Innovation and invention

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Summary

The Greek, Hellenistic and Roman worlds were characterized by a culture of knowledge that fostered and celebrated innovation and invention. Greeks and Romans not only embraced technological practices developed elsewhere in earlier periods, maximizing their use, but also saw the diffusion of a broad range of inventions and innovations in agriculture, manufacturing, construction, transport, and communication. These innovations not only had a tangible impact on everyday material culture, but also supported the increasingly complex social, economic and political networks that came to characterize the ancient Mediterranean.

Keywords: technology, innovation, invention, agriculture, manufacturing, transport, writing, mining, construction

Subjects: Science, Technology, and Medicine

Historical and Historiographical Background

Graeco-Roman antiquity was a pre-industrial and agrarian society. It had limited means to circulate knowledge, and there were structural constraints on the emergence and diffusion of innovations compared to the early modern and modern world. At the same time, the Graeco-Roman world grew into an increasingly vast and complex conglomerate of social, political, and economic networks that facilitated (and fostered) innovation more than ever before, which resulted in significant change in technological practice and a well-developed consumer culture in which invention and knowledge could be appreciated and celebrated.

For most of the twentieth century, Graeco-Roman technological culture was assessed in mostly negative terms: ancient technology was seen as relatively backward, and its progress was thought of as stagnant compared to the preceding millennia, which had seen the emergence of complex pottery, textile, and metalworking technologies.[1] From the 1980s onwards, this consensus has begun to crumble, and Graeco-Roman technological innovation and invention have begun to be evaluated considerably more positively in respect of both the eventual level of development achieved and the role of invention and innovation in transforming technological practice in the Graeco-Roman world.[2]

Culture of Knowledge

An important pillar for invention and innovation in the ancient Mediterranean was the Graeco-Roman culture of knowledge. While the Greeks and Romans were not the first in western Eurasia to embrace practices and institutions for collecting, expanding, and disseminating knowledge, they did so on a much larger scale than Babylonian and Egyptian predecessors and reached a much broader audience. From the Archaic period onwards, Greeks produced lengthy texts that captured and communicated practical and theoretical knowledge, and they did so on an increasingly wide range of topics, including medicine, nature (living and dead), and metaphysics.[3] The Hellenistic and Roman periods saw the flourishing of encyclopaedic traditions, with scholars producing multivolume works bringing together broad knowledge from a variety of directions.[4] At the same time, acquired knowledge became accessible for larger numbers of people through the establishment of learning institutions and libraries. Lower down the social scale, systems of apprenticeships among craftsmen—often transcending local boundaries—created networks of specialist knowledge within and between urban communities.[5] Hellenistic and Roman political elites assembled and centralized practical and technological knowledge in order to use it to their advantage. This did not take away all obstacles to the circulation of knowledge, but it made sure that knowledge could circulate more easily than ever before and, as a result of political, economic, and cultural integration, over a much larger area.

To this should be added that, especially from the Hellenistic period onwards, the principles of invention and innovation were recognized and could be celebrated. Authors like Pliny the Elder and Athenaeus present catalogues of inventions in which everyday practices, techniques, and ideas are ascribed to specific individuals or places of origin.[6] Several authors from the Roman imperial period notice how people present their inventions to the emperor, pointing to a practice in which innovation could be rewarded.[7] This suggests a culture of knowledge that was able to accommodate invention and innovation.

Agriculture

Agriculture understandably played a central role in Graeco-Roman knowledge culture, with Hellenistic and Roman authors producing lengthy handbooks on how to run a farm.[8] The Romans invested explicitly in gathering agricultural knowledge, for example, by confiscating Punic tractates on agriculture in the conquest of Carthage and translating them into Latin. The quality of this knowledge has sometimes been doubted—it is by no means scientific—but the fact that it was meant to circulate widely suggests a culture of knowledge-sharing that fostered cross-fertilization and, thus, innovation.

In reality, innovation in agriculture was predominantly organizational in nature and mostly restricted to the Hellenistic and Roman period, which brought the emergence both of larger-scale landholding and of government-driven development schemes. The latter meant that agricultural land in large areas was divided through centuriation systems, resulting in regularly shaped plots and more efficient land use.[9] Large-scale agricultural enterprises and increasing market integration allowed for specialization and, in the case of olive-oil and wine production, for large-scale, centralized pressing facilities streamlining the processing of produce after the harvest.

Otherwise, innovations in the agricultural process appear to have been much more limited. There is some evidence that ploughs became a bit heavier (and thus more powerful), but crop improvement remained limited, and techniques like grafting had already been established before the Classical period. While there was substantial variety in the number of cultivated crops, most were well established in the Mediterranean by the early 1st millennium BCE. Technologically, innovation in Graeco-Roman agriculture mainly consisted in maximizing the effectivity of known practices and applying them on a larger scale.

