السلام عليكم

peace be upon you

Scientific Method for Engineers

« an introduction »

ibn 'Abdullah

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Outline

Science

- Science is a systematic and logical approach to discovering how things in the universe work.
- The word "science" is derived from the Latin word **scientia**, which is knowledge based on *demonstrable* and *reproducible* data.
- Understanding *laws of nature* such as those involving physics, biology, chemistry and mathematics is what science is all about. Science makes us knowledgeable about our world and how it works.
- Science can only address natural phenomena (not *supernatural* phenomena—see ***qudratullah*).

*LAWS OF NATURE:
"SUNNATULLAH to Muslims—it refers to the way ALLAH rules and governs His creation's raison d'être"
**QUDRATULLAH:
"power of Allah"

See http://www.livescience.com/20896-science-scientific-method.html
    http://www.differencebetween.com/difference-between-science-and-vs-engineering/
    http://www.indiana.edu/~ensiweb/nos.html

Engineering

- Engineering is the study of the existing body of scientific knowledge to make its use to create new designs and structures.

- Engineering makes use of science and mathematical principles to come up with better and more efficient structures and designs.

- According to Accreditation Board for Engineering and Technology (ABET):
  ". . . engineering is the profession in which a knowledge of the mathematical and *natural sciences gained by study, experience, and practice is applied with judgement to develop ways to utilize, economically, the materials and forces of nature for the benefit of mankind."

*NATURAL SCIENCE:
"a branch of science that deals with the physical world, e.g. physics, chemistry, geology, and biology"

See http://www.livescience.com/20896-science-scientific-method.html
    http://www.differencebetween.com/difference-between-science-and-vs-engineering/

- One thousand years ago, Ibn al-Haytham (965–1039, Iraq), argued the importance of forming questions and subsequently testing them, an approach which was later advocated by . . .

- . . . Galileo with the publication of *Discourses and Mathematical Demonstrations Relating to Two New Sciences* (1638).

- The current method is based on a *hypothetico-deductive* model formulated in the 20th century, although it has undergone significant revision since first proposed.

- Nowadays, when conducting research, scientists/engineers use the *scientific method* to collect measurable, **empirical evidence* in an experiment related to a *hypothesis* (often in the form of an if/then statement), the results aiming to support or contradict a *scientific theory*.

*EMPIRICAL EVIDENCE:
"information acquired by observation or experimentation"

See http://www.livescience.com/21491-what-is-a-scientific-theory-definition-of-theory.html

Scientific Method is a way of solving problems through:

- **Observation**: what is seen or measured.
- **Hypothesis**: possible explanation why things behave the way they do.

  Hypothesis is an EDUCATED, not random, guess.

- **Experiment**: designed to test hypothesis, may/will lead to new observations and the cycle goes on . . .
- **Theory**: a hypothesis that has been investigated through experimental tests and observation and seems to be correct at explaining WHY things behave the way they do most of the time. Theory has predictive value(s) and if the prediction is wrong, the theory must be changed.

  Theory explains WHY a natural phenomenon occurs.

- **Law**: After a theory has been tested for an extended period of time using all possible methods of experimentation and observation and no exceptions have been found, then it is changed to a law, which summarizes a body of observations (often in the form of mathematical relationships).

  Law tells us HOW it happens i.e. equation of how things change.

Scientific Method is iterative in nature.
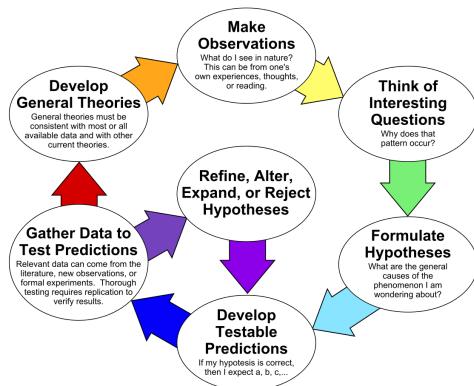
Figure 1: Scientific method.

See http://www.tvgreen.com/apchem/apnotes.htm
    https://en.wikipedia.org/wiki/Scientific_method

- Thanks to the advent of digital computers in the mid-20th century, the traditional scientific method has now spawned the *computational method*.
- Traditional science, using the *scientific method*, advances when someone
  1. carefully observes something,
  2. develops a hypothesis,
  3. designs experiments to test the hypothesis, and
  4. formulate a theory.

