[What] to teach or not to teach
- That is the question -

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The first century of modern geotechnology is coming to an end. There has been an explosion of knowledge in our field, and we have gained great insight into soil and rock behavior through exceptional experimental and numerical capabilities. Today, our field is broader than any single person can master, and we publish in more journals than we can follow (probably more than 30 journals, complemented by a similar number of trade magazines). There is unlimited access to information, and effective measurement systems and powerful analysis/design tools are readily available.

The first century has also highlighted difficulties in geotechnical design, to the point that we have extensively accepted that our field is a combination of both art and science. Could this be the reason for consistently disappointing blind prediction exercises? We need to reassess the role of empiricism, question often invisible biases and incorrect concepts or approaches that have crept into teaching and practice, and bring back an emphasis on deep understanding coupled with multi-disciplinary fluency.

Research and education are warranted by the practice of geotechnical engineering. Our students today will reach the prime of their professional careers at the time when geotechnical engineering challenges that are sprouting today will dominate their professional lives, for instance, issues related to climate change, sea level rise, energy needs and sustainability. Confronting those needs will require a sound and resourceful scientific foundation. In this context, let's pause to reflect on our educational programs.

Bare Core: The Fundamentals

While knowledge has expanded, teaching time remains limited and only a very small subset of concepts can be covered in the curriculum. I often wonder about the key fundamental concepts our students should deeply understand if we were forced to reduce the contents of our courses to a bare minimum, say, a few pages, while satisfying multi-disciplinary fluency. The underlying assumption is that young engineers will be able to readily add pragmatic procedures to a well-funded knowledge structure while still preserving the engineering versatility fundamentals provide.

Clearly, they will need mechanics (e.g., equilibrium and plasticity), physics (e.g., conservation), chemistry (e.g., water and minerals), biology (e.g., limiting factors to life and bio-mediated processes), earth science / geology (e.g., formation history), and materials (e.g., particulate matter).

For the sake of this letter, let me address the latter. I like to start the course on soils with the fundamental realization that *soils are particulate materials*. Then, all observations summarized in the table below are true and causally related.

The particulate nature of soils was recognized in the early stages of soil mechanics, yet it is seldom emphasized in our classes. Observations in the table apply to all soils and fractured rocks.

Soils are particulate geo-materials, therefore

Soils are inherently non-linear (Hertz and electrical contacts), non-elastic (Mindlin contact), porous and pervious (i.e., porosity between grains is interconnected).

Particle-level characteristics and processes integrate to make the macroscale response

- size: determines the balance between particle-level forces (capillary and electrical forces gain relevance when particles are smaller than 10μm-to-50μm in size);
- shape: reflects formation history and it affects grain packing, anisotropy, stiffness, strength and permeability - among others;
- spatial arrangement: is determined by electrical forces in fine grained sediments (pore fluid pH and ionic concentration), and by grain shape and relative grain size in coarse grained soils;
- porosity: varies widely and it is stress-dependent in [unstructured] fine grained soils, but it varies in a narrow range and it is mostly defined at the time of packing in coarse grained soils.

The particulate skeleton (frictional) coexists with the pore fluids (viscous)

- both are very different: the key is to anticipate their distinct responses to imposed boundary changes
- the skeleton and the fluid interact: this gives rise to coupled fluid pressure, effective stress, volumetric strains and shear response;
- mixed fluids: add capillary effects onto the particulate skeleton;
- generalization: all hydro-chemo-bio-thermo-mechanical processes are coupled.

The mechanical behavior of the particulate skeleton is effective stress-dependent:

- includes: stiffness (Hertz), frictional strength (Coulomb), and dilation upon shear (Taylor)
- frictional strength limits the maximum stress anisotropy a soil can experience
- other properties may depend on effective stress as well (e.g., thermal conductivity of dry soils)

Particle-level deformation mechanisms change with strain level

- small-strain deformation: it takes place at constant-fabric and grain deformations concentrate at inter-particle contacts; in this strain regime, volume change, pore pressure generation and frictional losses are minimal;
- large-strain deformation: it involves fabric changes (the role of contact-level grain deformation vanishes);
- threshold strain between the two regimes: it is higher for smaller particles and at higher confinement.

Soils are not inert, and often change within the time scale of engineering projects

- corollary: natural soils may behave differently than freshly remolded clay or recently packed sand

Not to Teach (Pruning)

There are enduring misnomers, superseded practices and restraining recipes in our field. We all share responsibility for pruning them out; in particular, we-educators, journal editors and conference organizers can play an effective role to this end. Examples follow.

