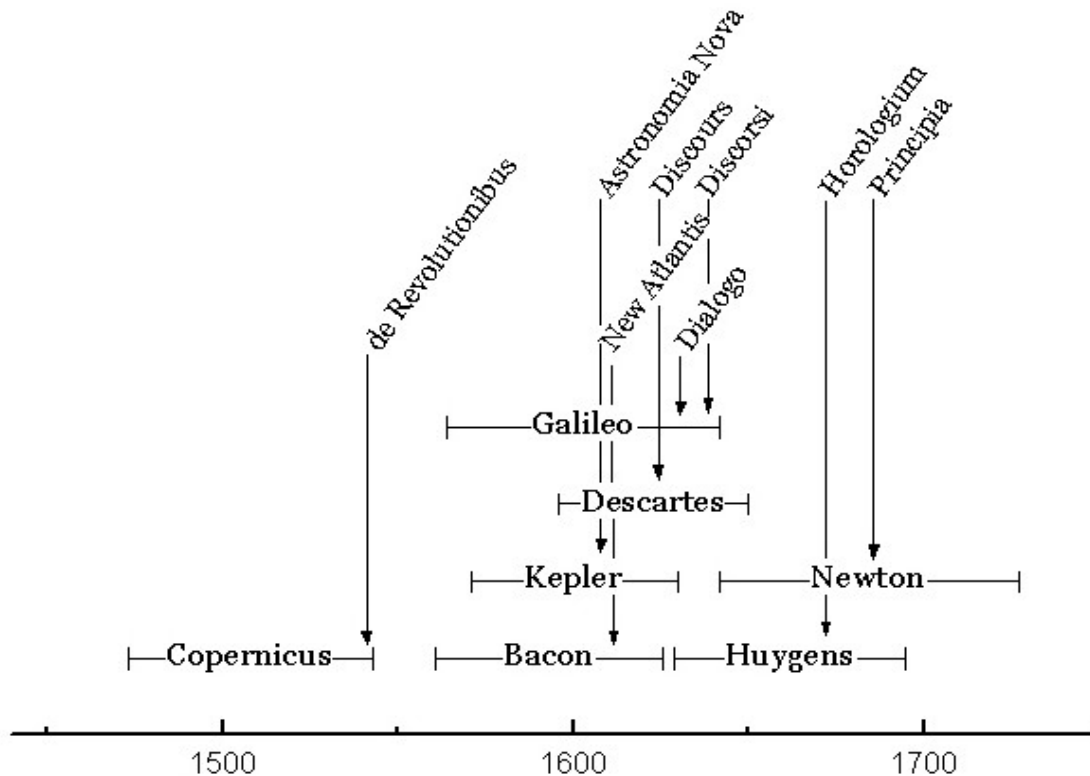


Revolução Científica

Rejeição de argumentos baseados em autoridade e autonomia da ciência com respeito à teses filosóficas e teológicas;

Uso de matemática na confecção de hipóteses;

Verificação de hipóteses por meio de experiências.



Método Experimental

Minkowski (1908) :

“The views of space and time that I wish to lay before you have **sprung from the soil of experimental physics**, and therein lies their strength. They are radical. Henceforth space by itself, and time by itself, are doomed to fade away in to mere shadows, and only a kind of union of the two will preserve an independent reality.”

Poincaré (1899):