  When the experimental data supports the theory, mathematical models are developed that can be used to predict future outcomes.
- There are often drawbacks to traditional science. As mathematical models become more complex, the procedures required are increasingly time consuming, tedious, and error-prone. Modern computer systems usher in *computational method* which can perform algorithms quickly, tirelessly, and with minimal computational error.
- *Computational method* is thus an extension of the traditional *scientific method*; it is an intersection between science, math, and computing.
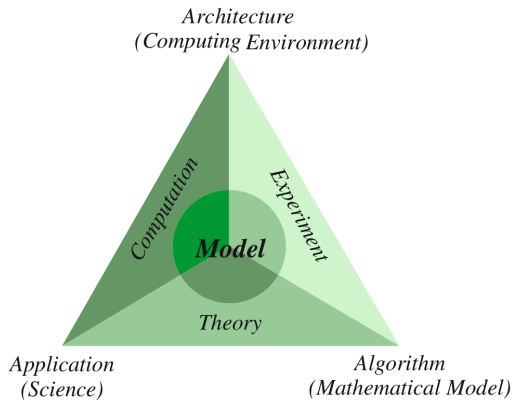
Figure 2: Overview of computational method.

Image from www.shodor.org

- Performance of a turbomachine is normally influenced by
  - control variables
  - geometric variables
  - fluid properties
- For hydraulic pump, for instance, we conject that the specific energy gH, efficiency η and power P as dependent variables

$$gH = f_1(Q, n, D, \rho, \mu, \frac{l_1}{D}, \ldots) \tag{1a}$$

$$\eta = f_2(Q, n, D, \rho, \mu, \frac{l_1}{D}, \ldots) \tag{1b}$$

$$P = f_3(Q, n, D, \rho, \mu, \frac{l_1}{D}, \ldots) \tag{1c}$$

- Through *dimensional analysis* we may form *dimensionless groups*. Selecting ρ, n and D as common factor in such exercise, we get

  - *head coefficient*

    $$\frac{gH}{n^2 D^2} = f_1 \left(\frac{Q}{nD^3}, \frac{\rho nD^2}{\mu}, \frac{l_1}{D}, \dots \right) \tag{2a}$$

  - *efficiency*

    $$\eta = f_2 \left(\frac{Q}{nD^3}, \frac{\rho nD^2}{\mu}, \frac{l_1}{D}, \dots \right) \tag{2b}$$

  - *Newton number*, *Ne*   **(a.k.a. *power coefficient*, $\hat{P}$)

    $$Ne = \frac{P}{\rho n^3 D^5} = f_3 \left(\frac{Q}{nD^3}, \frac{\rho nD^2}{\mu}, \frac{l_1}{D}, \dots \right) \tag{2c}$$

  where

  $$\frac{Q}{nD^3} \equiv \text{volumetric flow coefficient;} \qquad \frac{\rho nD^2}{\mu} \equiv \text{Reynolds number, } Re$$
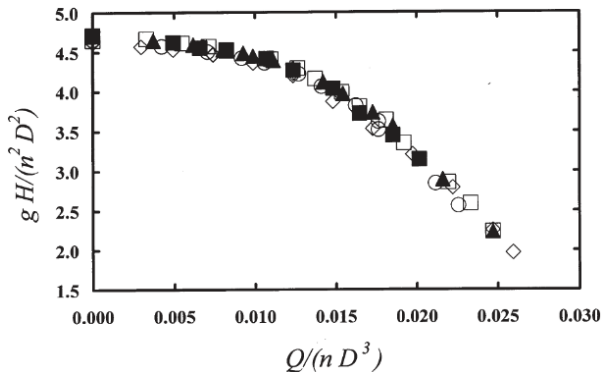
Figure 3: Dimensionless Performance Curve.
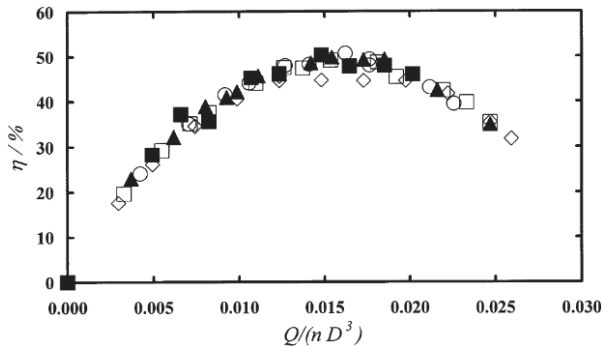
Figure 4: Dimensionless Performance Curve.
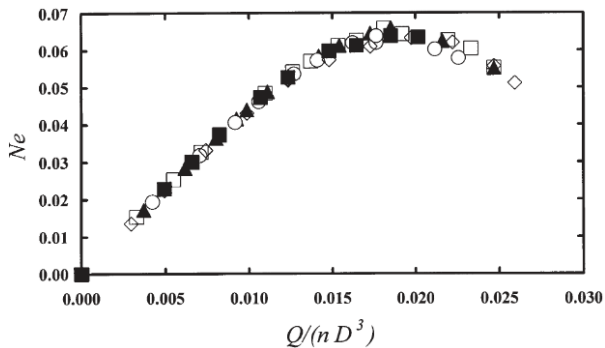
Figure 5: Dimensionless Performance Curve.

