Revolutions: agricultural, industrial and scientific

The date of the Agricultural Revolution—when mankind changed its previous hunting and gathering mode of existence into one of settled cultivation of crops and domestication of animals—is still somewhat controversial.[1] Commonly it is considered to have occurred around 10,000 BC (also called the Neolithic Revolution). Recent evidence suggests that agriculture may have started more than 10,000 years earlier [2]. As C.P. Snow has remarked, "these two revolutions, the agricultural and industrial–scientific, are the only qualitative changes in social living that men have ever known" [3]. The settlement that was the corollary of agriculture gave us villages, towns and cities, without which the development of civilization is inconceivable.

The Industrial Revolution, starting about a hundred years after the British Agricultural Revolution,[1] and in which Britain was also the pioneer, saw an even more dramatic increase in the output of material goods, compared with the preceding era of craft industry. In this revolution, the key innovations were engineering, especially mechanical (i.e., the development of machines) and the organization of men and women in an industrial system.

Although conventionally the Industrial Revolution is often stated to have been "science-based", even a rather cursory examination of the evidence shows that the science followed, often with great lag.[2] The machines were developed, at least initially, by artisans rather than engineers.[3] Hence there was continuity of familiarity, but the organization of human beings within industry was of a wholly new type and baffling to a society used to the strict hierarchies of armies, churches, courts and government officials.[4]

In his 1959 Rede lecture, C.P. Snow introduced the idea of a further profound change, starting around 1920, which he called the Scientific Revolution. He defined it roughly as "the time when atomic particles were first made industrial use of ... the industrial society of electronics, atomic energy, automation, is in cardinal respects different in kind from any that has gone before, and will change the world much more" [3]. As I have pointed out elsewhere [6], these technologies differed from the preceding ones in that they emerged more or less directly from scientific research and discovery, which in itself constituted a qualitative change. But it is in the social impacts that the changes have been, and continue to be, so great as to also constitute a qualitative change. Hence the epithet "revolution" is fully merited.

The idea of the Scientific Revolution was already anticipated by J.D. Bernal in the 1930s [7]. In a famous speech in 1963, Harold Wilson, who in the following year became Prime Minister of the UK, spoke of the new "Britain that is going to be forged in the white heat of this [scientific] revolution".[5] His aim was the gaining, or restoration, of ascendancy among the nations. In contrast, Snow's aim was the alleviation of the great menaces facing all of humanity, which he identified as nuclear war, overpopulation, and the gap between rich and poor.[6] Snow does not say a great deal about the first two—of which science might be said to be the cause (through the discovery of nuclear fission and fusion, and the enormous reduction in infant mortality through medical science). To neutralize the last menace, he very clearly sees that the solution is the industrialization of the underdeveloped, developing or "third" world. To do this at the scale and rapidity required to avert disaster,[7] vast

1 The term Agricultural Revolution is sometimes used to designate the significant increase in agricultural production in Britain from the mid-17th century onwards, and later elsewhere. It depended on important innovations such as enhanced crop rotation (generally ascribed to Charles "Turnip" Townshend, although since he was only born in 1674 this is chronologically unsound), changes in land allocation (enclosure), convertible husbandry (alternating plants and livestock in fields) and selective breeding of both plants and livestock [1]. An even more significant increase in agricultural production in the "Third World" is often called the Green Revolution and is associated with the name of Norman Borlaug. It signifies a great increase in the mass of harvested crops, based on greatly increasing the use of chemical fertilizers and pesticides, irrigation, and the development of high-yielding varieties. Its apotheosis is the creation of genetically modified organisms.

2 The archetypical example is James Clerk Maxwell's paper on the governor [4], which James Watt had introduced to the steam engine almost 100 years earlier.

3 The reasons for the launch of the Industrial Revolution are even more nebulous than those for the Agricultural Revolution. Inventiveness was certainly a factor [5], but what drove that? The preceding Agricultural Revolution created underemployed labourers eager to work in the new factories. Trade was burgeoning. The joint-stock company helped to finance new ventures, and so forth.

4 And, to those without direct experience of it, remains baffling to this day [3].

5 H. Wilson, *Labour's Plan for Science*. Speech delivered at the Annual Conference of the Labour Party, 1 October 1963, Scarborough.

6 These menaces are perennially discussed in the literature, but their nature has evolved over time. Thus in 2016 Callahan identified them as climate, food, water, disease and obesity [8].

7 The nature of the disaster that would befall the world if nothing were done to close the gap is not really discussed in Snow's essay [3]. Nowadays we can perceive that one consequence is the flooding of Europe and North America by poor immigrants, at a rate far faster than that at which they can be well assimilated.