Extraction

The Graeco-Roman period was characterized by an unprecedented exploitation of natural resources. In most processes of extraction, particularly in quarrying, innovations mainly involved the application of existing technologies on a much larger scale and were a product of both the improved transport infrastructure and the increasing economic power of cities, rulers, and emperors. In mining, however, it is clear that, in the Roman period, a range of innovations in water technology paved the way for large-scale operations in layers that previously had been unprofitable or even out of reach.[10]

In underground mining, the invention of mechanical devices for lifting water in the Hellenistic period made it possible to excavate galleries deep below the water table. The invention of these water-lifting devices, including the Archimedes screw and the water-lifting wheel antedates the Roman period, but they found application in Roman underground mines: water-lifting wheels are attested at Rio Tinto, Archimedean screws at several other mines.[11]

In open-cast mining in secondary (alluvial) deposits, the use of hydraulic mining by the Romans represented a particularly drastic innovation, with major consequences not only for the quantity of ores extracted, but also for the impact of mining on the landscape.[12] Hydraulic mining used the erosive power of water to expose or isolate metal ores. Techniques like hushing—washing away the overburden by releasing large quantities of water—and ground sluicing—breaking up and sorting alluvial deposits by subjecting them to a continuous stream of water—made it possible to exploit the environment on a large scale. Traces of both technologies are well attested in mining areas in Roman Spain and in Britain, and substantial aqueducts were constructed for Roman mining operations.

Manufacturing

Graeco-Roman manufacturing was traditionally seen as particularly stagnant: production, it was maintained, took place in small, skill-based workshops with very limited technological support, and basic production technologies in many crafts had already spread over the Mediterranean before or around the start of the 1st millennium BCE. Since the 1980s, however, a renewed interest in the archaeology of ancient workshops and the emergence of the archaeological sciences in artefact studies have almost completely reversed this picture. There was significant innovation in metallurgy and metalworking, in ceramics production and in glass-working, and textile production saw more innovation than has traditionally been acknowledged.

While basic technologies in metalworking had emerged by the early 1st millennium BCE, there was additional innovation both in metallurgy and in object manufacturing in Classical antiquity.[13] As far as metallurgy is concerned, the Graeco-Roman world saw the appearance, alongside bronze, of two new alloys—brass and pewter—and improvements in bronze composition. At the same time, Greek and Roman metalworkers became increasingly able decorators, producing refined everyday objects, particularly in bronze and silver, that were technically more complex (e.g., including multiple layers of metal or several independent parts) and more iconographically explicit.

In the production of fine ceramics, key firing technology, the principles of painted decoration, and, indeed, the potter's wheel had become part of Eastern Mediterranean technological practice by the middle of the 2nd millennium BCE, and the 1st millennium BCE initially mainly saw the further spread of these technologies.[14] Yet, from the 6th century BCE onwards, improvements in firing and slip technology made it possible to produce a glossy surface in red and black; Hellenistic experiments with glazing technology further expanded decorative practice.[15] The increased use of moulds in the Roman period led to mass-produced artefacts with standardized decoration that were accessible to a very broad group of consumers.

The flagship innovation in Graeco-Roman manufacturing, however, was glass-blowing.[16] Glass, in the form of beads and other small objects, had been around since the 3rd millennium, and the first (multicoloured) glass vessels had been produced from the middle of the 2nd millennium BCE onwards. Glass-blowing was invented in the mid-1st century BCE in the Levant, and further developed in Italy, spreading quickly over the Roman world; the proliferation of glass artefacts in the 1st century CE highlights the impact of this innovation on everyday life.[17]

The two key processes in textile production—spinning and weaving—did not change fundamentally in antiquity, so that, compared to later periods, productivity remained low; essential dyeing technology had also already emerged over the course of the 2nd millennium.[18] Nevertheless, innovations in loom design gave weavers more control over the weaving process and enabled them to produce more complex weaving patterns, resulting in output of a higher quality.[19]

It is true that in the manufacturing of everyday consumer goods human effort and skill were and remained crucial. In several food-processing industries, however, animal- and water-power became important from the late Roman republic onwards. In early imperial Roman Italy, flour was milled by mills rotated by horses or mules; in an increasing number of places, there is secure evidence of watermills being used for similar purposes—the complex at Barbegal is an extreme example.[20] In later antiquity, water power was also applied for other purposes, such as stone-sawing.

All in all, there was substantial innovation in manufacturing, though—water power excluded—its results did not so much affect the quantity of goods produced, but rather the quality of the artefacts. Arguably, many of these innovations were driven by the needs and opportunities of the emerging and, later, booming urban consumer markets of the Graeco-Roman Mediterranean, and they profoundly transformed everyday material culture.

Construction Practice

Construction practice was an area in which innovation had an even more dramatic impact on everyday life. While Archaic and Classical Greek construction practice used building principles and techniques that had a long history in the Aegean and the Near East—particularly columns, ashlar, and adobe—the last centuries BCE saw the arrival of two building techniques that were to transform the nature of Graeco-Roman construction and architecture, and the spatial configuration of everyday life: the arch and concrete.[21]

The arch was first attested in Rome in the late 6th century BCE in the form of the barrel vault, which was used in underground rooms like cisterns, but it became a more common element in architecture from the 3rd century BCE onwards, when it began to appear in city gates.[22] By the late 2nd century BCE the arch had become a regular feature in aqueduct bridges; in the imperial period, the arch was fundamental to the construction of free-standing theatres and amphitheatres—which otherwise would collapse under their own weight—and as a load-bearing element in walls of Roman concrete.[23] The innovative applications of the arch gave Roman architects more possibilities in large-scale architecture and in infrastructure projects.

