N.B. This is a very rough, preliminary, draft of the book which was finally published as 'The Glass Bathyscaphe: How Glass Changed the World' by Profile Books, London,2002. This draft was completed about nine months before the final book. Many arguments are provisional, the footnotes have not been checked, the order is different. But it does contain many bibliographical details and quotations which were excluded from the final published work. It may therefore be useful for those who wish to pursue the matter further or to know the background to certain statements in the published work.

PUZZLES AND CLUES

If one asks what have been the half dozen greatest transformations in the field of human knowledge, both in content and form, there can be little doubt that the Renaissance and the Scientific Revolution would be among those selected. Along with the discovery of language and writing, the enormous transformation in the technologies of thought that occurred between about 1300-1700 A.D. are clearly of enormous importance.[1] Upon them has been built a new technology of industrialism, a new social system, new communications networks, a new political system and the global culture which we now experience. The effects of what has happened in the very recent past, looking at human history as a whole, and first happened in only one corner of the world are dramatic indeed. Yet when we ask the question of why one of the great changes in human history occurred it is difficult to find any satisfactory answers.

Before we start on sketching out a new approach to this large puzzle, it is worth asking for some definitions of what, more precisely, we are trying to explain. Firstly there is the question of what exactly we mean by the 'Scientific Revolution' and the Renaissance. The 'scientific revolution' needs, in fact, to be split into two revolutions. The earlier one occurred roughly between 1250 and 1400 and consisted of several features including the absorption of Greek learning by way of Arabic scholars, the development of universities, the improvement of logical tools, a growing concern for precision and accuracy, the growing sophistication of mathematics chemistry, physics and in particular optics, a growing emphasis on the authority of observed visual evidence rather than the authority of the ancients as written in texts. As A.C.Crombie and others have argued,[2] this first revolution laid the necessary foundations, including the experimental method and method of scepticism, doubt and suspended judgment, for the more famous scientific revolution which is usually dated from the 1590's (Bacon, Galileo) through to the later seventeenth century (Hooke, Boyle, Newton). This second scientific revolution explicitly laid out the scientific project as we know it, with its use of scientific instruments in order to gain very large quantities of new reliable knowledge.

If we broaden the definition of the scientific revolution in this way we can see that it was not

[1] For excellent accounts of the importance of these transformations, see Jaspers, XXX and Gellner, XXX

[2] See XXX

just a sudden break-through, but had its roots deep in classical thought, which, combined with Arabic advances, flowered in the work of medieval thinkers such as Roger Bacon. We are thus dealing with something which covers half a millenium, from about 1200-1700. Likewise the geographical range is very wide for it was spread over western Europe. As regards the comparative question, the view of all those who have thought deeply about developments outside Western Europe is that while bits and pieces were found elsewhere, the whole set of interconnected parts was uniquely found in Western Europe. As Joseph Needham asked in the first volume of **Science and Civilisation in China**, 'Why... did **modern** science, the tradition of Galileo, Harvey, Vesalius, Kepler, Newton, universally verifiable and commanding universal rational assent... develop round the shortes of the Mediterranean and the Atlantic, and not in China or any other part of Asia?'[3]uff and others have devoted great efforts to trying to ascertain why, despite a much more sophisticated earlier tradition, one cannot speak of any sustained scientific revolution in Chinese or Islamic civilization, let alone in India, Russia or Japan.[4]

Thus there is a puzzle. Why did this great event which transformed human vision and understanding happen then (1200-1700), there (parts of western Europe) or at all? There was clearly nothing inevitable about it. Indeed, greater civilizations with more sophisticated technologies and social structures showed few signs of having such a revolution.[5] It was clearly an event which changed our world, so why did it happen?

If we turn to what we call the Renaissance, again we need to define, place and date it. It is conventionally thought of as occurring in the arts (painting, architecture, literature) and to have a set of features which include the following. There was a growing precision of observation and representation, the mathematization of the rules of painting and architecture, the development of methods to represent perspective so that three dimensional space could be convincingly depicted on a two-dimensional surface, growing realism in the portrayal of nature, new architectural and poetic devices which gave increased intensity and power, new concepts of the individual and his or her place in the universe, and a new concept of time.