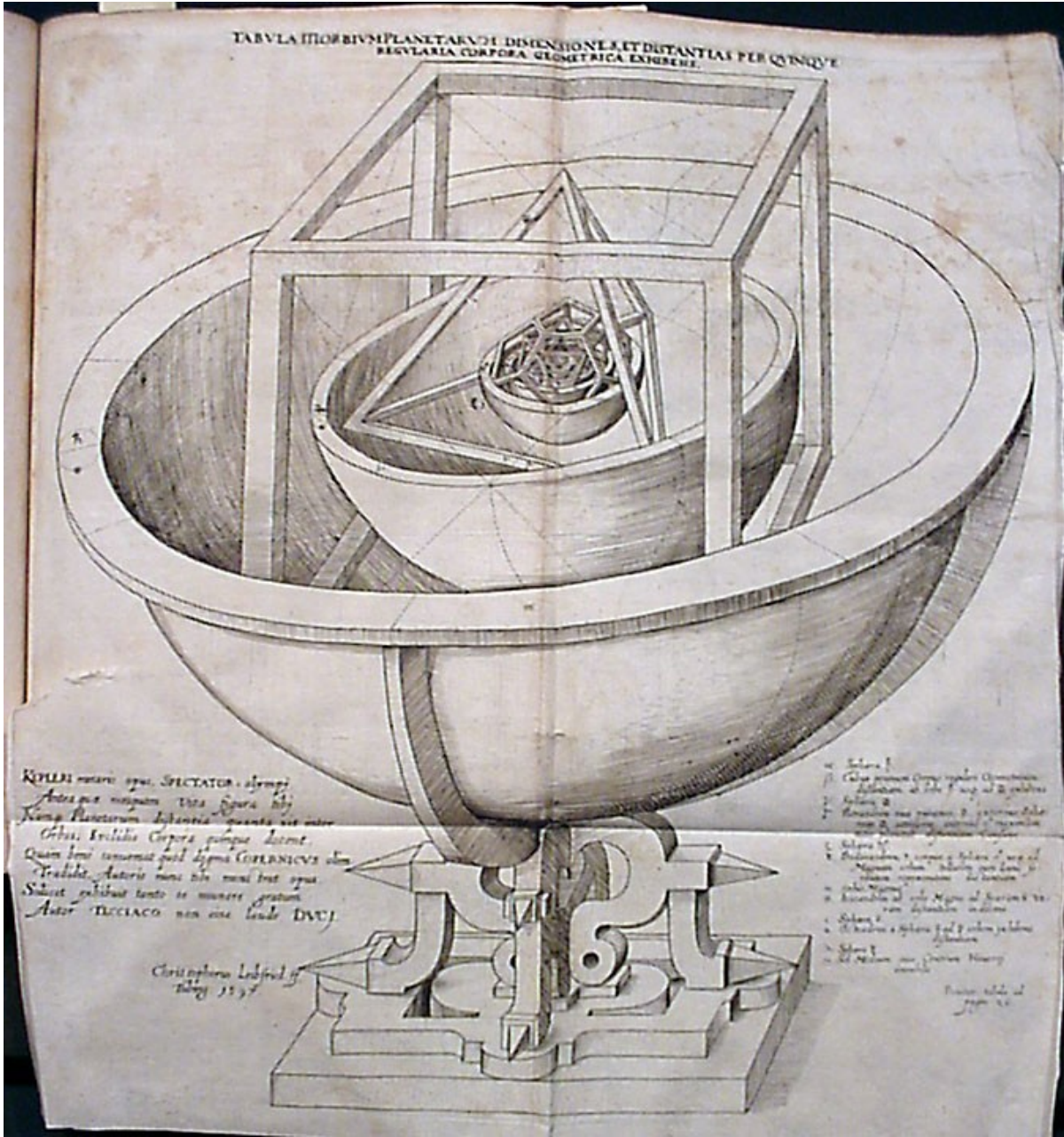
“Experiment is the sole source of truth”

Ferramentas:

1. Quantificar, trabalhar com incertezas
2. Visualização de dados quantitativos

Kepler: Imaginação fértil...

<http://www.chass.utoronto.ca/imago/drake.html>
The Stillman Drake Collection



Kepler: Cabeça fria.

“A nós, a quem Deus deu um excelente observador em Tycho Brahe cujas observações mostraram o erro de **8 minutos** nos cálculos feitos segundo Ptolemeus, cabe tranqüilamente reconhecer este benefício e usa-lo. [...] Estes 8 minutos me mostraram o caminho a uma **reforma total da astronomia**; viraram os fundamentos de um grande parte deste obra.” – *Astronomia nova (Heidelberg, 1609)*

Visualização de dados quantitativos

Desastre do ônibus espacial, 1986



The shuttle consists of an *orbiter* (which carries the crew and has powerful engines in the back), a large liquid-fuel *tank* for the orbiter engines, and 2 solid-fuel *booster rockets* mounted on the sides of the central tank. Segments of the booster rockets are shipped to the launch site, where

they are assembled to make the solid-fuel rockets. Where these segments mate, each joint is sealed by two rubber O-rings as shown above. In the case of the Challenger accident, one of these joints leaked, and a torch-like flame burned through the side of the booster rocket.



Less than 1 second after ignition, a puff of smoke appeared at the aft joint of the right booster, indicating that the O-rings burned through and failed to seal. At this point, all was lost.



