How the Natural Sciences Became Statistical

From Quetelet to Galton and Maxwell

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Alikhanyan National Laboratory, 2026-04-28

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ACADÉMIE ROYALE DE BELGIQUE 1772

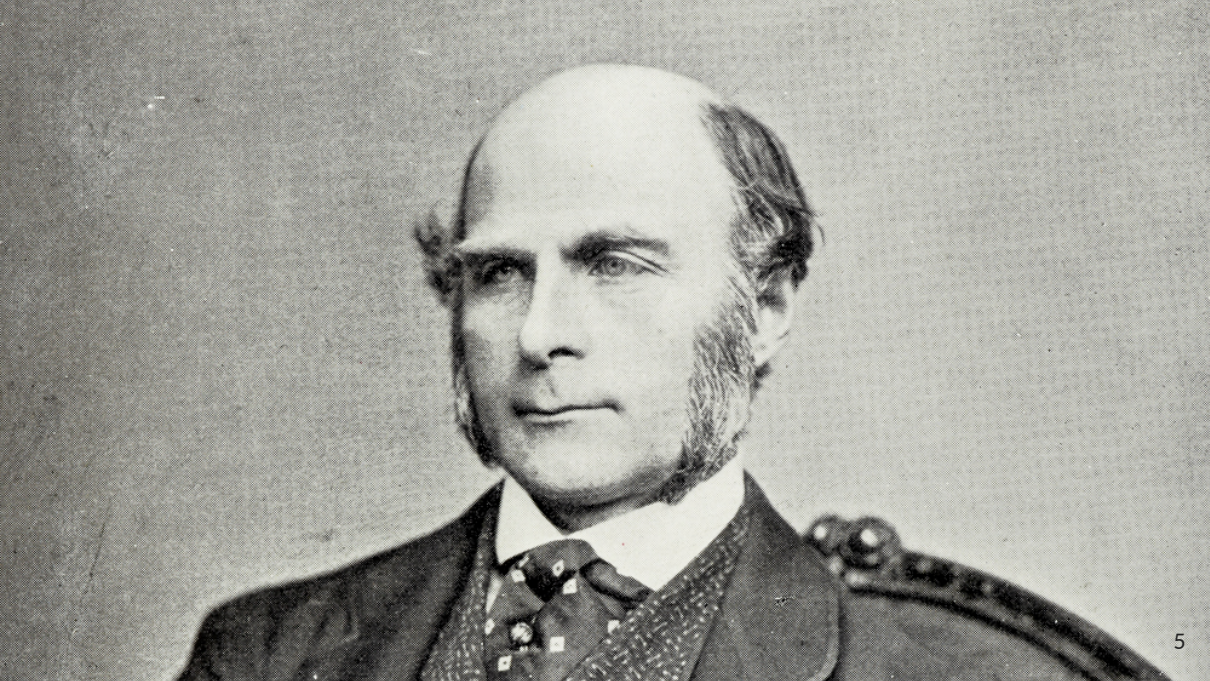
Outline

1. An historical paradox
2. From Quetelet to Galton
3. Proto-Statistical Biology
4. Toward Maxwell and Statistical Physics

The take-home: The application of statistics to the natural sciences was far from evident; the process was both technically and philosophically interesting.

An Historical Paradox

Quetelet's social physics won no important converts, and it has **never been seen as a viable approach to the human sciences.** [...] Historians of the mathematicization of the social sciences have been able to make little more of Quetelet as social physicist than a precursor, and the failure even of enthusiastic admirers to take up his program requires no deeper explanation than the observation that Quetelet himself never carried it beyond the programmatic, or even indicated how that could be done. (Porter 1985, 51)



The next year was to place in Weldon's hands a book—Francis Galton's *Natural Inheritance*, by which one avenue to the solution of such problems [of variation, correlation, and evolution], one quantitative method of attacking organic correlation, was opened out to Weldon; and **from this book as source spring two of the friendships and the whole of the biometric movement, which so changed the course of his life and work.** (Pearson 1906, 13–14)

...no one who studied it on its appearance and had a receptive and sufficiently trained mathematical mind could deny its great suggestiveness, or be other than grateful for all the new ideas and possible problems which it provided. The methods of *Natural Inheritance* may be antiquated now, but in the history of science **it will be ever memorable as marking a new epoch**... (Pearson 1930, 57–58)


IDEAS IN CONTEXT
THE Taming
OF Chance

> The argumentation surrounding this concept [the idea of “natural ability”] was, as frequently with Galton, very bad, but the concept was powerful if vague… (Norton 1978, 43)

[The biologist and textbook author W.K. Brooks] included a whole chapter on Galton in his *Foundations of Zoology* and explicitly addressed the ambiguities in his writings by quoting passages that seem both to support and to deny a role for selection in determining the fate of the new characters produced by saltation.