Journal of Biological Physics and Chemistry **21** (2021) 31–34
Received 30 June 2021

doi: 10.4024/07RA21E.jbpc.21.02

amounts of capital need to be injected from the developed world, and tens of thousands of "trained scientists and engineers adaptable enough to devote themselves to a foreign country's industrialization for at least ten years" [3]. The provision of the required capital is not a great problem [9], but we simply did not (and do not) have such quantities of suitably trained people. At the time, Russia (the USSR) was training about ten times as many engineers per capita as in the UK, and they had an active programme of foreign assistance, which could be realized since they had the trained manpower for it. Nowadays that role has been taken on by the People's Republic of China with its "Belt & Road Initiative", albeit without much altruism as far as can be perceived from the West [10].

Besides, it is now clear that such development as has already taken place in the Third World has not had unmitigated benefits. The industrialization of agriculture has led to a relentless deterioration of soil quality.[8] "High yields" means high harvested mass, but not necessarily an improvement in nutritional value. In fact, rapid plant growth tends to lead to a lower specific content of essential minerals and other nutrients such as valuable phytochemicals. Chemical fertilization all too easily becomes overfertilization with concomitant deleterious effects on lakes and rivers. The apotheosis of industrialized agriculture, namely the cultivation of crops genetically modified to make them resistant to a general herbicide, which is then applied to eliminate everything else, leads not only to an appalling loss of both floral and faunal biodiversity but also seemingly ineradicable and pervasive contamination of the environment with the herbicide (glyphosate) [11]. Finally, parallel developments in the medical sciences have led to an enormous increase of population, meaning that *per capita* quantities of food have tended to remain more or less stationary. The scientists' response to these and other problems is generally that more science is needed to overcome them. For example, soil is now perceived as being one of the most complex systems known to man [12]. Hence, the relatively new field of complexity science should be applied to understand it.

There is a long tradition of science "for the relief of man's estate", as Francis Bacon put it [13]. Bernal has a chapter on "Science in the service of man" [7], which envisages the rational application of the methods of science to solve practical problems without being beguiled by utopias. Examples of what such application might encompass in practice are given elsewhere ([7], pp. 225–6)—such as the ten key problems on which the Academy of Sciences of the USSR was to concentrate in connexion with the 3rd Five-Year Plan (starting in 1938): to develop geological, geochemical, and geophysical methods of prospecting for useful minerals; to solve the problem of electric power transmission by creating a unified high-voltage system; to rationalize and extend the use of natural gas; find a new type of fuel for internal combustion engines; to rationalize the technological processes in chemistry and metallurgy; to raise the grain yield; to establish the scientific basis for the development of animal husbandry and fisheries; to develop telemechanics (long-distance control of machinery) and to extend automatic processes in industry through application of theoretical physics; to draw up a balance sheet of the national economy; to study the history of the peoples of the USSR. It all sounds very modern and admirable and, of course, a good deal of this programme was accomplished, very much in the spirit of the Scientific Revolution.

At the present time there has been a resurgence of such ideas. In the UK, the Government is actively launching a host of initiatives [14]. Some of these have to do with pandemic control—it was natural enough for the Government to take the lead in combating Covid-19—and a great deal has to do with another kind of "green" revolution—the attainment of zero emissions of carbon dioxide by 2050 in order to combat climate change,[9] and there is already discussion about whether "zero carbon" also implies qualitative changes in lifestyle. The answer to this is probably "no"—for example, we will still have automobiles and aeroplanes, but they will be powered by electric motors and storage batteries rather than internal combustion engines, etc. But we are already in the midst of another qualitative change in social living, that brought about by pervasive computation—which has enabled the world wide web, the Internet of Things, cellular mobile telephony and social media, which we might date from around 1990. To understand why this fourth revolution, which we might call the Compunications Revolution (portmanteau of computers and communications [16]), happened so soon after the Scientific Revolution, let us look at Figure 1, which plots the number of human generations (conventionally taken to be 25 years) to achieve each of the preceding three revolutions. The log times to achieve the first three revolutions form a reasonably straight line and extrapolation to the fourth predicts that it should have occurred in about half a generation after the Scientific Revolution, suggesting that the Compunications Revolution was perhaps initiated by the Dartmouth Conference in 1956 [17].

---

8 The depletion of carbon and essential minerals, and erosion, are the main problems.

9 This is enshrined in law by the *Climate Change Act 2008 (2050 Target Amendment) Order 2019*. On 20 April 2021 a new target to cut CO_2 emissions by 78% by 2035 was announced by the UK Government.

