# Questions about Teaching Technical Topics Online

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Posted at www.eecs.berkeley.edu/~wkahan/QusTeach.pdf

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## Abstract:

In 1960, my computerized (on an IBM 650) grading of an exam on Numerical Analysis turned out to be disastrous. What did that teach me?

In 1961-3 I taught sophomore calculus to electrical engineers with one lecture per month and five supervised problem-solving hours per week. It worked well if judged by encomiums from students encountered several years afterwards. But why, after the second year of teaching this way, was I commanded to stop it?

In 1969, upon my arrival in Berkeley, what stopped me from trying to teach calculus via problem-solving as I had done several years before? (But I did run the *Putnam Problems Practice Seminar* for the dozen years before retirement.)

To a course about analysis, problem-solving, and/or engineered designs, what value can an experienced teacher add that a student cannot get nearly so easily from a book, a DVD, or an automatically graded online course?

# Contents

# Early Experience

**1954:** New graduate student instructor, started teaching at Univ. of Toronto.
Reputation for persuasiveness: I can "*Lecture the Leaves Off the Trees*".

**1960:** New Ass't Prof. of Math. and of Computer Sci. at Univ. of Toronto.
An early morning lecture (90 min./week for 15 weeks, 1 unit credit) on
Freshman Numerical Analysis for Math., Physics & Chemistry.
1st. 20 min./lecture reviewed solutions to previous week's problems
solved with ubiquitous Slide-Rules (no hand-held calculators**!**)

This subject can be mind-deadening. How interesting were my lectures?
Each was attended by almost all of about 100 enrolled students.

Final exam designed to be graded by computer (IBM 650, punched cards):

"Perform any four of the following six computations.
Earn 8 points for every correct sig. dec.
Lose 8 points for every incorrect sig. dec., so don't just guess**!** "

Problems' data were pseudo-randomized via the student's surname.

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Problems were designed painstakingly so that, in a 3-hour exam, …

1 sig. dec. $\Rightarrow$ Acquaintance with the topic (~ 15 min,)
2 sig. dec. $\Rightarrow$ Modest competency (~ 25 min,)
3 sig. dec. $\Rightarrow$ Substantial understanding (~ 35 min,)

# DISASTER **!**

Average score $\approx$ 25 Max. scores $\approx$ 70 - 80

A senior professor (G. de B. R.) over-rode my grades by adding 50 to each.

# WHAT DID THIS DISASTER TEACH ME ?

- No matter how memorable the lecture,
  students will understand far less of it than the lecturer intended
  unless it is reinforced promptly by ample interesting practice.

- Though pernicious, ***Grading on the Curve*** is pervasive because
  the throughput of diplomas and certificates from our educational institutions
  is predetermined
  and correlated weakly with the competencies they are presumed to certify.

Educators must strive to inculcate understanding
not so much as an academic ideal but rather
to resist acquiescence to incompetency,
if only in self-defence.

~~“Tout comprendre rend très indulgent.”~~
~~(Mme. de Staël, 1766-1817)~~

**1961 - 1963:** Teaching the Second Year of Calculus to Electrical Engineers

- One lecture per month to survey the topics in a chapter of the textbook.
- Five hours per week, one hour per day, of supervised problem-solving.
  - About 70 students supervised by me and two TAs.
    - First day or two: Drill exercises from the text.
    - Rest of the week: My problems, many from Elect. Eng'g.
      - Supplements: Putnam-type problems for top students & TAs.

- TAs and I walked the aisles looking over students' shoulders.
  - Some collaboration was encouraged; quick student paired with slow.
  - TAs trained to answer a student's questions only with more questions.
  - Intervention with questions if a student seemed stuck or mistaken.

Goals, besides covering the prescribed topics:

- Get students to practice asking themselves questions, imitating us.
- Diagnose misunderstandings promptly before they become entrenched:
  - Entrenched misconceptions take far too long to correct by questions.
  - When the student appears to be on the road to discovering the facts, let that triumph be *his*, not ours. Don't wait for his "Aha**!**".

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## How well did that teaching system work?

- There were occasions when students described me as "Sadistic".
- For 3 – 10 years afterwards, a few students would go out of their way in the streets to tell me how much better equipped they were than contemporaries, who had not taken the course from me, for subsequent classes, industrial jobs, prelim. exams in grad. school, research, … . More important,

  They had a better understanding of what "Understand" means.

But after two years teaching that way,

the Math. Dept's Chairman, with regrets, commanded me to *Stop It*.

WHY ?

**1961 - 1963:** Teaching the Second Year of Calculus to Electrical Engineers

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WHY ?

Complaints came from professors in the Elect. Eng. Dept. about excuses offered by students to explain their late Lab Reports:

They had been working on Prof. Kahan's problems.

(And some students had muttered doubts about an E.E. Prof's explanations of Transient and Steady-State behaviour of L-C-R circuits already explained by a few of Kahan's problems.)

**1969:** Berkeley Prof. of Math., of Computer Sci., & in the Computing Center.

What stopped me from trying
to teach technical subjects via lots of problem-solving
as I had in 1961 - 1963 ?