On the launch pad, the leak lasted only about 2 seconds and then apparently was plugged by putty and insulation as the shuttle rose, flying through rather strong cross-winds. Then 58.788 seconds after ignition, when the Challenger was 6 miles up, a flicker of flame emerged from the leaky joint. Within seconds, the flame grew and engulfed the fuel tank (containing liquid hydrogen and liquid oxygen). That tank ruptured and exploded, destroying the shuttle.



Evidências apresentadas antes da decisão do lançamento

HISTORY OF O-RING DAMAGE ON SRM FIELD JOINTS

11.6.1
OCT 30, 1985

AFT

SRM No.	Cross Sectional View			Top View		Clocking Location (deg)	
	Erosion Depth (in.)	Perimeter Affected (deg)	Nominal Dia. (in.)	Length Of Max Erosion (in.)	Total Heat Affected Length (in.)		
61A LH Center Field**	22A	None	None	0.280	None	None	36° -- 66°
61A LH CENTER FIELD**	22A	NONE	NONE	0.280	NONE	NONE	338° - 18°
51C LH Forward Field**	15A	0.010	154.0	0.280	4.25	5.25	163
51C RH Center Field (prim)***	15B	0.038	130.0	0.280	12.50	58.75	354
51C RH Center Field (sec)***	15B	None	45.0	0.280	None	29.50	354
41D RH Forward Field	13B	0.028	110.0	0.280	3.00	None	275
41C LH Aft Field*	11A	None	None	0.280	None	None	--
41B LH Forward Field	10A	0.040	217.0	0.280	3.00	14.50	351
STS-2 RH Aft Field	2B	0.053	116.0	0.280	--	--	90

July

*Hot gas path detected in putty. Indication of heat on O-ring, but no damage.

**Soot behind primary O-ring.

***Soot behind primary O-ring, heat affected secondary O-ring.

Clocking location of leak check port - 0 deg.

OTHER SRM-15 FIELD JOINTS HAD NO BLOWHOLES IN PUTTY AND NO SOOT NEAR OR BEYOND THE PRIMARY O-RING.

SRM-22 FORWARD FIELD JOINT HAD PUTTY PATH TO PRIMARY O-RING, BUT NO O-RING EROSION AND NO SOOT BLOWBY. OTHER SRM-22 FIELD JOINTS HAD NO BLOWHOLES IN PUTTY.

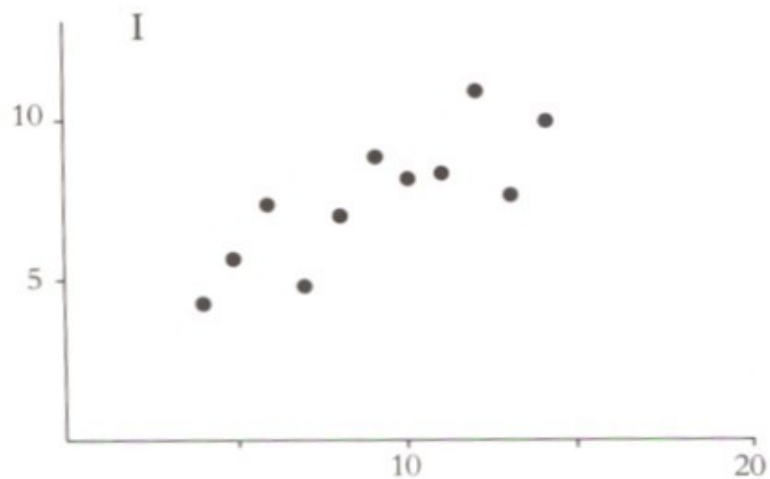
Quatro conjuntos de dados, com as *mesmas* características estatísticas

I		II		III		IV	
X	Y	X	Y	X	Y	X	Y
10.0	8.04	10.0	9.14	10.0	7.46	8.0	6.58
8.0	6.95	8.0	8.14	8.0	6.77	8.0	5.76
13.0	7.58	13.0	8.74	13.0	12.74	8.0	7.71
9.0	8.81	9.0	8.77	9.0	7.11	8.0	8.84
11.0	8.33	11.0	9.26	11.0	7.81	8.0	8.47
14.0	9.96	14.0	8.10	14.0	8.84	8.0	7.04
6.0	7.24	6.0	6.13	6.0	6.08	8.0	5.25
4.0	4.26	4.0	3.10	4.0	5.39	19.0	12.50
12.0	10.84	12.0	9.13	12.0	8.15	8.0	5.56
7.0	4.82	7.0	7.26	7.0	6.42	8.0	7.91
5.0	5.68	5.0	4.74	5.0	5.73	8.0	6.89

