SLAC-PUB-12701
August 2007

On Learning in Engineering and Science When Old

Martin L. Perl (1995 Nobel Laureate in Physics)
Stanford Linear Accelerator Center, Stanford University,
2575 Sand Hill Road, Menlo Park, CA 94025, USA
martin@slac.stanford.edu

I just celebrated my eightieth birthday and in the past few years I have faced the problem of the older student who is an engineer or scientist and who wants to learn a new technical subject or who wants to get current in a subject that has changed drastically. This paper is concerned with learning for research or for teaching or for technical management, not for cultural pleasure.

I have had one grand success, learning how to design instruments using diffractive optics, and one dismal failure, an attempt to learn the rudiments of the string theory of elementary particles. In the process of these studies I learned about the problems facing the older student.

The major problem is that the time required for serious technical learning is not a few hours a week, it is of the order of ten hours per week. After all, in graduate or undergraduate school one spends of the order of ten hours per week, or more, on a technical course.

The next problem is how to learn. If there is suitable course and you will be accepted as an auditor whose homework and tests will be graded, this is the best but such opportunities are rare. My recourse is self-directed study using one or two books.

I have found that it is better to use newer textbooks or new editions rather than one's thirty or forty year old student textbook [1]. Exposition has improved with time and in a rapidly changing field newness is important. Also computer based calculations are now part of many textbooks, broadening applications and helping understanding. Mathematica, MATLAB, and Maple are all very useful. But in the learning stage one should avoid highly detailed, 'blackbox' software written for specific applications.

It is crucial to work through the examples and the derivations in the text and to do the exercises. The older student's limited time for study tends to encourage skipping. You think "this theorem is true, I don't have to know its derivation". I find it is best to pretend that the homework will be marked and that there will be tests. In fact if you intend to *use* this new knowledge you will be tested by the success of your research or teaching or your management decisions. Incidentally it is very useful to have the answer book for the text, sometimes it can be bought, sometimes it can be obtained by asking the author or publisher. Sometimes if I am stuck on working out an exercise I ask a colleague, but unless they are teaching the subject they usually cannot help. They know the theorems but have forgotten the derivations and the tricks used in applications. A student taking the course is the best helper.

Sometimes there is a particularly fruitful joint learning situation. About five years ago a bright young man, Irwin Lee, was working with me as a graduate student on a search for elementary particles with fractional electric charge using a new technology version of the Millikan oil drop method [2]. Irwin was taking a course in fluid mechanics and I had to learn the fluid mechanics involved in our experiment [2]. I bought the book being used and he gave me a copy of each problem set. We worked out the problem sets separately and then compared our work. Irwin, now Dr. Lee, was of great help to me and I hope I was a little help to him

Submitted to IPSI Transactions on Advanced Research

Work supported in part by US Department of Energy contract DE-AC02-76SF00515

A few word's on the use of the Internet for self-study. There are Web Sites that offer high level engineering and science courses. My preference is to work with a textbook and a paper notebook (not a computer notebook) using the notebook's pages to do the exercises and to fill in missing steps in the textbook. Of course one can use the textbook and a computer notebook or just use the a computer if the course is on a Web Site. I prefer a real book that I can carry with me and I like the pile of real papers with my work written out.

Now what about my attempt to learn the rudiments of string theory. I dropped my self-directed course in the middle because that the time required conflicted with the strength of my motivation. From the beginning I had no hope of contributing to string theory itself, I am not sufficiently mathematically agile. I did hope that I would learn enough to find a new way to experimentally test some parts of the theory. And here is where being eighty was a limitation for me. I was not willing to spend my limited time. And my skepticism about the relevance of string theory, at least in my lifetime, made me wonder if I was wasting my time.

When I was a Columbia Ph. D. student, it was different, there seemed to be infinite time for learning. About 1952 I took a general relativity course under Llewellyn Thomas of Thomas precession fame. It was hard work because Thomas was a notoriously poor teacher. I never expected to contribute to the field of general relativity because I had already realized my limited mathematical agility. But theoretical and observational work in general relativity was growing and I wanted to be able to follow that work.

Now I am deciding what self-directed course to take next. Eric Lee [3], I, and our colleagues have just completed a decade long series of searches for elementary particles with fractional electric charge. We found nothing but did develop the technology of working with small liquid drops, about 25 μm in diameter. I am working on ideas for extending our technology to searches for hypothetical, very massive, stable charged particles trapped in bulk matter [4]. There are two new technologies that may help me: microfluidics and nanophotonics, I have bought text books in both areas [5,6] and am deciding which area to study first.

Also I want to be more knowledgeable in statistical mechanics. Perhaps some subtlety of statistical mechanics will allow me to look for these hypothetical massive particles. My statistical mechanics course at Columbia was taught by the Nobel Laureate Isadore Rabi who was my thesis advisor. Rabi was also a notoriously poor teacher and our textbook was Richard Tolman's *Principles of Statistical Mechanics* ; a thick book, long on philosophy but short on how to calculate. The book was useless to me. So I have acquired a stimulating new statistical mechanics book [7] .

For the next few of my semesters I'll study microfluidics, nanophotonics and statistical mechanics. Meanwhile if string theory is verified by a measurement equivalent to Eddington's verification of the factor of 2 in Einstein's formula for the bending of light, I can go back to studying string theory.

[1] For my diffractive optics studies I used E, Hecht, *Optics*, Fourth Edition (Pearson, San Francisco,2002) and J. W. Goodman, *Introduction to Fourier Optics*, Third Edition (Roberts & Company, Englewood, 2005).

[2] I. T. Lee *et al.*, Large bulk matter search for fractional charge particles, *Phys. Rev.***D66**, 012002 (2002).

[3] E. R. Lee *et al.*, Automated electric charge measurements of fluid microdrops using the Millikan method, *Metrologia* **41**, 1 (2004).

[4] M. L. Perl *et al.*, The search for stable massive elementary particles, *Int. J. Mod. Phys.*, **A16**, 2137(2001).

[5] P. Tabeling, *Microfluidics* (Oxford University Press, Oxford, 2005).
[6] P, N, Prasad, *Nanophotonics* (Wiley-Interscience Hoboken,2004).
[7] J. P. Sethna, *Entropy, Order Parameters, and Complexity* Oxford University Press, Oxford, 2006).