- **Crowded Syllabi**

  We try here to "cover" almost as much in 20 weeks as were allocated 36 weeks at the Univ. of Toronto. Are Berkeley students so much faster?

  *E.g.*: Prerequisite Math. courses must cater to listed needs of other departments, thus crowding the syllabus with topics to memorize.

  **More time is the proper remedy.** Don't succumb to the temptation to offer each department its own Math. or CS courses, thus enforcing insularity.

- **The Smorgasbord of Course Offerings**

  A student can or may have to choose a course so long, like a semester, after taking its prerequisites that they have been forgotten, so an instructor has to spend too much time "reviewing" them for a fraction of the class.

  **Only computerized online instruction can ameliorate this problem.**

  Then an instructor can say "Next week we shall need these prerequisites: … " and offer URLs.

Besides covering the relevant topics,

a good course on analysis, problem solving and/or engineered design conveys to students …

- Understanding that goes far enough beyond mere memorization that it becomes apparent when students use it to practice solving problems.

- Diagnosis and repair of misunderstandings before they become entrenched.

- A habit of asking relevant and sometimes impertinent questions.

  This may require re-ignition of a student's curiosity and imagination stultified during earlier "education" blighted by narrow-minded or impoverished implementations of doctrines like "No Student Left Behind".

What is Understanding?

What is Misunderstanding?

# How does Understanding differ from mere Memorization ?

Sales of a succinct answer to this question could bring its publisher great wealth.

## Partial Answers:

By linking Imagination with Memories,
Understanding opens unobvious opportunities to apply them together.

There is no pill you can swallow and then know
just what you wished to know but no more.

If you wish to understand a topic,
you may have to learn far more about it than you intended.

Each mind has its viscosity, some more than others,
which limits how fast understanding can penetrate,
so Understanding costs both students' and teachers' time.

Mere Memorization happens a lot faster, though often inaccurately, and
cannot be distinguished easily from Understanding until
a Misunderstanding is revealed.

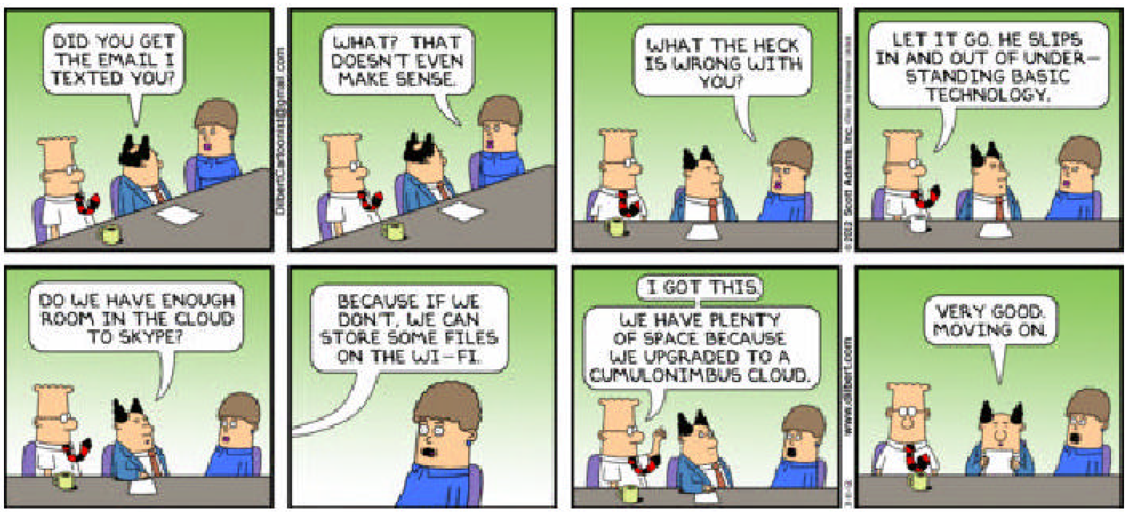
# How is Misunderstanding like Hard-Core Pornography ?

It may be difficult to define well enough,

"… But I know it when I see it, …"

Supreme Court Associate Justice Potter Stewart (1964)

See "Dilbert" by Scott Adams for 11 Mar. 2012 :



Diagnosis and correction of misunderstanding remains difficult for interactive online instruction without individualized attention from a human instructor.

Some other options are …

- "Tricky" multiple-choice questions refreshed often to foil mere memorization.
  Someone who misunderstands a topic will think such a question tricky.

- Answers requiring derivations that MAPLE or MATHEMATICA can check.
  Feasible currently only for algebraic derivations.

- A student's attempted answer goes out to a forum other students scrutinize.
  But don't put too much faith in "The Wisdom of the Crowd" ...

# What can a Forum on a Social Network teach ?

## **"The Wisdom of the Crowd"**

But it too often propagates a widely believed falsehood,
especially if believed by a dominating personality.