In the end, however, it seems that Galton was simply ambiguous on the question of the role played by selection… (Bowler 2014, 276, 274)

From Quetelet to Galton

My first serious interest in the Gaussian Law of Error was due to the inspiration of William Spottiswoode, who had used it long ago in a Geographical memoir for discussing the probability of the elevations of certain mountain chains being due to a common cause. He explained to me the far-reaching application of that extraordinarily beautiful law, which I fully apprehended. I had also the pleasure of making the acquaintance of Quetelet, who was the first to apply it to human measurements, in its elementary binomial form, which I used in my *Hereditary Genius*. (Galton 1908, 304)

The man whom I consider here is, in society, the analogue of the center of gravity in bodies; he is the mean around which the social elements oscillate: it is, if you will, a fictitious being for whom all things happen in conformity with the results obtained for the society. **If one looks to establish, in some sense, the basis of a *social physics*, it is him that one must consider, without going into specific cases or anomalies,** and without seeing whether such an individual could have a greater or lesser development in one of his faculties. (Quetelet 1835, 1.21)

> What sad condition of the human race! We can enumerate in advance how many individuals will dirty their hands with the blood of their fellow men, how many will be counterfeiters, how many poisoners, not unlike how we can enumerate in advance the births and deaths that must take place. (Quetelet 1835, 1.10)

> I know of scarcely anything so apt to impress the imagination as the wonderful form of cosmic order expressed by the “law of error.” A savage, if he could understand it, would worship it as a god. It reigns with serenity in complete self-effacement amidst the wildest confusion. The huger the mob and the greater the anarchy the more perfect is its sway. (Galton 1886, 494–5)

The Rise of Chance in Evolutionary Theory

A Pompous Parade of Arithmetic

Proto-Statistical Biology: Particulate Transmission

The outline of my problem of this evening is, that since the characteristics of all plants and animals tend to conform to the law of deviation, let us suppose **a typical case, in which the conformity shall be exact,** and which shall admit of discussion as a mathematical problem, and find what the laws of heredity must then be to enable *successive* generations to maintain statistical identity. (Galton 1877a, 493)

FIG. 7.

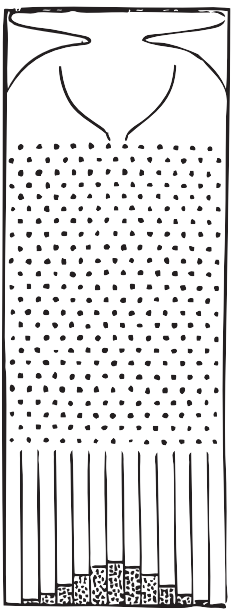


FIG. 8.

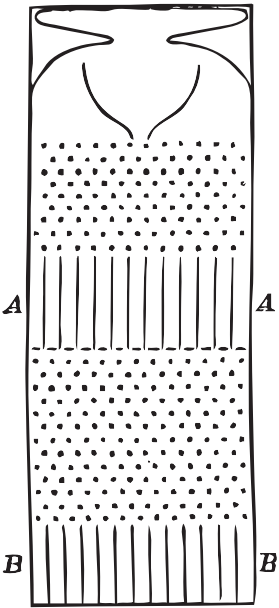
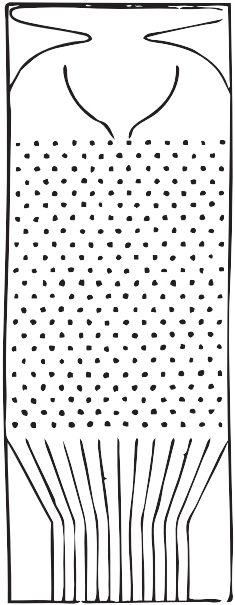


FIG. 9.



...in addition to [the constant effects of the mean and of gravity], there were a **host of petty disturbing influences,** represented by the spikes among which the pellets tumbled in all sorts of ways. The theory of combination shows that the commonest case is that where a pellet falls equally often to the right of a spike as to the left of it.... It also shows that the cases are very rare of runs of luck carrying the pellet much oftener to one side than the other. (Galton 1877a, 495)

…although characteristics of plants and animals conform to the law, **the reason of their doing so is as yet totally unexplained.** The essence of the law is that differences should be wholly due to the collective actions of a host of independent *petty* influences in various combinations… **Now the processes of heredity…are not petty influences, but very important ones.** (Galton 1877b, 512)

It would seem that while the embryo is developing itself, the particles more or less qualified for each new post wait as it were in competition, to obtain it. Also that the particle that succeeds, must owe its success partly to accident of position and partly to being better qualified than any equally well placed competitor to gain a lodgment. (Galton 1889, 9)

Proto-Statistical Biology: Chance and Causation

The example that I have just cited deserves, I think, our full attention: il shows us that things **happen absolutely as if the chests that have been measured were modeled after a single type,** after a single individual, ideal if we will, but of whom we can grasp the proportions via sufficiently prolonged experience. If such were not the law of nature, the measurements would not cluster together, despite their defects, with the stunning symmetry that the law of possibility assigns them. (Quetelet 1846, 137)

[The intention of the first chapter] has been to show the large part that is always played by chance in the course of hereditary transmission, and to establish the importance of an intelligent use of the laws of chance and of the statistical methods that are based upon them, in **expressing the conditions under which heredity acts.** (Galton 1889, 17)

A parade of great· accuracy is foolish, **because precision is unattainable in biological and social statistics;** their results being never strictly constant. [...] We require no more than a fairly just and comprehensive method of expressing the way in which each measurable quality is. distributed among the members of any group... (Galton 1889, 36)

Toward Maxwell and Statistical Physics

ART. I. — 1. *Lettres à S. A. R. le Duc règnant de Saxe-Cobourg et Gotha sur la Théorie des Probabilités appliquée aux Sciences Morales et Politiques.* Par M. A. QUETELET, Astron. Royal de la Belgique, &c. &c. 1 vol. in 8vo. 1846. Chez M. Hayez, à Bruxelles.

