From semi-empirical ideas to from-first-principle pedagogy

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1. How to teach better: an important question

- Instructors are bombarded by empirically successful innovative pedagogical ideas.
- For many of us, it is difficult to separate:
  - truly effective techniques from
  - techniques whose empirical success is largely due to their promoters' enthusiasm.

2. Why it is difficult to decide: an example

- In Russia, where two of us are originally from, we have a clear example of this.
- At some point, Andrei Kolmorogov, a great mathematician:
  - was frustrated by the results of school math teaching, so
  - he came up with his own techniques (and his own textbooks).
- He himself volunteered to teach in school.
- When he taught himself, it was a spectacular success.
- This success encouraged school boards to switch to the new techniques and new textbooks.

3. Why it is difficult to decide: an example (cont-d)

- The result this time was a disaster: much worse outcomes that for the traditional teaching.
- This, unfortunately, is a rather typical example:
  - a new teaching method is proposed,
  - enthusiastic instructors use it and get great results,
  - administrators like this success and ask everyone to use it,
  - and the results are often not good.

4. What psychologists advice

- One known way to separate them is to select ideas supported by psychology and neurophysiology.
- This sounds like a great idea.
- The problem is that different psychologists endorse different approaches.
- To decide whom to follow requires a deep understanding of psychology.
- And most of instructors know even less about psychology than we know about pedagogy.

5. What we propose: general idea and an example

- We propose an alternative: to select pedagogical ideas that naturally come from first principles.
- We show that some ideas can be thus derived.
- An example is Ukhtomsky's dominant theory:
  - each person has some area in which he/she can perform the best, and
  - one of the teacher's tasks is to help the student find this area.

6. How Ukhtomsky's dominant theory can be explained from first principles

- In mathematical terms, Ukhtomsky's theory means that the student's productivity has a unique global maximum.
- Why?
- A person's productivity is affected by many difficult-to-predict factors.
- It is kind of "random".
- And under some reasonable assumptions, random functions do have a single global maximum.
- Indeed, suppose that we have two points $x \neq x'$ at which the function attains its maximum M.

7. How Ukhtomsky's dominant theory can be explained from first principles (cont-d)

- The points x and x' can be separated if we:
  - form a segment xx',
  - take its midpoint m, and
  - form a (hyper)plane starting at m which is orthogonal to xx'.
- This plane divides the space into two half-spaces containing, correspondingly, x and x'.
- Parts of the function at each half-space are reasonably independent.
- So, the difference $d = M_1 - M_2$ between the maxima of two subspaces is random.
- For a truly random variable, the probability of being exactly equal to a given number is 0.

8. How Ukhtomsky's dominant theory can be explained from first principles (cont-d)

- So, in almost all cases, this difference is not 0.
- This means that the maxima M_i cannot be equal – contrary to our assumption.

9. But is it a good idea?

- Ukhtomsky's idea may be good for each person.
- But a natural question is: is it good for the society as a whole?
- Suppose that too many people have the most talent in poetry.
- So we will have millions of poets and not enough, e.g., teachers?
- A counter-argument is that many great discoveries – that eventually brought great help to humanity – were considered useless at that time.
- Even electricity started as a useless study – not to mention quantum physics and relativity theory.
- Are poets useful the same way? Yes, e.g., Einstein famously said that in his discoveries:
  - he was much more inspired by the writer Dostoyevsky
  - than by the mathematics of the great Gauss.
- If we let everyone fully utilize their talent, we will get the most gain – and this will help future success.

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