Cheap editions of books and guidebooks found a wide circulation and readership, and they were carried around by craftsmen on the move. This early modern readership was composed of educated readers at the courts and universities, but it also came from the emerging middle classes and, occasionally, from working people. In all these cases, however, this extending readership did not necessarily represent radical new beginnings, but rather built on developments rooted in the Middle Ages.

The printing press also contributed significantly to the development of a joint horizon of expectations in terms of science and technological change, on the part of those literate Europeans who participated in the discussions that fostered the development of public opinion. These processes had a specifically European dimension. Exchanges through transnational infrastructures such as roads, canals, and the postal system accelerated the interaction between the users of technological advances in different regions of Europe, from the urban centres of Italy to the rural peripheries of northeastern Europe. Travelling craftsmen, with their spatial and intellectual mobility, fostered a transnational culture of experts in the early modern period. But these developments also had exclusionary effects that were previously unknown to the people of Europe. Above all they resulted in demarcations, as can be seen in the emerging law on patents, for example, which was intended to protect inventions from unauthorised imitations. The first patent letters are documented for medieval England (1331). In Italy this development began somewhat later: in 1416, the Republic of Venice granted the first patent for a device that processed wool into felt. It was in Venice that a distinct patent culture developed in the following decades, initially in glass-making, which gradually spread across Europe through migrating craftsmen, among others.

Overall, from about 1500 onwards, the everyday experience of large populations in Europe was increasingly shaped by products of technical innovation. Printed books were tangible outcomes of these transformations. The most lasting changes, however, came from developments that we summarise with the term *industrialisation*.

Industrialisation

Economic development in the early modern period, which has been termed by posterity the period of 'proto-industrialisation', was characterised by the proliferation and coexistence of artisans' workshops in cities and market towns, and by the division of labour among small enterprises operating within a framework of home industries. There were relatively few large-scale factories or mining enterprises at this point. Urbanised settlements made it possible for entrepreneur merchants and manufactory owners to supervise the activities of nearby rural home producers by distributing raw materials and tools to them (a process called the *Verlagssystem*), or by setting standards and schedules for the deliveries of semi-manufactured products and seeing to the marketing of finished goods (the *Kaufsystem*). The final phase of the production process was carried out in the cities and towns, where the workshops of major guilds and manufactories (the so-called proto-factories) were operating. At the same time, large numbers of the peasantry were hired on a seasonal or part-time basis and gradually turned into 'labourers', becoming dependent on an entrepreneurial system well before the development of large-scale industrial production. The early modern system of distribution had first appeared in the fourteenth century, and the sixteenth and seventeenth centuries saw it adopted by the textile industry; the system remained in use until well after the onset of the 'industrial revolution'.

In the early modern age, the dominance of small-scale forms of industrial activity is clearly shown by the fact that approximately 2.2 million people were employed as artisans in the Holy Roman Empire, of whom one million were operating on the basis of a distribution system relying on household industries, compared with the 100,000 people working in large-scale manufactories or in mines. Similar proportions and phenomena are discernible in the northern Italian weaving industry and in the early industrialisation of France, where two-thirds of industrial production were dependent on small-scale businesses.

In Lancashire, commonly regarded as the birthplace of the industrial revolution in England, just as many people were employed in small workshops as in factories. This over-representation of home industries was largely due to low wages and entrepreneurial flexibility. Not surprisingly, these circumstances also account for the belated mechanisation process of industrial production in other parts of Europe.

The first large-scale businesses, such as the manufactories, were established to satisfy the needs of modern states, which were undertaking to develop their armies in the sixteenth century. The state was especially interested in arms production, the textile industry, and metallurgy. Manufactories were heavily subsidised by the state.

Manufactories also acted as indispensable levers of technological transfer. Apprentices of small workshops (operating with two or three employees within the guild system) tended to acquire work and life experiences in the course of their wandering about Europe. With the manufactories, finally, there seems to have developed an intrinsic relationship between migration and innovation. Italian craftsmen producing highly esteemed stained glasses or silk fabrics fled from the Spanish Inquisition and settled in the Holy Roman Empire in the sixteenth century. Huguenot weavers and makers of Gobelin tapestries fled from France in the late seventeenth century and settled in England and the United Provinces of the Netherlands, and they exerted lasting influence on the development of Prussia's network of manufactories. Nevertheless, the proportion of large-scale businesses remained relatively low in the early modern age: even at the end of the eighteenth century, in continental Europe there existed very few manufactories employing as many as several hundred people. Barcelona stood out in this respect, as there were approximately 100 large manufacturing plants in the city.

The rise of the modern industrial age could not do without the division of labour, large-scale specialisation, technological innovation, and continuous capital investment. This first manifested in England from the 1730s onwards, with the advent of the industrial revolution. The term 'revolution' may be somewhat misleading, however, as the development was far from radical and swift.