Once these characteristics are listed, we can easily see how the set of attributes overlaps greatly with the scientific or knowledge revolution. This overlap is nowhere better represented than in the work of Leonardo da Vinci, both a 'scientific' and a 'Renaissance' genius. It is easy to see that both movements are basically about the extension of reliable knowledge. Gains in one sub-field, for example mathematics or the representation of three dimensional space, soon feed back into the others. The most obvious example of this is in the field of optics, which was the foundation discipline in both the early scientific revolution and Renaissance art.

The Renaissance in these senses started in the same period as the first scientific revolution, that is about the middle of the thirteenth century and it extended up to about the start of the second phase of the scientific revolution, that is up to about 1600. The area in which it occurred was roughly the same, with a particular locus in northern Italy and north-western Europe. It was

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[3] Needham, Science, I, 19, quoted in Crombie, Science, Optics, 41; Crombie quotes Einstein's famous answer to the same question also.

[4] give refs. to work of Bernal, Huff, Lindberg, Needham et al.

[5] See, for example, XXX - Huff, Needham and others on the 'Needham problem, and perhaps diag. of Needham.

not to be found in any civilization outside Western Europe.

If this characterization is correct, namely that the scientific revolutions and the Renaissance were really all part of one phenomenon, that they were manifestations of one tremendous development, then it is sensible to stop differentiating them, just as it is profitable to suspend the distinction between the first and second scientific revolutions. So I shall unite all these major developments, following John Ziman's term for science as 'Reliable Knowledge'.[6]

* * *

Having done this, we can see that in order to explain why the Reliable Revolution occurred, any explanation has to meet certain criteria. Since its start was roughly about the middle of the thirteenth century, an explanation must contain elements which were present from that date. Hence the invention of the printing press or the discovery of the New World are too late to be the original cause, though they may sustain and expand the movement. Then again, an explanation must suggest factors which grew rapidly after about 1200, being largely absent or muted before. Furthermore, whatever the factors, they must be particularly strongly present in both Italy and north western Europe, for the Reliable Revolution occurred simultaneously in these two areas. Furthermore, using the comparative method, the factor or factors must be largely absent in all other civilizations, where the Reliable Revolution did not occur at this time. Finally, co-existence or co-incidence is not enough. It must be possible to show how the factor or factors actually produced the central feature of the Reliable Revolution. That is to say, how could it or they have directly or indirectly encouraged a more precise, realistic and detailed knowledge of nature, helped give the basis for the rules which made the representation of nature more accurate, and stimulated curiosity and confidence in the pursuit of this objective?

Judged by these demanding criteria we can go through the various explanations which have been advanced by numerous writers to solve these puzzles in order to see how far they meet these tests. If we leave on one side for the moment the deeper philosophical and cultural factors which provided an indispensable basis for what happened, it is worth listing the most likely candidates which could be contenders for an explanation. These include the following: the mechanization of the world view through the development of machines; specific legal traditions (e.g. Roman and Common Law); the growth of particular types of city; a particular social structure emphasizing the middling sort; trade and exploration; a plural and yet culturally united civilization; the development of commercial capitalism; the development of logical and rhetorical methods; the improvement of methods of storage and dissemination of information (e.g. printing); universities ; tools of time (clocks); arts of memory; tools of measurement and calculation; networks of knowledge.[7]

Clearly all of these are important, and I shall discuss these, and other theories, in the conclusion to this book. But for the time being we can short circuit the discussion by stating that few of them seem to meet all of the criteria set out above. Probably the three most promising are mechanical clocks, universities and other corporate institutions, and a particular fragmented yet

[6] Ziman, **Reliable Knowledge**.

[7] Some references for sources for these ideas. xxx

unified political and economic system. Perhaps the best fit so far is the one which Toby Huff put forward, having surveyed and rejected other explanations, that is forms of corporate, knowledge generating, institutions which we call universities were peculiar to the West.[8] They may well be a necessary ingredient, but it would seem likely that there are too many other things needed to believe that universities alone could explain the work of Alberti, Durer, Leonardo da Vinci or Galileo. Furthermore, Huff's specific link to the importance of Roman Law fails to account for the important English case, where a major centre of scientific work in the thirteenth century was situated in a Common Law environment which explicitly rejected revived Roman Law. Likewise, the theories which link mechanical clocks to a new view of precision are attractive.[9] The recent work of Crosby on the more precise tools of thought developed in measuring and recording is also intriguing.[10] While behind all of this a number of arguments concerning the diversity, yet unity, of the political and cultural landscape of western Europe are also very suggestive. [11]

Yet there still seems to be something missing. We have a picture of many of the pre-conditions, yet what tied them together and allowed one civilization to move toward new systems of thought still seems to elude us. So where else should we look? If we were detectives, we might look for something that has been overlooked because it is too obvious, staring one in the face.