$N = 11$
 mean of X's = 9.0
 mean of Y's = 7.5
 equation of regression line: $Y = 3 + 0.5X$
 standard error of estimate of slope = 0.118
 $t = 4.24$
 sum of squares $X - \bar{X} = 110.0$
 regression sum of squares = 27.50
 residual sum of squares of Y = 13.75
 correlation coefficient = .82
 $r^2 = .67$

And yet how they differ, as the graphical display of the data makes vividly clear:

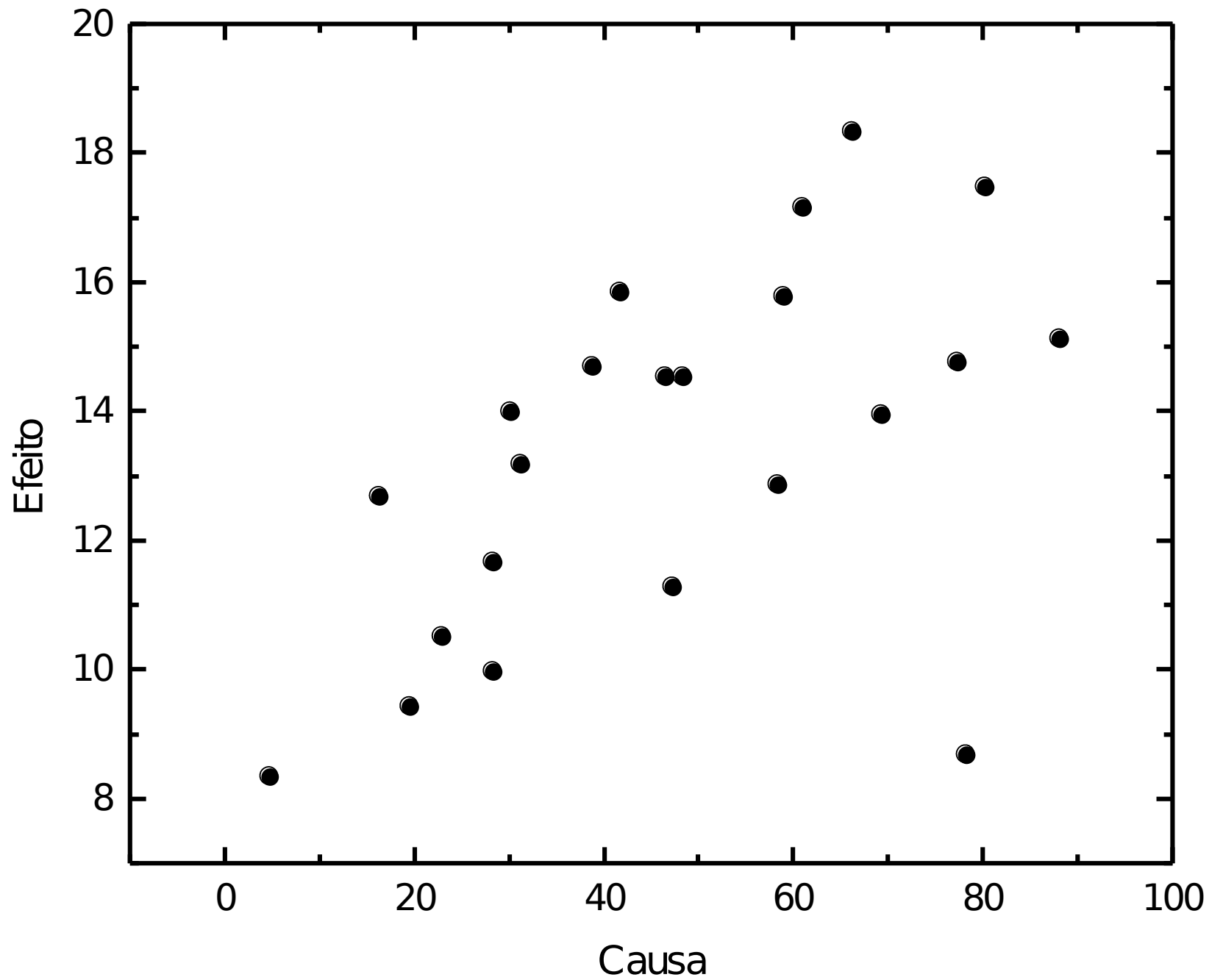
F. J. Anscombe, "Graphs in Statistical Analysis," *American Statistician*, 27 (February 1973), 17-21.