Regarding the direct application of set procedures, the skills and knowledge involved in the eighteenth-century beginnings of modern industry were rather precarious, though certain practices based on observation and experimentation had already been methodically applied from the late seventeenth century onwards. The most striking feature of eighteenth-century technical innovations in England had not been worked out by scientists, but rather by experimenting tinkers, self-taught mechanics, engineers, and entrepreneurs. The early decades of the eighteenth century saw two foundational innovations which had lasting effects. First, there was the introduction of coke heating in the process of melting iron, getting rid of the dependency on charcoal (invented in Coalbrookdale in 1709 by Abraham Darby (1678–1717), an ironmonger). The second invention, which supplemented and gradually replaced the wind and water wheels as a source of energy, was the development of the steam engine (invented in 1712 by Thomas Newcomen (1664–1729), tinker and ironmonger in Staffordshire; and developed in 1769 by James Watt, mathematician and

tool maker in Glasgow). These innovations and procedures originated with technicians rather than scientists and were soon adopted on the continent. It was these early modern innovations—which can at best be termed 'applied science'—which shaped the further course of industrialisation.

The early modern period also saw the intensification of communication within Europe and the sophistication of trade networks and colonial expansion by European powers worldwide. In the colonies, crucial inventions were developed as well, such as the cotton gin developed by the American inventor Eli Whitney (1765–1825) in 1793 in the recently independent United States. This made it easier to separate the cotton fibres from the seeds of the plant, speeding up production. New techniques developed by European settlers and their descendants were tried out on slaves and indigenous people whenever this seemed profitable. The exploitation of colonised people and the extraction of resources in many cases was the prerequisite for industrialisation in Europe. This is the darker side of what Europeans understood by scientific and technological progress.

Conclusion

In the early modern period, science and technology were intimately connected. Technical innovations and their diffusion were based on new bodies of knowledge, while new devices helped to expand knowledge horizons. This is evident on several levels. From the thirteenth century onward, a distinct written culture emerged. In the fourteenth and fifteenth centuries, ever more texts were produced and read by clerics, scholars, and other members of the literate elites. Gutenberg developed the printing press around 1440, making it easier to produce books. The channels for distributing pamphlets, books, and other printed texts improved as well, based on complex infrastructures of knowledge. The result was a Republic of Letters.

Science and technology developed in and through networks—the interpersonal communication networks of scholars, artists, craftsmen, tinkers, and engineers, but also the material networks of infrastructure, such as roads, canals, and the postal system that transported scholars' letters.

Knowledge of technological innovations circulated between European countries and around the globe. This diffusion of innovations emanated from the hub of Italy, because craftsmen and artisans who travelled there brought knowledge (and methods of protecting knowledge through patents) back home with them. These travellers were producers and consumers of technology at the same time. Thus, in the early modern period there was an intimate connection between innovation and migration. This new knowledge was a precondition for the industrialisation that unfolded from the eighteenth century onward, especially in England. Even before the 'industrial revolution,'

however, there were new forms of production related to scientific and technological change. This early form of industrialisation first took place in micro-spaces such as artisan workshops and home industries, before large-scale industrial production advanced from the eighteenth century onward, profoundly changing the (early) modern world.

Discussion questions

1. In which ways did the development of the printing press influence early modern society in Europe?
2. Is it right to argue that the introduction of the printing press led to industrialisation in Europe? Why or why not?
3. What was the role of colonialism in the history of technological change in early modern Europe?

Suggested reading

Michael Adas, ed., *Technology and European Overseas Enterprise: Diffusion, Adaptation and Adoption* (London: Routledge, 1996).

Burke, Peter, *A Social History of Knowledge: From Gutenberg to Diderot* (Cambridge: Polity, 2000).

Chartrier, Roger, *The Order of Books* (Cambridge: Polity, 1994).

Horst, Thomas, Marília dos Santos Lopes and Henrique Leitão, eds, *Renaissance Craftsmen and Humanistic Scholars* (Bern: Peter Lang, 2016).

Christian Jacob, ed., *Lieux de savoir: Espaces et communautés* (Paris: Albin Michel, 2007).

Park, Katharine and Lorraine Daston, eds, *The Cambridge History of Science, vol. III: Early Modern Science* (Cambridge: Cambridge University Press, 2006).

Raymond, Joad and Noah Moxham, *News Networks in Early Modern Europe* (Leiden and Boston: Brill, 2016).

Reid, Phillip, *The Merchant Ship in the British Atlantic, 1600–1800* (Leiden and Boston: Brill, 2020).

Rogers, Everett M., *Diffusion of Innovations* (New York: Free Press, 1962).

Scott, Hamish, ed., *The Oxford Handbook of Early Modern European History, 1350–1750* (Oxford: Oxford University Press, 2018).