It takes a genius to see the obvious and we find such a genius in Lewis Mumford. Mumford's work is largely overlooked nowadays , but in a series of important books he mapped out the history of technologies, or what he called technics, and their impact on civilization.[12] Of particular interest to us here is his account of the medieval technologies that affected thought. When he briefly summarizes the effects of the three great 'Radical Inventions' in the medieval period, it is glass which he starts with[13]. In his major account of the subject he starts by writing that 'most important of all was the part played by glass in the eotechnic economy. Through glass new worlds were conceived and brought within reach and unveiled.'[14] He devotes six and a half pages to glass and only just over two pages to printing and its effects and less than a page to clocks.

It is his suggestive insights into the role of glass in science, art, psychology and daily life that largely inspired my interest in the subject. I shall draw on his seminal ideas throughout the following pages. When perhaps the greatest historian of the relations between technics and thought provides such an intriguing case for considering the impact of glass, we might have expected there to have been a wide range of subsequent work. Yet there is very little published along the lines which he suggested.[15] Why should there be such a deafening silence? Why has it

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[8] Huff, XXX

[9] E.g. Landes...

[10] Crosby, xxxx

[11] E.g. John Hall, Powers...

[12] Cf. works of Mumford....

[13] Mumford, Myth, 284

[14] Mumford, Technics, 124

[15] A very brief exception is the one and a half pages under 'Murano' in Norman Davies acclaimed **History of Europe**, pp.xx, which is largely based, it would seem, on Mumford.

taken so long for the strikingly obvious to be investigated in some depth?

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It could be argued that it is a curious feature of all technologies that while they alter and shape our world, they are very difficult to study. Being extensions of humans, they somehow become confounded with us and it takes an effort to separate them and study them in their own right. This is particularly true of technologies of the mind, that is those which shape the way we see and think. While it is not too difficult to discuss the effects of guns or ploughs, the impact of new mental technologies, effecting our very brains, are difficult to grasp. They subtly shift our world views without us being aware of it. This is one of the reasons why we are so confused about the impact of recent technological revolutions which clearly alter our world, in particular in computing and television.

Yet this cannot be the only reason, for Mumford's other two technologies of the intellect have been studied in considerable depth since his work was published. In the case of clocks, the single most striking account is David Landes magisterial work on **Revolutions in Time**, but there have been many other works. It is now widely admitted that there was a revolutionary change in the perception of time with the rise of the mechanical clock, and that this, for a long period, was limited to western Europe. The reasons for the development of clockwork and clock time and the immense consequences are widely discussed. Without clocks, the development of commercial capitalism, exploration of the world and the development of science and engineering would either not have occurred or been profoundly different.[16]

Likewise since Mumford there has been a growing literature on the social effects of printing. Again there is one central magisterial work, the two volumes by Elizabeth Eisenstein on **The printing press as an agent of social change**. Again this is supplemented by a very large literature on the differential impact of printing, from the famous early theories of Marshall Mcluchan on the **Gutenberg Galaxy** to much more recent work on the comparative history of printing. It is widely acknowledged that printing, like clocks, profoundly altered the western world, leading to changes in religion, politics, art, science and so on. Without printing, people argue, the Renaissance, the Reformation, the Scientific Revolution, the nation state would have either not occurred or been very different.[17]

Yet if we look at the literature in the field of the social history of glass (leaving on one side the excellent set of works on the aesthetics, chemistry, technology and so on of glass) there is scarcely anything of note in the field. If we ask what book we could recommend to an interested reader roughly in the field of 'the anthropology of glass' there is nothing. We shall come across insightful articles and parts of books on particular aspects of the history of glass, on mirrors, on the impact of glass instruments in Japan, on medieval optics. But while it is easy to recommend to a student two or three really good overviews of the social history of clocks or printing, nothing similar exists in relation to glass. Why should this be the case? Why is it even more invisible than other thought technologies?

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[16] On effects of clocks, see XXX

[17] On nationalism, for example, see Anderson's theories on the effects of 'print-capitalism' in **Imagined Communities**.