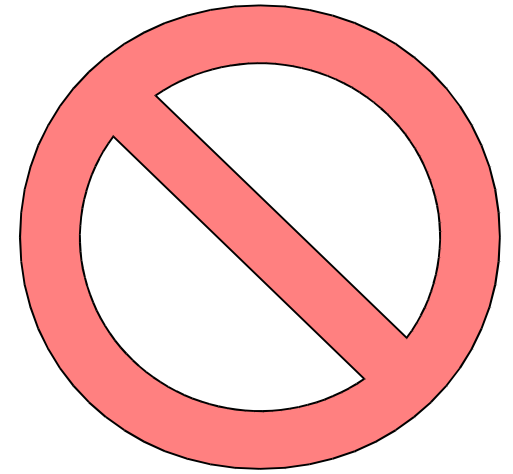
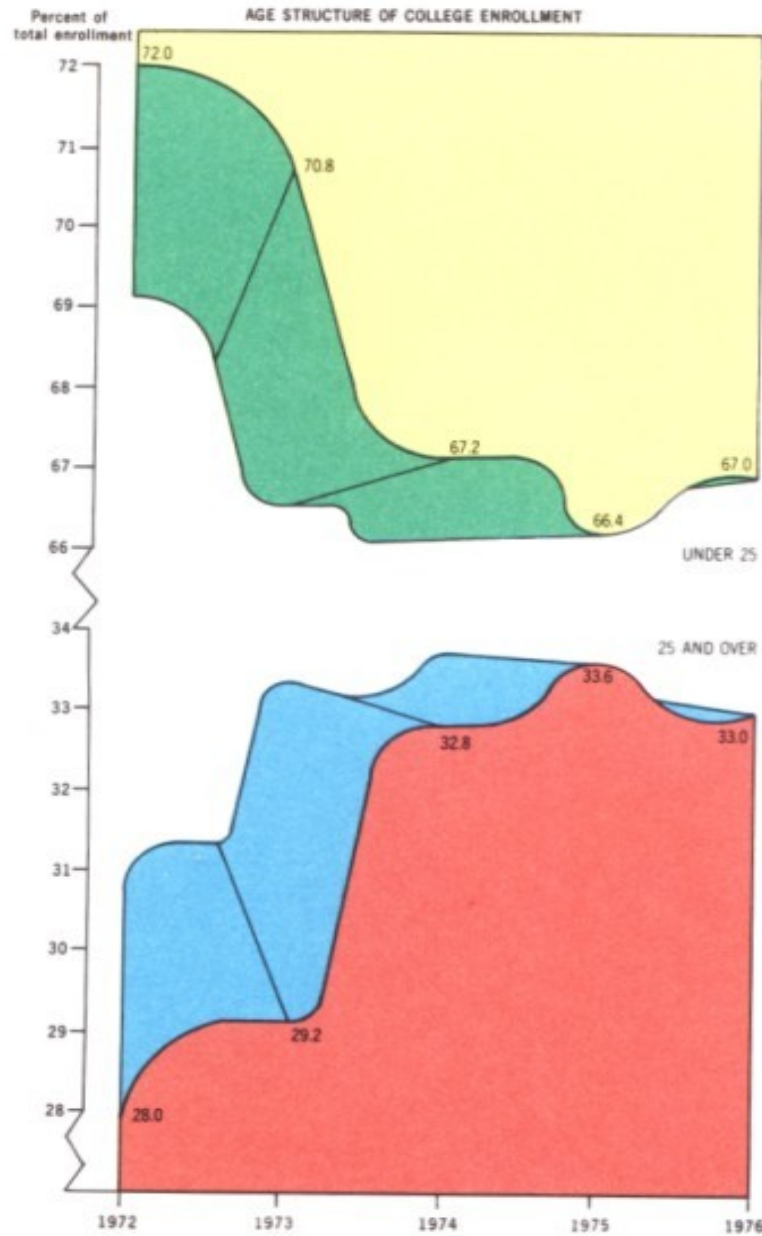
E. R. Tufte, *The visual display of quantitative information* ,