- Terms with multiple semantics: the term "clay" is used to indicate size, mineral (crystal or amorphous), or any soil that plots above the A-line on the plasticity chart. Let's use the term "clay" to indicate "clay minerals", and classify fine grained soils according to their sensitivity to changes in pore fluid chemistry.
- Misnomers: the salient example is "cohesive soil" – this is a dangerous oxymoron indeed. Let's abandon the qualifier cohesion (to the extent that it results from curve fitting improper strength data), and related expressions such as "cohesive soil" and "cohesionless soil".
- Incorrect concepts: We often misuse the term "lubrication" in discussions of friction and to explain the dry-branch of the compaction curve. We imagine primary and secondary consolidation as sequential rather than concurrent processes. We infer peak strength and critical state void ratio even when specimens experienced progressive failure and shear localization. We invoke tensile strength to explain desiccation crack formation. And, we make indiscriminate use of the term thixotropy in relation to time-dependent changes in fine-grained sediments.
- Superseded: We teach graphical approaches that have become detached from their physical-mathematical underpinning (e.g., the determination of coefficient of consolidation using sqrt-t or log-t methods: a simple spreadsheet calculation can readily fit the diffusion equation to the data). We keep concepts developed for hand plotting and hand calculations (e.g., meaning of preconsolidation pressure and its determination), and preserve the use of parameters that add limited information (e.g., plastic limit is highly correlated to LL, then, we need to re-assess its value and the adequacy of PI-based correlations).
- Restrictive/simplistic "tricks" that are not sound: from "buoyant unit weight" and UU tests … to total stress analyses - Are we not ready for a clean parting from total stress yet?
- Fragile correlations and equations with local validity: diagnostic symptoms include dimensionally inhomogeneous expressions and equations that violate asymptotic trends for extreme values of the variables

To Tweak and Refocus

In an attempt to bring clarity, we have polarized soil conditions and have developed a curriculum around extremes. Consider two cases. First, we teach as if soils are either dry or water saturated, while reality involves these two extremes and all unsaturated conditions in between. Second, we cover drained and undrained analyses, yet, these are two extremes when the rate of pore pressure dissipation is either much faster (drained) or much slower (undrained) than the rate of loading.

There are some old-sounding but most elegant concepts that I like to cover in class, but with renewed emphasis on understanding rather than on devoting full focus to the development of engineering solutions. Examples include "feeling" equilibrium with Mohr circle, combining equilibrium and failure conditions in a Mohr-Coulomb analysis to show limiting stress anisotropy in soils, the beauty of elastic solutions, the "essentially engineering" upper and lower bounds (i.e., we do not need the exact solution, but reliable and narrow bounds), and even flownets (i.e., to highlight the identification of boundary conditions and to "experience" flow patterns and seepage forces).

To Teach (Evolving Emphasis)

Gradually, my lectures are evolving by shifting emphasis and incorporating other topics that –in my mind- students will need to remain up-to-date and intellectually agile in a changing world:

- Place continued emphasis on the particulate nature of soils and fractured rocks, and the critical relevance of effective stress! Extend the coverage of other needed scientific foundations (Note: early reviewers of this note suggested a dual track: one that emphasizes skills that will be immediately useful in practice -with exposure to the scientific foundations-, and another that emphasizes the scientific foundations and provides less of the practice-oriented skills).
- Present an updated discussion of formation history and diagenesis, bonding and structured soils (i.e., salient deviations from observations made in the table), natural and manufactured soils (e.g., mine tailings and fly ash), stratigraphy and spatial variability (at all scales).

- Increase emphasis on well-designed field tests to measure properties for engineering design. Principally, the laboratory-measured stiffness/compressibility is critically affected by sampling effects and aggravated by seating effects; in particular, oedometer tests should be limited to situations where the anticipated vertical shortening is a significant fraction of the specimen initial height.
- Extend teaching examples to a wide range of fluids, pressure, effective stress and temperature conditions that upcoming geotechnical problems will impose (including grain crushing effects).
- Emphasize both short- and long-term performance monitoring with a focus on making *a priori* predictions and assessing interpretations (noting that there are innate monitoring limitations such as accelerating bifurcations).
- Increase awareness of the pervasive tendency to localizations of all kinds which break down the common assumption of homogeneity (from shear bands and compaction bands, to dissolution pipes, flow localization, fingering, and a wide range of opening mode discontinuities or fractures).
- Introduce repetitive loads (mechanical, thermal, chemical, moisture): they may determine long-term performance.
- Continue reflecting on the role of the engineer in society, within an ever changing world as the driver for innovation.

Closing - Your Thoughts?

Geotechnical engineering has evolved and continues to develop as a result of the synergistic interaction between education, research and practice. This synergism is needed today more than ever before as our field gains preeminent roles in the most challenging problems humanity has ever faced. I would like to see our students embrace these challenges and thrive in the new opportunities our field presents, and hope that this excitement permeates into the classroom.

Geotechnical education has underplayed the importance of first principles while trying to focus on prescriptive solutions needed by practitioners to solve today’s problems. If we let the pendulum swing further towards the “practice” end, we will delay advances needed to enhance the solution of today’s problems and future generations of students will be ill-prepared to tackle the challenges that our profession will face.

But, choices are difficult, and I must admit that I struggle with the decision of what to teach and not to teach… I look forward to hearing your thoughts! I will compile your feedback -sent to me or directly to this blog- and synthesize it in the closure.