A World of Glass

Alan Macfarlane and Gerry Martin

This year's essay series highlights the benefits that scientists, science, and technology have brought to society throughout history.

Anyone who has looked at the long-term history of human civilizations over the last 50,000 years will notice that one of the most significant transformations took place during the period 1200 to 1850. This transformation affected two of the most important human capacities: the way in which we think and our sense of sight. Compare the nature of painting in Europe in 1200 with that in 1850, or the amount of chemical, physical, and biological knowledge in Europe in 1200 to that in 1850, and one would not hesitate to pronounce that a revolution took place within this 650-year period. This revolution manifested itself not only in the world of art and architecture, but also in transport, housing, energy sources, agriculture, and manufacturing.

Improvements in glass production contributed to the sweeping changes that engulfed Europe from 1200 to 1850.

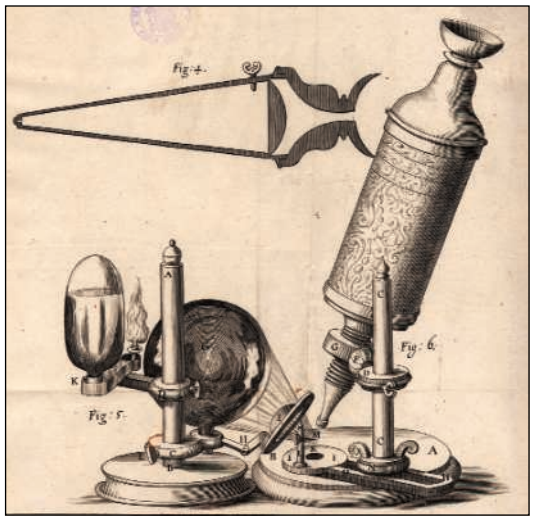
We know that all this happened, but after that there is little agreement. We are still uncertain as to why the Renaissance of the 14th, 15th, and 16th centuries, and the scientific and industrial revolutions of the 17th and 18th centuries took place. Nor do we understand why these sweeping changes happened in western Europe, and not in the great Islamic or Chinese civilizations.

The interplay between the availability of more reliable information and the improved manufacture of tools, instruments, and artifacts contributed to the remarkable changes that swept through western Europe. Often in history, we witness the generation of new knowledge through experimentation, which then leads to significant innovations and a richer appreciation of new or improved physical artifacts. These artifacts, if they are useful, in demand, and relatively easy to produce, are often disseminated in large quantities. These objects then change the conditions of everyday life and may fund further theoretical explorations. Such artifacts can do this in two ways: by generating wealth that funds increased efforts to acquire fresh knowledge and by providing better tools for scientific enquiry.

Historically, this triangle of knowledge–innovation–quantification emerged in many spheres of life, most notably in agriculture. The loop is enduring when artifacts are widely disseminated and is a cumulative process. The speed of movement around the triangle and the frequency of its repetition provide a measure of the development of human civilizations. Our analysis of this triangle in the history of glass production and application reveals that glass contributed to the rampant changes that swept through western Europe between 1200 and 1850.*

A Brief History of Glass

No one is certain where, when, or how glass originated. It may have appeared first in the Middle East in regions such as Egypt and Mesopotamia around 3000 to 2000 B.C. although there are hints of glazing on pottery as early as 8000 B.C. Glass was almost certainly discovered by accident—so the Roman historian Pliny (A.D. 23–79) tells us—by Phoenician traders, who apparently noticed that a clear liquid formed when the nitrate blocks on which they placed their cooking pots melted and mixed with sand from the beach. Egyptian craftsmen developed a method for producing glass vessels around 1500 B.C., and the first manual of glassmaking appeared on Assyrian stone tablets about 650 B.C. About 2000 years ago, Syrian craftsmen invented glassblowing, a skill adopted by the Romans, who carried it with them as they swept through western Europe on their conquests. The rise of Venice to prominence in the 13th century enabled this city to become the center of glassmaking in the western world. As the industrial revolution gathered momentum, new manufacturing technologies enabled the mass production of glass scientific instruments, bottles, window panes, and many other items.