Análise de John Snow da epidemia de cólera em Londres, 1859

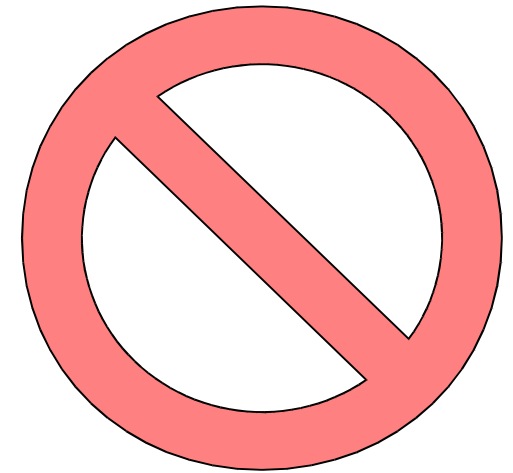
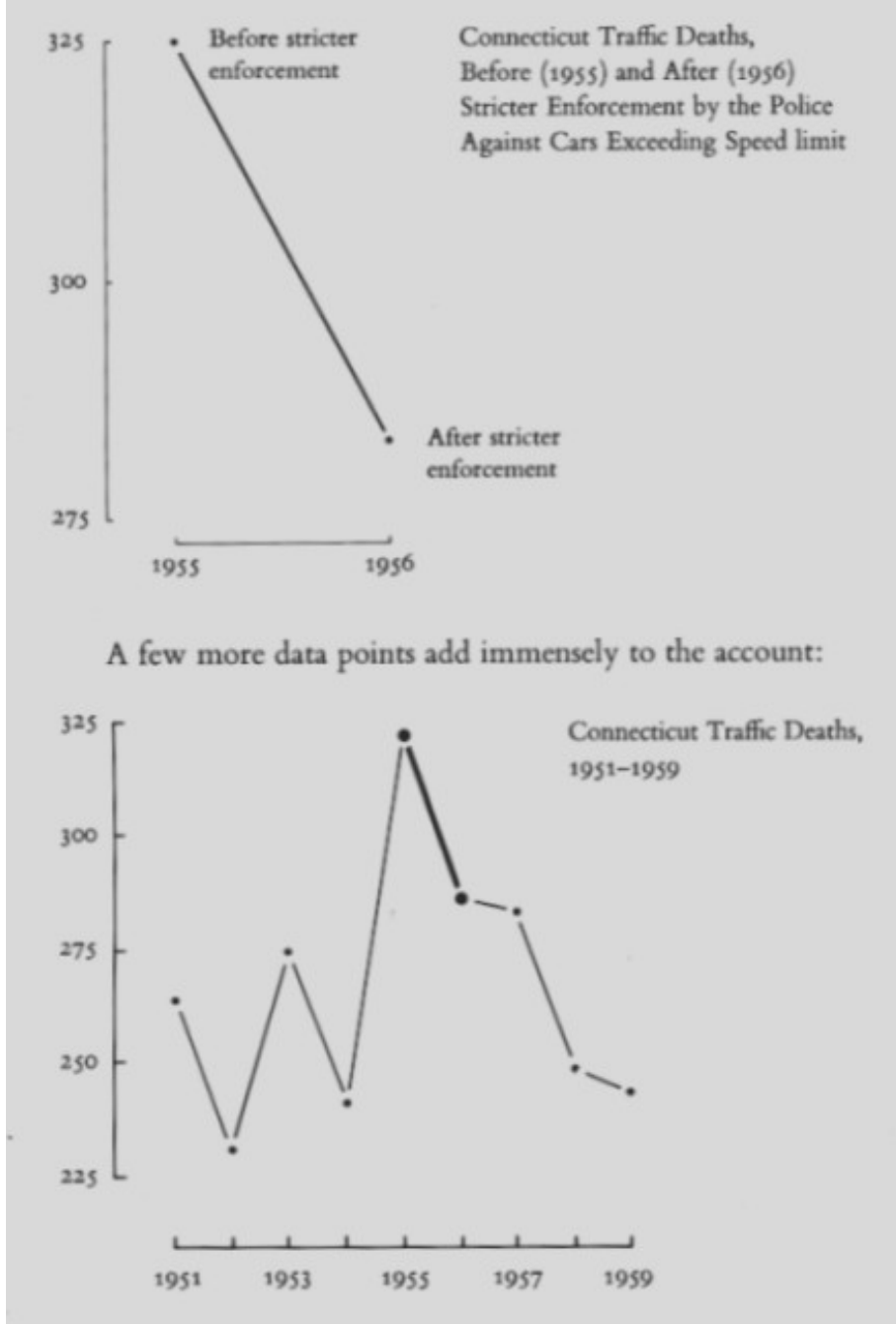