- Question: What will be needed when collecting, recording, plotting, and interpreting technical data?
- **g3data session . . .**
- Two pertinent issues in interpreting technical data
  1. graphical *presentation* of scientific data, and
  2. graphical *analysis* of plotted data
- quick, freehand plot of the data is produced to provide a visual first impression of the results; beyond this, spreadsheet software provides recording and plotting capability.
- Many forms of graphs and charts may be encountered. Which one to choose?
- **geany/SciDAVis/Octave (Matlab) session . . .**

See http://www.frantz.fi/software/g3data.php
    https://www.mathworks.com/
    http://scidavis.sourceforge.net/

- Curve fitting is needed once the data has been collected and recorded because it "*...is the process of constructing a curve, or (more importantly, constructing a) mathematical function, that has the best fit to a series of data points, possibly subject to constraints.*"

See https://en.wikipedia.org/wiki/Curve_fitting

- There are many fitting methods:
  - Linear
    - ★ point-to-point
    - ★ linear regression: $y = mx + c$
  - Polynomial
    - ★ quadratic: $y = a + bx + cx^2$
    - ★ cubic: $y = a + bx + cx^2 + dx^3$
    - ★ quartic: $y = a + bx + cx^2 + dx^3 + ex^4$
    - ★ quintic:
      $y = a + bx + cx^2 + dx^3 + ex^4 + fx^5$
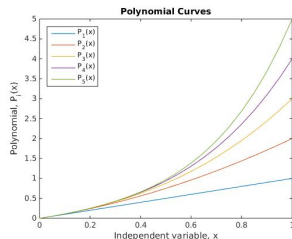
Figure 6: Polynomials.

... fitting methods:

- (Common) Nonlinear
  - ★ basic exponential: $y = a + be^{-cx}$
  - ★ power curve: $y = ax^b$
- (Less Common) Nonlinear
  - ★ half-life exponential: $y = a + \dfrac{b}{2^{x/c}}$
  - ★ proportial rate growth or decrease: $y = Y0 - \dfrac{V0}{K}(1 - e^{-Kx})$
  - ★ Gaussian bell curve: $y = ae^{\left(-(x-b)^2/(2c)^2\right)}$
  - ★ sigmoid curve: $y = \dfrac{L}{1 + e^{-k(x-x_0)}}$
- Splines
  - ★ natural cubic spline
  - ★ Akima spline
  - ★ B-spline
- User defined

