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Mathematics of Experimentation

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This paper started with the history of great scientific experiments, which served to develop the content of a theory (decompose a simple phenomenon, demonstrate underlying unity within apparent variety, find hidden mechanism of a known effect, provide existence evidence), elaborate the formal aspects of method (decide between rival hypotheses, exploit an accident, explore the characteristics of a naturally-occurring process, find the form of a law, inductively, interpret null results, use models to simulate processes) and establish techniques (determine accuracy and care in manipulation, show power and versatility of apparatus), and, then, covered the significance of proper experimental design (using mathematical and statistical tools) in an experimental study. A number of papers submitted in high-impact journals do not get accepted because they lack proper experimental strategy. The main reasons of *inefficient experiments* (resulting in excessive cost or time delay in reaching a decision) and *poor experiments* (resulting in wrong decisions) are bad engineering decisions by setting vague objectives for projects, inappropriate statistics courses taught in the colleges and in the universities, incorrect decisions based on insufficient data and lack of training in the strategy of experimenting. The paper, also, dealt with the concepts of 'calibration' (converting undesired outputs to desired outputs using a functional relationship, preferably linear, between the two sets of outputs — *e. g.*, converting mercury height to temperature in a thermometer, converting angular deviation to ampéré or its fraction in galvanometer), 'synchronization' (of watches means at a particular instant the two watches read the same time), 'sensitivity' (of a scientific instrument is the reading given by the instrument, when it measures a unit of a physical quantity, *i. e*, current, voltage, charge, length, *etc.* — increasing the distance of scale from the galvanometer, having lamp and scale arrangement, should increase its sensitivity), 'reliability' (of equipment is [1 – *Probability of Breakdown*] — a brand name is expensive because one has reliability data available on that product; a 'guarantee' covers the breakdown and the replacement costs based on mathematical-statistical models) and 'tolerance' (the ability of an instrument to withstand shock, impact, intense radiation, variations of temperature or other distorting or damaging forces) as well as types of errors and ways to deal with them. When one handles raw data *similarities* are shown in mean (measure of central tendency) and *differences* in deviation (measure of dispersion). An appropriate measure of dispersion to use is *standard deviation*, when the data are normally distributed (large sample size). If that is not the case, one should employ *mean deviation*. 'Accuracy (A)' and 'precision (P)' were re-defined as (modified after our previous work — σ_R obtained upon replacing *arithmetic mean* by the *reference value* in the expressions of σ, standard deviation)**:**

$$A = 100\left[1 - \frac{\sigma_R}{\sigma_R + \overline{\overline{|O|}}}\right];\ P = 100\left[1 - \frac{\sigma}{\sigma + \overline{\overline{|O|}}}\right]$$

Worked Example**:** http://www.ngds-ku.org/Presentations/Physics2/Additional_File.pdf. It was suggested that Physics Laboratory Course might be used to inculcate creative thinking and critical analysis in students and the course might become the first training ground of an experimental-research physicist, if the experiments encouraged unconventional thinking. The experiments discussed included (*a*) study of variation of intensity with distance from multiple sources (point, line, laser) using photocell, (*b*) appearance (disappearance) of Newton's rings if plano-convex lens was moved away (towards) the sodium light source (study of fringe movement using edge-based algorithm to be included for advanced undergraduate laboratory) and (*c*) height and curvature maps of solid objects (cylinders, spheres, cones, wedges) using moiré fringe topography and rasterstereography (edge-based moiré and edge-based raster to quantify infinitesimal movements might be suitable for graduate laboratory). This approach of close coördination between a theorist and an experimentalist, also, sets objectives for the former to model physical phenomena to levels of accuracy compatible with experimental techniques available at that epoch of time. This lecture is dedicated to the loving memory of Prof. Dr. Muhammed Rafi and Prof. Dr. Muhammed Razi Hussain, both of them taught me during my undergraduate studies. Prof. Rafi was my mentor, who motivated me to achieve excellence in research, teaching and administration. Prof. Hussain was more of a friend and an associate, who gave me good advice at times of hardship. My life has been deeply touched by both. The topic was chosen by the speaker because both professors were experimental physicists.

*Keywords***:** Experiment design, calibration, reproducibility, accuracy, precision

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