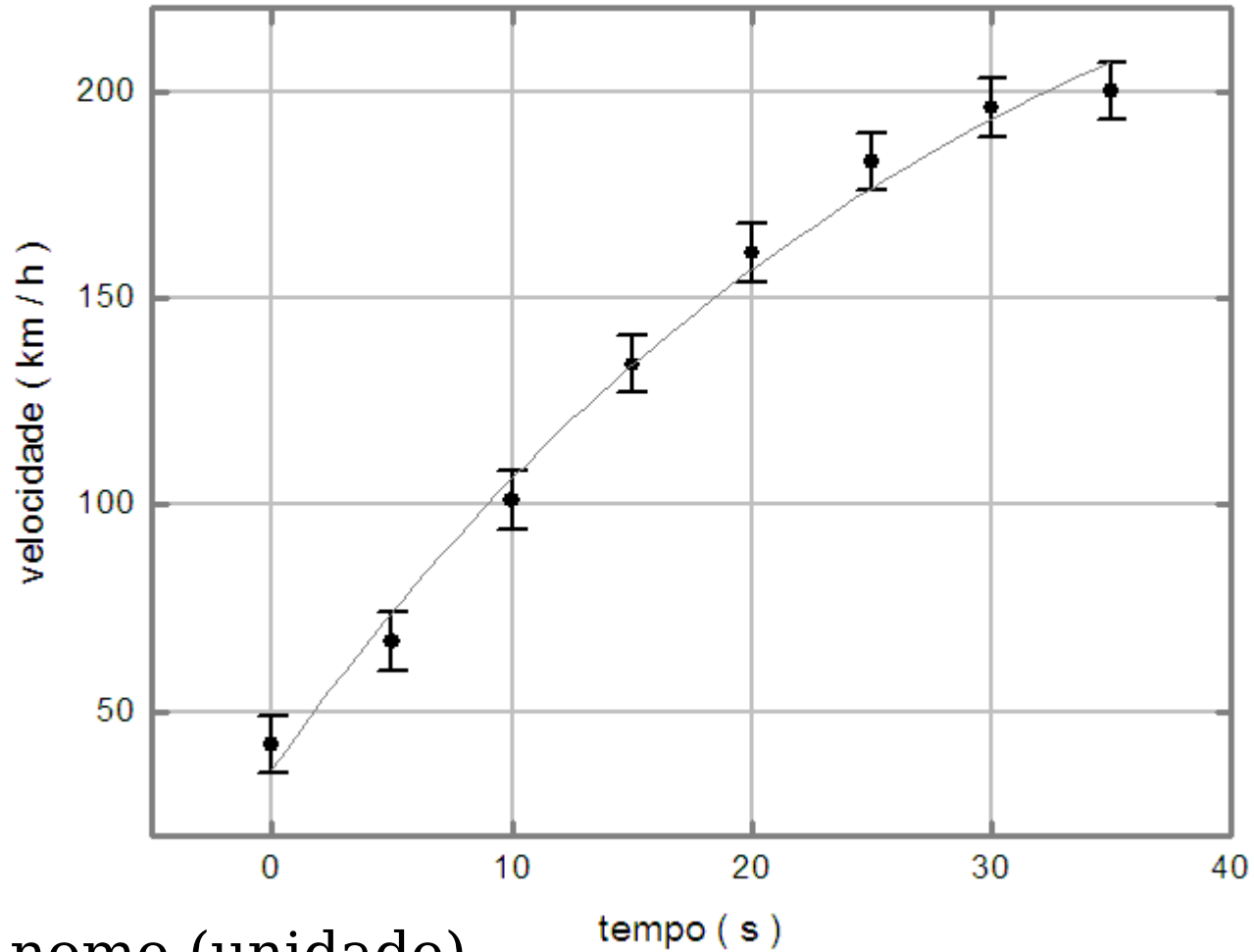


Decoração
supérfluo



Falta de Contexto





1. Eixos : nome (unidade),
2. Escalas : regra do 1,2,5
3. Dados: pontos com barras de incerteza

faltam nome, unidade e divisões principais da escala

não indique as coordenadas dos pontos,
apenas as divisões principais da escala

196

183

161

134

101

67

42

0