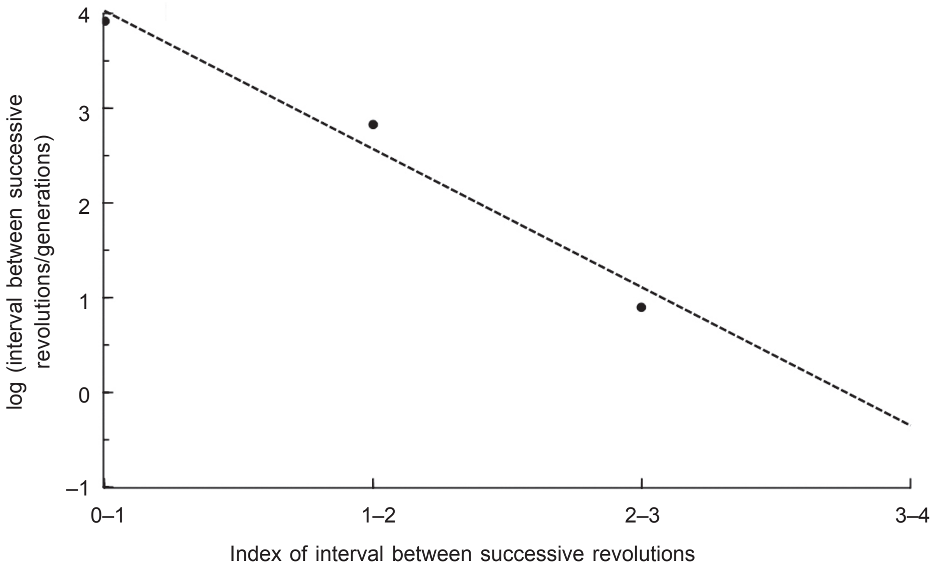

Figure 1. Logarithm (base 10) of the number of generations to achieve the Agricultural, Industrial and Scientific Revolutions, starting with the origin of *H. sapiens*, usually taken to be about 200,000 years ago, although recent evidence suggests an earlier origin of about 300,000 years ago [15], plotted against successive qualitative changes in social living ("revolutions"). The start of agriculture is taken to be about 17,000 years ago (because of the logarithmic scale, the uncertainties in these dates do not much affect the plot). The Industrial Revolution is dated to 1700, and the Scientific Revolution to 1940. The dashed line is a linear regression on the first three points, with the equation log (interval/generations) = 4.029 – 1.4595 × (revolution index). In this equation, '0' is assigned to 0–1 and so forth.

This plot makes it clear that there is nothing surprising about the Compunications Revolution having happened so soon after the Scientific Revolution (on the achievements of which it was built). The intervals between successive stages of social living decrease exponentially. A further corollary is that successive revolutions will now happen thick and fast—including "Industrie 4.0", in which cloud computing, artificial intelligence and big data are harnessed to dramatically increase productivity. Perhaps when the interval between the revolutions reaches the minimum time required for a change in social living, a "social singularity" (cf. Ray Kurzweil's "singularity" [18]—when computing power becomes equivalent to the human brain) occurs. The 5th, 6th, 7th and 8th revolutions will occur after about 20 weeks, 5 days, 4 hours and 8 and a half minutes respectively. The 9th occurs after only 18 seconds, which is shorter than a TikTok video, which might approximate to this minimum time. As Holt points out [18], at the singularity one passes through the event horizon and emerges into a universe dramatically different from the previous one. By analogy, the social singularity implies profound, almost unimaginable changes in our ethical framework, and it may have already happened.[10,11]

Bernal, Snow and Kurzweil (with his Singularity University) lay great emphasis on education. "To say, we have to educate ourselves or watch a steep decline in our own lifetime, is about right. We can't do it, I am now convinced, without breaking the existing pattern" [3]. Snow draws an analogy with the Venetian Republic as it terminally declined in the last half of the 18th century. "They knew, just as clearly as we know, that the current of history had begun to flow against them. Many of them gave their minds to working out ways to keep going. It would have meant breaking the pattern into which they had crystallized. They were fond of the pattern, just as we are fond of ours. They never found the will to break it" [3].[12]

Some years ago I myself wrote about education with some modest proposals for reform [21]. Educational thinking tends to be dominated by gradualism [22]. In the midst of revolutions, possibly passing through a singularity,

[10] Seen in this light, the notion of an era of slowing down [19] seems to be completely untenable.

[11] There is, of course, resistance from those who find the present way of life too congenial to abandon, and this may delay the onsets of the revolutions. Hunter–gatherers doubtless resisted agriculture (well captured in Isaac Bashevis Singer's novel *The King of the Fields*) and resistance to the changes of the Industrial Revolution is well known, and indeed forms much of the material discussed in C.P. Snow's essay [3]. The latter type of resistance is readily adaptable to the Scientific and Compunications Revolutions. Interestingly, the tenets of the "green" ("zero carbon") revolution are being harnessed by some as a means of resisting the revolutions presently occurring.