Through a glass brightly. The compound microscope used by Robert Hooke enabled him to produce one of the first illustrated books of microscopic objects. The book, *Micrographia*, published in London in 1665, helped to launch discoveries that led to the development of germ theory and the founding of infectious disease research. Hooke's compound microscope revealed a world invisible to the naked eye, which only scientists—with the help of glass—could probe. [Reproduced from the first edition of *Micrographia*, 1665]

The Many Uses of Glass

Historically, glass has been used in five different ways, which varied depending on the locality. Glass beads, counters, toys, and jewelry were produced almost universally throughout Eurasia before 1850, with glass becoming a substitute for precious stones. The great developers of glass vessels, vases, and containers were the Italians, first the Romans and later the Venetians. The use of glass vessels was largely restricted to the western part of Eurasia until the 1850s, with little evidence of use in India, China, and Japan. In the Islamic territories and Russia, the use of glass declined dramatically from about the 14th century until modern times due to the Mongol incursions.

Another crucial use of glass was for making windows. Until the 20th century, window glass was found mainly in the western regions of Eurasia (principally north of the Alps), appearing rarely in China, Japan, and India. Another application of glass depended on its reflective capacity when silvered. Produced by the Venetians in

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the 16th century, the use of glass mirrors spread throughout the whole of western Europe, but appeared rarely if at all in Islamic civilizations or in India, China, or Japan. A final critical application of glass was in the production of lenses and prisms. This led to the manufacture of spectacles to improve human sight; eyeglasses first appeared in Europe during the 13th and 14th centuries. The concept of the light-bending and magnifying properties of glass, discovered by the Chinese in the 12th century, was probably known to all Eurasian civilizations. Yet only in western Europe did the practice of making lenses really develop. This coincides precisely with the surge in interest in optics and mathematics during medieval times, which fed into other branches of learning, including architecture and painting.

The reasons for the different uses of glass in different parts of the world may be largely accidental, reflecting variations in climate, drinking habits, availability of pottery, political events, and many other characteristics. Intention, planning, individual psychology, superior intellect, or better resources seem to have little to do with it. Yet these accidents instigated the move of western European societies around the knowledge–innovation–quantification triangle. Improvements in glassmaking and the production of more sophisticated glass instruments yielded more accurate information about the natural and physical worlds, which fed back into refinements in glass manufacture and, hence, in glass quality.

Glass and Scientific Knowledge

Glass helped to accelerate the amazing acquisition of knowledge about the natural and physical worlds by providing new scientific instruments: microscopes, telescopes, barometers, thermometers, vacuum flasks, retort flasks, and many others. Glass literally opened people's eyes and minds to new possibilities and turned western civilization from an aural to a visual mode of interpreting experience. We randomly picked 20 famous experiments that changed our world—Thomson's discovery of electrons, Faraday's work on electricity, and Newton's splitting of white light into its component colors with a prism, for example—and found that 15 of them could not have been performed without glass tools. That the knowledge revolution of the last 500 years took place in western Europe and not elsewhere, can be attributed in part to the collapse of glass manufacturing in Islamic civilizations and its diminished importance in India, Japan, and China.

The list of scientific fields of enquiry that could not have existed without glass instrumentation are legion: histology, pathology, protozoology, bacteriology, and molecular biology to name but a few. Astronomy, the more general biological sciences, physics, mineralogy, engineering, paleontology, vulcanology, and geology would have emerged much more slowly and in a very different form without the help of glass instruments. For example, without clear glass, the gas laws would not have been discovered and so there would have been no steam engine, no internal combustion engine, no electricity, no light bulbs, no cameras, and no television. Without clear glass, Hooke, van Leeuwenhoek, Pasteur, and Koch would not have been able to visualize microorganisms under the microscope, an achievement that led to the birth of germ theory and a new understanding of infectious disease, which launched the medical revolution (see the photograph on page 1407).