*E.g.*:

- Computational Rules of Thumb inherited from Slide-Rule era were *Never Correct*, and yet perpetuated in FORTRAN, C++, JAVA, …
- Consensus in 1950s that Floating-Point Arithmetic is refractory to Error-Analysis, an opinion misattributed to John von Neumann
- *Greed is Good* according to the *Great Communicator*; but what about its mate *Selfishness*? Isn't Greed among the seven deadly sins?

**Truth does not triumph. At best, it endures.**

Teaching a technical topic, the Wisdom of the Crowd malfunctions occasionally unless monitored by an experienced instructor, and sometimes despite that.

Someone who has faith in the Wisdom of the Crowd has not served on many committees.

## Can Online Instruction Ultimately Dispense with Experienced Teachers?

Not for courses on analysis, problem solving and/or engineered design.

( I cannot speak for topics like the History of Ancient Art, or Baroque Music.)

Some fields, like Engineering and Science, change rapidly enough to render obsolete some of last year's instructional material. Undergraduate Mathematics and Statistics change little, but their tools, like MAPLE, MATLAB, …, change enough to require revisions every few years.

Moreover, all these fields require continual refreshing of exercises and exams to combat mere memorization posing as understanding.

Hereunder follows an illustration of an experienced instructor's introduction to a concept that many people find difficult. Some memorize all of it including the exercises' solutions without understanding the concept. As you read it, ask ...

"How can someone misunderstand this?
And how can that misunderstanding be detected, diagnosed and corrected?"

An experienced teacher has seen almost all of a topic's misconceptions that any student can imagine. To incorporate defences against all of them into a lecture course just bores most students by belaboring the obvious. Instead, a lecture should be kept as short as possible. Then the more common misconceptions can be fended off by aptly chosen exercises assigned immediately after the lecture.

Example: Do not *introduce* the concept of a sequence's ***Limit*** by saying

" $\lambda = \lim_{n\to\infty} x_n$ " just when, as many a textbook still says,

for every $\varepsilon > 0$, there exists some $N(\varepsilon)$ such that

" $\varepsilon > |x_n - \lambda|$ for all integers $n > N(\varepsilon)$ " .

Instead say

" $\lambda = \lim_{n\to\infty} x_n$ " just when

every open interval around $\lambda$ contains all but finitely many $x_n$ 's .

Exercises: For each #… determine $\lambda = \lim_{n\to\infty} x_n$ only if it exists.

#1: $x_n = (-1)^n$

#2: $x_n = \big(1 + (-1)^n\big)/n$

#3: $x_0 = 9$ and $x_{n+1} = x_n/2 + 1/x_n$

#4: $x_n = \tan(10^n \text{ degrees})$

#5: For every $N$ there exists some $\varepsilon > |x_n|$ for all integers $n > N$ .

# Explanations for the foregoing Example:

- First the instructor must provide an example of convergence to a limit, like a bounded monotonic sequence $x_n = 1 - 1/10^n = 0.999...999$ .
- Next the instructor must demonstrate the equivalence of the two definitions of the Limit concept by deriving the $\varepsilon$ - $N(\varepsilon)$ definition from the succinct one.

Many texts show just "N" instead of "$N(\varepsilon)$" written here in an attempt to fend off a misconception revealed by exercise #5 if only "N" were used.

#1: $x_n = (-1)^n$ shows that a sequence $\{x_0, x_1, x_2, ..., x_n, ...\}$ need not have a limit.

#2: $x_n = \left(1 + (-1)^n\right)/n$ shows that convergence to a limit need not be monotonic.

#3: $x_0 = 9$ and $x_{n+1} = x_n/2 + 1/x_n$ converges. *To what*? *Why*? (It's not hard.)

#4: $x_n = \tan(10^n \text{ degrees})$ reveals a defect in some hand-held calculators. *What*?

#5: For every N there exists some $\varepsilon > |x_n|$ for all integers $n > N$ . Whoever says " $\lambda = 0$ " doesn't understand why $\varepsilon$ must be chosen *before* N.

What makes the *Limit* concept so difficult for some students to understand?
Perhaps their first experience of mathematics not simply computational; or perhaps the rôle of inequalities in finding a limit and proving it exists.

Many concepts are harder to understand for some than for others; for instance, ...
Proof vs. Persuasion; Music vs. Noise; Creation vs. Excretion of “Art”.
Entropy, Probability, Statistics, the Central Limit Theorem.
Set Theory, Infinite, Countable, Uncountable, Constructible.
Stability, Controllability, Reachability, Limited Predictability vs. Chaos.
Genetics, Evolution, Altruism, Nature vs. Nurture, Racial Differences.
. . .

All teachers often find Memorization hard to distinguish from Understanding:
**Memory** recognizes vastly many situations & for each an appropriate procedure.
**Understanding** synthesizes appropriate procedures by combining curiosity with imagination and relatively few understood principles.

We need both kinds of people. Computers can easily help teach the first kind, not yet so easily the second, without costly experienced individual interaction. Let’s not fool ourselves into thinking the computer has done more than it can.

The greatest promise of the Computer,
if we are clever enough to realize it, is that
computers can treat humans more humanely than humans do,
and can relieve some of the burdens that fall upon
those of us who must deal with other humans.