Concrete was an invention of mid-republican Italy and came to play a crucial role in Roman building practice from the mid-2nd century BCE onwards, gradually replacing ashlar and other construction techniques depending on stacked stones.[24] By the early imperial period, concrete had become a leading building technique in both private and public construction in large parts of the Graeco-Roman Mediterranean and beyond.[25] Concrete gave Roman builders an almost complete freedom of design and made it possible to build walls and substructures with a much broader range of materials and without the need to cut stones to any precise shape. This made construction easier and cheaper, and it not only affected the nature of architecture, but also the scale of civil engineering.

Transport Infrastructure

The Graeco-Roman world saw a substantial amount of innovation in transport technology. Innovations affected both transport on water and transport on land, and concerned the means of transport, the containers used for moving around (bulk) goods, and the transport infrastructure. As the Graeco-Roman world remained tied together through maritime connections, improvements in maritime technology had a significant impact. The use of pegged mortise and tenon joints in hull construction from the late Archaic period onwards made it possible to construct larger ships of greater strength and thus set the standard for shipbuilding until late antiquity.[26] Subsequent improvements in hull design facilitated the construction of large cargo ships that served the supply economies of the large urban centres of the Roman Mediterranean.[27] The development of the most widely used containers for bulk goods, transport amphorae, followed innovations in shipbuilding: as bulk transport became more common, these amphorae, which in a rudimentary form had existed since the late 3rd millennium BCE, got a knobbed foot and an ever more elongated form which facilitated both transport and handling.[28]

Permanent man-made transport infrastructure, including roads and harbours, was a major innovation of the Roman period, and its spread was supported by the innovations in building technology. The arch played a crucial role in the emergence of the bridge in the 2nd century BCE.[29] Bridges made it possible to quickly cross rivers, streams, and valleys independently of weather conditions, and with a loaded wagon, thus making long-distance overland connections more reliable and efficient. The role of hydraulic concrete in harbour construction is well documented and made it possible to build free-standing structures in the open sea, allowing for the construction of well-protected harbour basins in formerly inhospitable coastlines with few natural harbours.[30] Both roads and harbours played an essential role in communication networks in the Roman world and were fundamental to the political and economic integration of the Roman Empire.

Communication Technology

Information and communication technology, as a field of practice, was not only fundamental to invention and innovation, but was, over time, substantially transformed by a range of Greek and Roman inventions and innovations. This, of course, began with the adaptation of the Phoenician alphabet to the Greek language through the “invention” of vowels in the 8th century BCE and with the subsequent spread of alphabetic writing culture throughout the Greek world and in the Italian peninsula.[31] Compared to earlier writing systems of western Eurasia, the Greek alphabet appears to have been easily accessible to a much larger group of people: as it was relatively easy to learn how to read and write, the use of the alphabet did not remain restricted to professional scribes, as had mostly been the case in the Near East and Egypt.

Equally fundamental to the alphabet were the improvements in writing technology and, particularly, the emergence of a range of lightweight, durable, and portable media that could be used for transmitting knowledge. From the early 1st millennium BCE onwards, Greeks began to write in ink on Egyptian papyrus scrolls, but due to the scarcity of papyrus in the Mediterranean, papyrus never became the dominant writing medium. By the Hellenistic period, Greeks had perfected the process of making parchment, and by the (later) Roman imperial period, the invention of the codex made it possible to quickly navigate extremely long documents and to store large amounts of information in a durable way. Additionally, several media for shorter documents were developed, such as wax tablets, which were widely used for personal correspondence and contracts. For everyday writing, scratching remained more common than ink.

The result of these innovations, in the long run, was both a substantial democratization of written communication—a larger number of people were able to read and write—and a significant broadening of writing practice—writing was used in support of a much broader range of social, cultural, and economic processes. Even if literacy rates are thought to have remained relatively low, Graeco-Roman writing culture was instrumental in facilitating reliable communication over longer distances and thus played a crucial role in (Roman) imperial governance and in the economy.

Discussion

The Graeco-Roman Mediterranean saw, besides the adoption of technologies and practices developed in the Near East and Egypt, significant, sustained, and widespread innovation in many fields of everyday technological practice. While the impact of this innovation on economic growth or living standards may have remained limited and remains mostly unmeasurable for modern scholars, new or improved technological practices transformed landscapes, material culture, and everyday social and economic processes, and they sometimes did so beyond recognition, even if the nature of invention and innovation in Graeco-Roman antiquity cannot be easily understood in modern (economic) terms.

Historically, much innovation in everyday technological practice was both a product of Graeco-Roman urbanism and a factor in its growth: many innovations either made it possible to serve the needs of urban populations more efficiently or enabled the production of higher-quality products associated with urban consumer culture; as far as scale and distance are concerned, innovation also was facilitated by (and contributed to) the increased economic and political integration of the Mediterranean, which saw the emergence of economic networks with key agents—both states and individuals—of unprecedented economic power.

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