Chemistry depends heavily on glass instrumentation. Thanks to glass, European scientists elucidated the chemistry of nitrogen and learned to fix this gas in the form of ammonia to produce artificial nitrogenous fertilizers, a huge step forward in 19th- and 20th-century agriculture. Without glass, there would have been no means of demonstrating the structure of the solar system, no measurement of stellar parallax, no way of substantiating the conjectures of Copernicus and Galileo. The application of glass instruments revolutionized our understanding of the universe and deep space, completely altering our whole concept of cosmology. Furthermore, without glass, we would have no understanding of cell division (or of cells), no detailed understanding of genetics, and certainly no discovery of DNA. Without spectacles, most individuals over the age of 50 would not have been able to read this article. Glass may be an unforeseen accident, but it follows a predictable pattern of movement around the triangle: deeper reliable knowledge enabling the manufacture of innovative artifacts followed by their mass production.

Glass in Everyday Life

We have discussed the contributions of glass from the scientific perspective. But from 1200 onwards, all knowledge was interconnected. Without mirrors, lenses, and panes of glass, the startling changes that marked the Renaissance would not have taken place. A new understanding of the laws of optics, and the accuracy and precision of paintings by Da Vinci, Durer, and their contemporaries largely depended on glass instruments of various kinds. The divergence of world art systems between 1350 and 1500 is impossible to imagine without the development of very high quality glass by the Venetians. Glass in the form of church stained-glass windows affected what we believed; in the form of mirrors, it affected how we perceived ourselves.

Glass, however, is not just a tool to think and perceive with, but also a tool to improve everyday life. The period between the 13th and mid-19th centuries in Europe saw many changes made possible by glass that contributed not only to the intellectual flowering of this era but also to an improved standard of living for many people. For example, glass in the form of windows lengthened the working day and improved conditions for workers. Glass let light into interiors allowing house dirt to become more apparent leading to improvements in hygiene and health. Also, glass is a tough, protective surface that is easy to clean. Glass windows wrought changes not only in private homes, but also in shops with shopkeepers eventually placing much of their produce and merchandise behind glass windows and under glass cabinets.

This clear molten liquid began to transform agriculture and horticulture. The use of glass houses to promote the precocious growth of plants was not an invention of early modern Europe. Indeed, the Romans used forcing houses to promote plant growth and protected their grapes with glass. The Roman idea was revived in the later Middle Ages, when glass pavilions for growing flowers and later fruit and vegetables began to appear. As glass became cheaper and, particularly, flat window glass improved in quality, many more applications appeared. Glass cloches and greenhouses improved the cultivation of fruit and vegetables, bringing a healthier diet to the population. In the 19th century, glass made it possible to bring plants from all over the world to enrich European farms and gardens.

There are many other useful applications of glass that altered everyday life from the 15th century onward. Among them were storm-proof lanterns, enclosed coaches, watch-glasses, lighthouses, and street lighting. The sextant required glass, and the precision chronometer invented by Harrison in 1714, which provided a solution to calculating longitude at sea, would not have been possible without glass. Thus, glass directly contributed to navigation and travel. Then, there was the contribution of glass bottles, which increasingly revolutionized the distribution and storage of drinks, foods, and medicines. Indeed, glass bottles created a revolution in drinking habits by allowing wine and beer to be more easily stored and transported. First through drinking vessels and windows, then through lanterns, lighthouses, and greenhouses, and finally through cameras, television, and many other glass artifacts, our modern world has emerged from a sea of glass.

The different applications of glass are all interconnected—windows improved working conditions, spectacles lengthened working life, stained glass added to the fascination and mystery of light and, hence, a desire to study optics. The rich set of interconnections of this largely invisible substance have made glass both fascinating and powerful, a molten liquid that has shaped our world.

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