See https://sourceforge.net/projects/scidavis/
https://en.wikipedia.org/wiki/Logistic_function
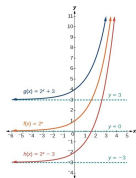
Figure 7: Basic exponential.
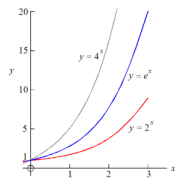
Figure 8: Power function.
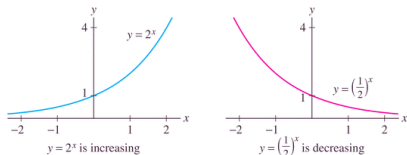
Figure 9: Half life exponential.
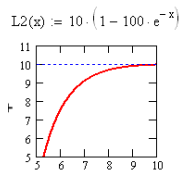
Figure 10: Proportional rate growth function.
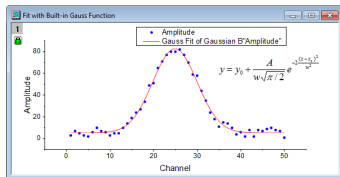
Figure 11: Gaussian bell curve.
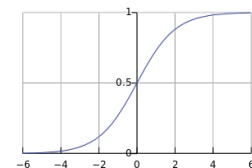
Figure 12: Sigmoid function.
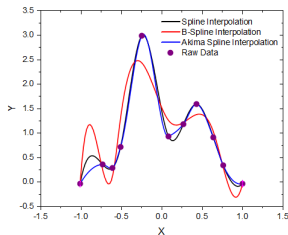
Figure 13: Splines.

Major ingredients of a scientific thesis should include

(a) **Fundamentals**—derive, prove, show mathematical model of theory/law

(b) **Applications**—utilize theory/law from part (a) to solve problem in hand (e.g. M.Sc. or Ph.D. project)

(c) **Quantitative/Deductive Reasonings**—(infuse ability to) draw inferences from evidence in parts (a) & (b)

- **Quantitative Reasoning (QR)** "...*is the application of basic mathematics skills, such as algebra, to the analysis and interpretation of real-world quantitative information in the context of a discipline or an interdisciplinary problem to draw conclusions that are relevant. It is not just mathematics.*"

- **Deductive Reasoning (DR)** *is the process of reasoning from one or more statements to reach a logically certain conclusion.* Aristotle's classic example:
  - (S) All men are mortal.
  - (S) Socrates is a man.
  - (C) Therefore, Socrates is mortal.

See https://www.aacu.org/peerreview/2014/summer/elrod
    https://en.wikipedia.org/wiki/Deductive_reasoning

- A look at the table of contents of a standard thesis . . .

**THE APPLICATION OF HIGH INLET
SWIRL ANGLES FOR BROAD
OPERATING RANGE
TURBOCHARGER COMPRESSOR**

submitted by
Abu Hasan ABDULLAH
for the degree of Doctor of Philosophy
of the University of Bath
1996

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Presenting a Scientific Thesis
A Quick Look at ToC of a Typical Thesis

Contents

Presenting a Scientific Thesis
A Quick Look at ToC of a Typical Thesis

postscriptum

Last but NOT Least

- It was narrated that Anas bin Malik said: The Messenger of Allah said

  Seeking knowledge is a duty upon every Muslim.

  <div align="right">SUNAN IBN E MAJAH, BOOK OF SUNNAH, HADITH # 224</div>

- *Imam al-Ghazali* in his masterpiece, IHYA 'ULUM AD-DIN, cited *Khalil bin Ahmad al-Bisri* who put man & his knowledge into four groups, and advised accordingly

  ▶ RAJUL[UN] LA YADRI WALA YADRI ANNAHU LA YADRI
    "Someone who does not know and he does not know that he does not know", leave him.
  ▶ RAJUL[UN] LA YADRI WA YADRI ANNAHU LA YADRI
    "Someone who does not know and he knows that he does not know", teach him.
  ▶ RAJUL[UN] YADRI WALA YADRI ANNAHU YADRI
    "Someone who knows but he does not know that he knows", wake him.
  ▶ RAJUL[UN] YADRI WA YADRI ANNAHU YADRI
    "Someone who knows and he knows that he knows", follow him.

- It was narrated that Abu Hurrairah said: The Messenger of Allah said:

  Whoever acquires knowledge by which the pleasure of Allah is sought, but he only acquires it for the purpose of worldly gain, will not smell the fragrance of Paradise on the Day of Resurrection.

  <div align="right">SUNAN IBN E MAJAH, BOOK OF SUNNAH, HADITH # 252</div>

- . . . and I end my presentation with two supplications

رَّبِّ زِدْنِي عِلْمًا

my Lord! increase me in knowledge

(TAA-HAA (20):114)

اَللّٰهُمَّ اِنَّا نَسْئَلُكَ عِلْمًا نَافِعًا

O Allah! We ask You for knowledge that is of benefit

(IBN MAJAH)