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One reason lies in the substance itself. Glass is so very strange. Not only do we usually look through it, but when we do notice it we find it difficult to place since it slips and slides between categories. But this, of course, is also one source of its great attraction and power. For glass is indeed a very mysterious substance. One author puts the puzzle thus. 'Glass to anyone who is not a chemist is a mystery. Why should opaque and gritty materials like sand, soda and lime, when mixed together in certain proportions and fired, produce the crystal clear, smooth and impervious substance called glass, which can be adapted for so many different uses?'[18] But even chemists find it defies their classifications. Technically it seems quite simple. 'Glass is a rigid but non-crystalline substance, usually transparent. It is made by fusing together alkalis (or their salts), lime, and sand (or flint). It is a mixture of silicates of alkalis (soda or potash) and alkaline earths...'[19] Yet the product is anomalous, unlike all others. 'The properties of glass, neither true solid nor true liquid, make it one of the most versatile materials manufactured by humankind. It has been described as a fourth state of matter, in addition to solids, liquids and gases: a super-cooled liquid, completely fluid at high temperatures, flowing less and less as it cools, until it becomes strong enough to hold its shape for centuries.'[20] Faraday described it as a 'solution of different substances'. Perkowitz comments that 'because the molecules are disordered, it is not yet possible to predict the optial properties of glass from a quantum model for all the linked atoms of the material.'[21]

For a very long time it baffled scientists. 'Unlike many solid substances, glass shows no trace of crystalline structure under the microscope and until recent years it was thought to be completely amorphous.'[22] Its mysterious nature was further shown by watching it as it cooled. 'Further evidence that glass is essentially a 'structureless' material is to be found in the temperature-time curves which are obtained when glass is cooled from the molten to the solid condition.'[23] It is thus defined by some as 'a super-cooled solution in which the molecules have been immobilized by a very large increase in the viscosity.'[24]
Vose writes that 'A sheet of glass can be regarded as one large molecule, which explains why it is transparent: a ray of light passing through it hits only two optical boundaries, with a a light loss of only eight to ten per cent.'[25]

McGrath further summarizes some of its properties as follows: 'With regard to the properties which are usually considered its most characteristic are its durability, transparency and brittleness.'[26] Let us look at each of these. As regards brittleness, this is its one weakness. As is

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[18] Things, 180-1
[19] Singer, II, 312
[20] Allen, Roman Glass, 6
[21] Perkowitz, Empire of Light, 139-40.
[22] McGrath, Glass in Arch., 424
[23] McGrath, Glass, 424
[24] McGrath, Glass, 425
[25] Vose, Glass, 21
[26] McGrath, Glass, 425

well known, 'Glass is a bad conductor of heat. When boiling water is poured into a glass vessel, the vessel frequently breaks, on account of the unequal expansion of the inner and outer layers.'[27] This had long been seen as its major weakness, and it was of considerable symbolic as well as practical interest. As a sixteenth century technical author put it: 'Considering its brief and short life, owing to its brittleness, it cannot and must not be given too much love, and it must be used and kept in mind as an example of the life of man and of the things of this world which, though beautiful, are transitory and frail.'[28]

As for durability and flexibility, it was second to none. 'The fluidity of glass at a high temperature renders possible the processes of ladelling, pouring, casting and stirring. A mass of glass in a viscous state can be rolled with an iron roller like dough; can be rendered hollow by the pressure of the human breath or by compressed air; can be forced by air pressure, or by a mechanically driven plunger, to take the shape and impression of a mould; and can be almost indefinitely extended as solid rod or as hollow tube. So extensible is viscous glass that it can be drawn out into a filament sufficiently fine and elastic to be woven into a fabric.'[29]

Another description which does justice to its extraordinary versatility is worth quoting at length, since unless we understand what an unique substance it is, unlike all others, we will not begin to comprehend how it may have been one of the three most important technical developments in human civilization, on a par with fire and the wheel, but coming much later and hence deeply implicated in the second great revolution in human civilization which we believe to be at the root of the modern world, namely the Renaissance and the Scientific and Industrial revolutions. McGrath writes that glass 'can take any colour and, though possessing no texture in the ordinary sense of the word, any surface treatment. As for responsiveness to light and shade, it has no serious competitor. It is capable of extreme finish and delicacy, is clean, durable and compact, may be graduated almost imperceptibly from transparency through translucency to opacity, from perfect reflection through diffusion to the completely matt surface. There is, in fact, hardly any surface quality that it cannot assume. Yet at the same time it has a highly characteristic nature and in whatever manner we treat it or whatever surface we impose upon it, it still retains that unmistakable 'glassiness'. Whether it is embossed, engraved, painted, sand-blasted, mirrored, impressed with any pattern we choose, moulded, blown, flashed and so on - there is almost no limit to what it will endure or to the possible permutations and combinations of the different treatments - its vitreous qualities remain its decorative **raison d'etre**.'[30]