[12] Cf. the need to break patterns in management practices [20].

radicalism is needed. Mastery of one or more languages is of course essential—as much part of being human as breathing, seeing, tasting and feeling—and as much mathematics as one can manage. These are the only two invariants. Survival skills—food preparation, running one's everyday life, earning a living—can presumably be imparted by parents. Socialization comes as a matter of course (and more or less any kind of school is good for that). But all the rest, which at present occupies such a substantial part of the school curriculum, could be taught *ad hoc*. Ideally the children themselves should ask to be taught about what interests them, and if the expertise is unavailable within the school, external people, perhaps even parents, can be invited to give a talk. Bernal was scathing about science education in English schools; a proposed syllabus contained "nothing later than 1890" in physics, and the whole chemistry course contained "nothing not known in 1810" (ref. [7], pp, 74–5).[13]

C.P. Snow remarked that "we know almost nothing about [the scientific revolution]" [3], about two decades after it had already got under way. How much less do we know (in any deep sense) about the Compunications Revolution! The problem now is that before we can know the previous revolution, the next one is already under way. We are already passing through the event horizon.

J.J. Ramsden

References

1. C.P. Timmer, The turnip, the new husbandry, and the English agricultural revolution. *Q. J. Econ.* **83** (1969) 375–395.
2. A. Snir et al., The origin of cultivation and proto-weeds, long before Neolithic farming. *PLoS ONE* **10** (2015) 0131422.
3. C.P. Snow, *The Two Cultures* (Rede Lecture). Cambridge: University Press (1959).
4. J.C. Maxwell, On governors. *Proc. R. Soc. Lond.* **16** (1867–8) 270–283.
5. R.R. Meisenzahl and J. Mokyr, The rate and direction of invention in the British industrial revolution: incentives and institutions. In: *The Rate and Direction of Inventive Activity Revisited* (eds J. Lerner and S. Stern), pp. 443–479. Chicago: University of Chicago Press (2012).
6. J.J. Ramsden, *Applied Nanotechnology* (3rd edn), chs 1 & 2. Elsevier (2018).
7. J.D. Bernal, *The Social Function of Science*. Cambridge, Mass., MIT Press (1967) (first published in 1939).
8. D. Callahan, *The Five Horsemen of the Modern World*. New York: Columbia University Press (2016). Reviewed by J.J. Ramsden, *Nanotechnol. Perceptions* **14** (2018) 44–47.
9. J.J. Ramsden, Sovereign money. *Nanotechnol. Perceptions* **14** (2018) 3–7.
10. J.J. Ramsden, China: a modern Machiavellian state. *J. Biol. Phys. Chem.* **20** (2020) 47–49.
11. J.J. Ramsden, A contemporary view of glyphosate. *J. Biol. Phys. Chem.* 15 (2015) 83–88.
12. K. Ritz , Soil as a paradigm of a Complex System. In: *Complexity and Security* (eds J.J. Ramsden & P.J. Kervalishvili), pp. 103–121. Amsterdam: IOS Press (2008).
13. J. Pethica, Science: exploration and exploitation. *Nanotechnol. Perceptions* **4** (2008) 94–97.
14. J.J. Ramsden, Taking stock. *Materials World* (June 2021) 28–31.
15. J.-J. Hublin et al., New fossils from Jebel Irhoud, Morocco and the pan-African origin of *Homo sapiens*. *Nature* **546** (2017) 289–292.
16. A.G. Oettinger and J.C. Legates, 'Compunications': a policy agenda. *Telecommun. Policy* **1** (1977) 431–433.
17. R.R. Kline, Cybernetics, automata studies, and the Dartmouth conference on artificial intelligence. *IEEE Ann. History Computing* **33**(4) (2011) 5–16.
18. R. Kurzweil, *The Singularity Is Near*. New York: Viking Press (2005). Reviewed by G.C. Holt, *Nanotechnol. Perceptions* **1** (2005) 173–175.
19. D. Dorling, *Slowdown: The End of the Great Acceleration—and Why It's Good for the Planet, the Economy, and Our Lives*. New Haven: Yale University Press (2020).
20. P.A. Hunter, Creating sustained performance improvement. In: *Spiritual Motivation: New Thinking for Business and Management* (eds J.J. Ramsden, S. Aida & A. Kakabadse), Ch. 15 (pp. 185–206). Basingstoke: Palgrave Macmillan (2007).
21. J.J. Ramsden, Education. *Nanotechnol. Perceptions* **13** (2017) 95–104.
22. W.H.G. Armytage, *Four Hundred Years of English Education*. Cambridge: University Press (1964).
23. F. Webster, The post-modern university, research and media studies. *J. Biol. Phys. Chem.* **13** (2013) 83–88.

[13] At that time, in 1939, things were little better in the universities: "the general examination in the University of London, for instance, is on a syllabus in which most of the facts were known in 1880" [7]. Thankfully, things have greatly improved since then in that regard, but other problems now get in the way [23].