7

14

21

28

35

42

49

56

63

70

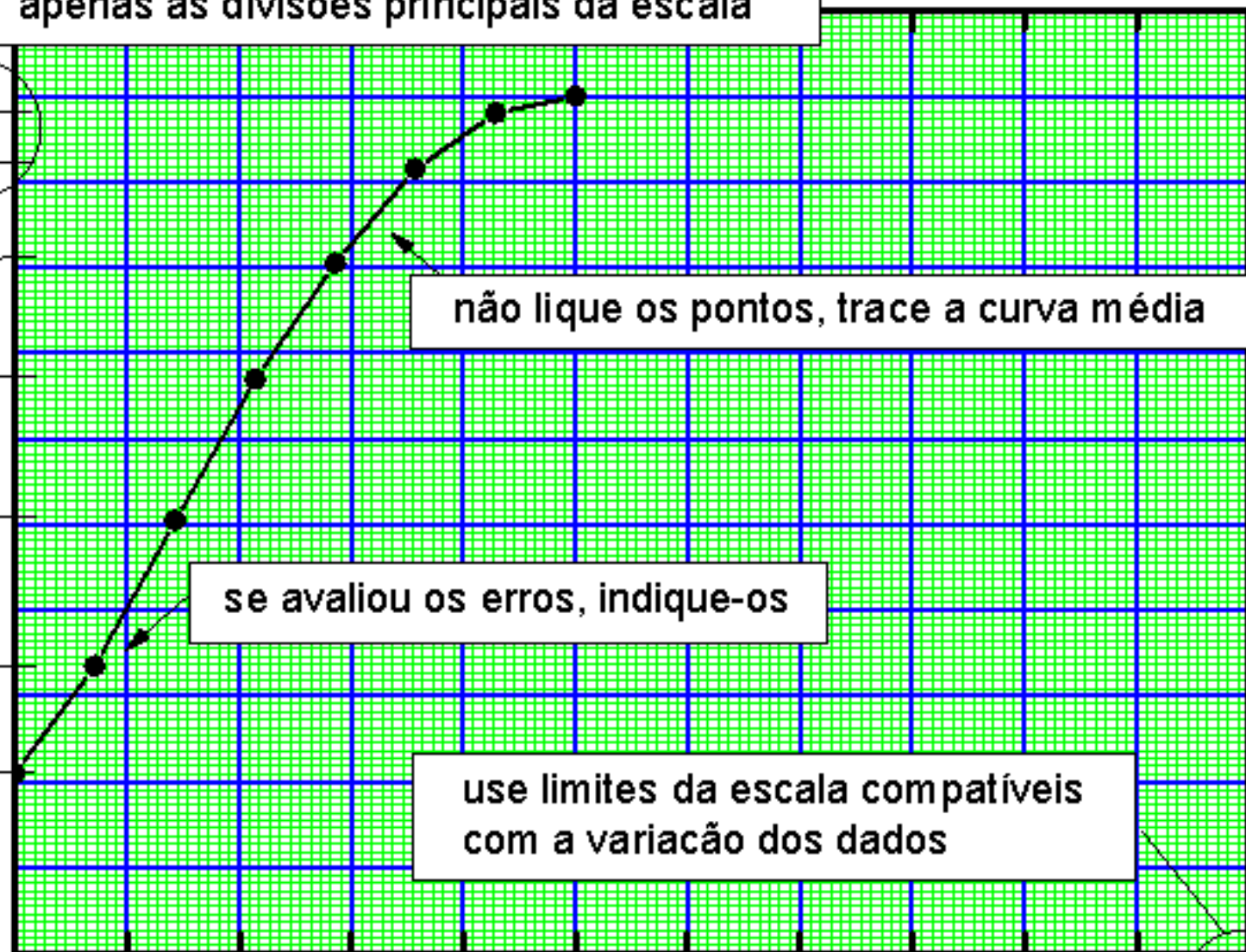
77

não lique os pontos, trace a curva média

se avaliou os erros, indique-os

use limites da escala compatíveis
com a variação dos dados

faltam nome e unidade; divisão da escala não adequada



Ewout ter Haar, 29/09/2007

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