Our sense of wonder at its properties is captured by one of the great historians of glass, W.B.Honey. His passage is worth quoting because, as we shall see, much of the early history of glass was concerned not with its utility, which only later became apparent, but its beauty. It developed largely to satisfy man's craving for aesthetic delight, and then, through one of those great accidents of history, its light-bending capacities turned it into man's most important avenue to truth about the natural world. It is a wonderful illustration of Keats' famous assertion: 'truth is beauty, beauty truth'.

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[27] Enc.Brit., 'Glass'

[28] De Pirotechnia, 132

[29] Enc. Brit., 'Glass'

[30] McGrath, Glass in Arch, 297

Honey writes as follows. 'Glass is nowadays too familiar to arouse all the wonder it deserves. Intrinsically wonderful as the product of mere sand and ashes it may be the occasion of further miracles when made into vessels. For its beauty never seems to be wholly the result of calculation. Its forms may be designed and controlled, its colour may be named and secured by a percentage of oxides; but beyond all these there is a quality in the material that defies prediction, and the play of light and colour within it, its insubstantial air, and the 'pattern of a gesture' which its form so often quite literally records, are only the chief elements, perhaps, in the beauty it may assume at the will of the artist.'[31] It was the major extension to the human eye and hence the human brain, and it also played on the human love of pattern and colour. Furthermore 'It is impermeable to water and resistant to attack by the ordinary weathering agencies: it has a brilliant surface which can readily be kept clean: and above all, it lends itself to large-scale production in a variety of forms ranging from thin sheets to massive structural units.'[32]

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Another reason for the lack of interest in the social history of glass is that in some ways its development seems, at first sight, unproblematic and is thought to be uniform. We think we know all about it already. Because glass as a technology of thought has not attracted much comparative attention, most of us believe, as I did before I started this work, that the development of glass was roughly similar over most of the world. Pushed to describe such a history a few years ago, I would have assumed that, having been invented some thousands of years ago, it spread all over Europe and Asia, was used in roughly the same ways and same extent, and so flowed up to the present. I might have been dimly aware that it reached a peak in Venice during the Renaissance, but otherwise it seemed a universally useful and available substance.

Assuming this, it did not make sense to use its presence or absence in different cultures or times to explain much. It would be like trying to explain cultural or social phenomena by differences in its sister substance, water. One of the purposes of this short book is to destabilise this received wisdom and to share my surprise and wonder at discovering that glass has been practically non-existent in almost all civilizations and that its role varied enormously over time and space. This comparative approach immediately makes it an amazingly interesting substance. We can no long assume that once it has been invented it will be used, and we can begin to ask what it means to be without glass, or to give up its use as some civilizations have done.

Another reason for the ignoring of glass has already been alluded to, which is that most of us are so strongly surrounded by glass, in the form of windows, mirrors, drinking glasses, spectacles, lenses (television and photography) and so on, that it has become invisible. This is helped by the fact that like air, at its best, it is translucent. It takes a real effort to bring it back into focus. A second aim of this book is to restore something of that sense of wonder and surprise at something so obvious and all-surrounding. As McGrath writes, 'Glass has, in fact, reached a point where even its remarkable versatility almost ceases to astonish. It has reached the point where its absence is more noticeable than its presence. It has arrived.'[33]

[31] Honey, Glass, 1

[32] McGrath, Glass, 425

[33] McGrath, Glass in Arch., 20

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It is really very difficult to arouse a sense of the wonder of glass except by travelling very widely in time and space and by treating glass in all its manifestations. Only then will be we begin to get a sense of its power and magic. What I hope to restore is that sense of its astonishing nature which is so wonderfully captured by Dr Johnson in the eighteenth century in a superb overview of many of the social implications of glass.