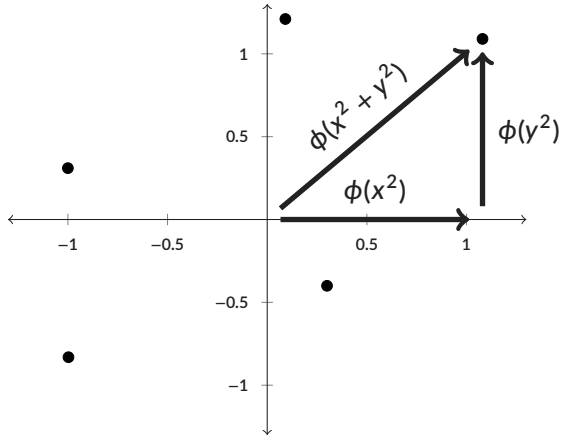
2. *Letters addressed to H. R. H. the Grand Duke of Saxe-Cobourg and Gotha on the Theory of Probabilities as applied to the Moral and Political Sciences.* By M. A. QUETELET, Astronomer Royal of Belgium, Corresponding Member of the Institute of France, &c. &c. Translated from the French by OLINTHUS GREGORY DOWNES, of the Œconomic Life Assurance Society. London: 1849.

EXPERIENCE has been declared, with equal truth and poetry, to adopt occasionally the tone, and attain to something like the certainty, of Prophecy. In the contemplating mind the past and the future are linked by a bond as indissoluble as that which

The ‘Principle of Least Squares,’ which Quetelet derives:

> ...the most probable determination of one or more invariable elements from observation is that in which the sum of the squares of the individual errors or aberrations from exactness which the observations imply, shall be the least possible. (Herschel 1850, 18)

Suppose a ball dropped from a given height, with the intention that it shall fall on a given mark. Fall as it may, its deviation from the mark is *error*, and the probability of that error is the unknown function of its square, *i. e.* of the sum of the squares of its deviations in any two rectangular directions. Now, the probability of any deviation depending solely on its magnitude, and not on its direction, it follows that the probability of each of these rectangular deviations must be the same function of *its* square. (Herschel 1850, 20)


1
0.5
−1
−0.5
0.5
1
−0.5
−1
$\phi(x^2 + y^2)$
$\phi(y^2)$
$\phi(x^2)$

And since the observed oblique deviation is equivalent to the two rectangular ones, supposed concurrent, and is, therefore, a compound event of which they are the simple constituents, therefore its probability will be the product of their separate probabilities. Thus the form of our unknown function comes to be determined from this condition, viz. that the product of such functions of two independent elements is equal to the same function of their sum. (Herschel 1850, 20)

$$\phi(x^2 + y^2) = \phi(x^2)\phi(y^2)$$

But it is shown in every work on algebra that this property is the peculiar characteristic of, and belongs only to, the exponential or antilogarithmic function. This, then, is the function of the square of the error, which expresses the probability of committing that error. (Herschel 1850, 20)

$$\phi(x^2 + y^2) = \phi(x^2)\phi(y^2)$$

$$\phi(x^2) = e^{-ax^2}$$

But the directions of the coordinates are perfectly arbitrary, and therefore this number [of particles per unit volume] must depend on the distance from the origin alone, that is

$$f(x)f(y)f(z) = \phi(x^2 + y^2 + z^2)$$

Solving this functional equation, we find

$$f(x) = Ce^{Ax^2}, \phi(r^2) = C^3 e^{Ar^2}.$$

If we make A positive, the number of particles will increase with the velocity, and we should find the whole number of particles infinite. We therefore make A negative and equal to $-\frac{I}{\alpha^2}$ [which gives for the whole number of particles $C = \frac{1}{\alpha\sqrt{\pi}}$], $f(x)$ is therefore

$$\frac{1}{\alpha\sqrt{\pi}} e^{-\frac{x^2}{\alpha^2}}.$$

(Maxwell 1860, 22–3)

As noted by Forfar (2002), this **just is** the derivation that Herschel presents, after Quetelet, but in three dimensions instead of two, and for velocities instead of positions.

The modern atomists have therefore adopted a method which is I believe new in the department of mathematical physics, though it has long been in use in the Section of Statistics. When the working members of [the statistical section of the BA] get hold of a Report of the Census…they begin by distributing the whole population into groups…. **The varying number of individuals in each group, and not the varying state of each individual, is the primary datum from which they work.** (Maxwell 1873, 440)

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