'"Who when he first saw the sand and ashes by a casual intenseness of heat melted into a metalline form, rugged with excrescences and clouded with impurities, would have imagined that in this shapeless lump lay concealed so many conveniences of life as would, in time, constitute a great part of the happiness of the world. Yet by some such fortuitous liquefaction was mankind taught to procure a body at once in a high degree solid and transparent; which might admit the light of the sun, and exclude the violence of the wind; which might extend the sight of the philosopher to new ranges of existence, and charm him at one time with the unbounded extent of material creation, and at another with the endless subordination of animal life; and, what is of yet more importance, might supply the decays of nature, and succour old age with subsidiary sight. Thus was the first artificer in glass employed, though without his knowledge or expectation. He was facilitating and prolonging the enjoyment of light, enlarging the avenues of science, and conferring the highest and most lasting pleasures; he was enabling the student to contemplate nature, and the beauty to behold herself.' [34]

Here we have a lightning sketch of so many of the themes of this book. There is the accidental nature of the discovery. There is the recognition that 'a great part of the happiness of the world' has arisen from this huge accident. The contradictory nature of the substance, its abilities to let through light but not sun; its importance in philosophy and science, in lengthening our reading life and in the beauty it portrays, all are alluded to. As a sixteenth century author put it, 'Certainly it is a very beautiful thing and one that should not be left buried in silence, in consideration first of how great a thing art has been able to discover, and then because its beauty makes it such a pleasing thing for making drinking glasses and an infinite number of other ornamental things that satisfy the desires of man.'[35]

As I have mentioned, to get glass into perspective requires one to go back ten thousand years and over the whole known globe. This is not easy, and the difficulty is compounded by the fact that glass must be approached through many different disciplines. Each of these has tended to see a part of the enigma of glass, like the blind philosophers and the elephant, each of whom only touched one part of the beast. The lack of an inter-disciplinary overview means that the total picture is absent. This is well illustrated by displays of glass in museums. When researching this book, I went to look at the fine collection in the Victorian and Albert Museum in London and the Fitzwilliam Museum in Cambridge. These only displayed fine drinking glasses and mirrors, In the National Science Museum and Whipple Museum dedicated to the History of Science and Philosophy, there was only lenses and prisms. The British Museum just showed archaeological and art objects, almost exclusively imitation jewellry and glass containers. None of them dealt with windows and it was only the presence of King's College chapel with its wonderful medieval stained glass which reminded me of one of its central roles in history. The intercon-

[34] McGrath, Glass in Architecture, 5

[35] De Pirotechnia, p.126

nections between the different parts of history of a world made of glass world were missing. Only by moving from one to another and assembling all their collections in a virtual memory museum, could one begin to put together the shattered history of this marvellous substance. Likewise a recent compact disc on glass scarcely covered more than a tiny part of its real history, dealing exclusively with jewellry and glass utensils and having nothing on mirrors, lenses and windows. [36]

Thus we only have the fragments of an account scattered in the work of historians of art, historians of technology, historians of science, anthropologists, economic historians, biologists, chemists and in the remaining objects in museum collections and the windows of magnificent buildings. Anyone who hopes to bring glass into focus thus has to travel lightly through many disciplines. This is the only way to proceed though one is bound to make mistakes. Yet while the course of good sense is to remain within one's competence, it seems more fruitful, if only of productive errors, to try to move across disciplinary boundaries. This means that I am heavily dependent on experts in other disciplines and hence my rather frequent quotation of work which I could not possibly have done myself.

A final reason why there is a huge gap in the literature lies in the difficulty of proving anything. Glass is such a complex substance and its influence so little understood, that it is very difficult to prove any of its effects. We sense that the mirror shaped our notions of the individual; but it is impossible to prove. We sense that lenses changed optics and hence profoundly affected the Renaissance, but it is impossible to prove. All that we can do is suggest connections, elective affinities as Max Weber might have called them, which seem plausible and possibly satisfying. These will generate further work of refutation or confirmation, but we are not yet in a position to do more than suggest tentative links. Many academics are rightly wary of so much guesswork. All I can urge in my defence is a remark of the great French mathematician H. Poincare: 'guessing before demonstrating! Do I need to remind you that this was how all important discoveries are made?'[37] This book full of guesses; I hope it will stimulate others to investigate the degree to which they are demonstrably true or false.

[36] Corning Museum CD on glass.

[37] Quoted in Ramuni, Amsterdam Conf.,14