Levels of *What* and *How* in the Education of Geo-engineering on Problematic Soils

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ABSTRACT: Majority of recent studies discussing the development issues of civil engineering education focus the attention on the innovative teaching and learning methods. Evolution of the engineers' habit of mind demands, in addition, the conscious harmonization and synchronization of educational level, basic mathematical and mechanical preliminaries and professional content. Consideration of the interdependence among these factors results in some conclusions usable for educators interested in creating innovative curricula. Distinction between BEng and MEng levels of competence has to be identified properly. Geotechnical works on or in problematic soils deserve this attention, in particular.

KEYWORDS: Burland-tetrahedron**,** Levels of competency, Complexity and multidisciplinarity, Analogy with medicine

1. INTRODUCTION

Society demands professional knowledge at its every possible level. However, there is a conflict of interest between the traditional content offered by the educating institutions and the current need of society; there is a permanent dissonance between the long waves of educational supply and short term employment demand. That is why practicing educators, politicians and professionals have to discuss occasionally the definitions of education levels, the content of knowledge to be obtained at these levels, the time period of education, the identification of the relationship between educational credentials and professional training.

Students enrolled in undergraduate courses on geo-engineering are scarcely aware of the learning challenges they face if had engaged this profession. Their visions about their future competence and activity are influenced and motivated by case histories, often presented in the first classes, describing magnificent projects, challenging situations, dramatic failures and elegant structures. Explanation of the subject, time and effort needed for earning a grade in geo-engineering knowledge often erode this enthusiasm, both that of the student and the teacher. Well-established previous studies, professionally selected content of the subject, innovative methods of teaching may compensate this fade-out.

Educators of geo-engineering accommodate themselves to this challenge. Papers presented at earlier and recent conferences, conference sections and symposia (such as edited by Manoliu and Radulescu, 2008, McCabe, Pantazidou, Philips, 2012, Prakash, 2013, Jaksa, 2013) pay due attention to actions that could or should be done for identifying and developing best practices.

Most studies and discussions focus on the considerations and techniques aiming at the evolution of the students' geo-engineering habit of mind. Adaptation and application of innovative teaching methods have been conscious (Mitchell, 1999, Jaksa, 2013). There is a general consensus that the MEng level knowledge must be complex and multidisciplinary. Otherwise, educating methods cannot be ranked; almost any of them can be effective in given local circumstances, traditions, teacher's educational and didactic initiatives. Case studies are used in all teaching techniques fruitfully.

Less wide consensus appears to be about the structure of the curricula, when the two stage system (BEng and MEng, traditional in the Anglo-Saxon cultures and introduced recently in the European Union) was accepted (Augusti, 2006). Linear ranking of the educational levels (first bachelor, then master) makes necessary the proper distribution of content, both from the technical and intellectual points of view. Furthermore, importance of harmonization of the evaluation methods used for student performance qualification is increasing in the era of global mobility (escorted, for instance, by the introduction of the European Credit Transfer and Accumulation System – Patil, Codner, 2007).

Purpose of this paper is to outline considerations using some findings of cognitive psychology, based on which several debated questions could be answered with relatively little bias. Example of geo-engineering is used to illustrate the points, because of its specific features considering problematic lessons and habits of mind.

This attitude was motivated by the students' question: do I really need to learn structural mechanics to become a good geo-engineer? with the teacher's answer: yes, you must. And vice versa.

2. VOCATION AND CONSCIOUSNESS

Success of the work done in the undergraduate (BEng) geo-engineering curriculum remains uncertain if enthusiastic students are not aware of the knowledge, intelligence and experience needed to earn the geo-engineer's full (MEng) competence. One of the possible educational strategies to rouse and stabilize the vocational stimuli is to tell them at an early stage how the geo-engineer controls the problematic phenomena and lessons inherent in her or his profession.

Educators have both the chance and responsibility to enlighten in due course (and not too late) why the habit of mind in this field is built onto multidisciplinary knowledge. Two features of this problematic character occur both at BEng and MEng level. There seems to be no reasons to procrastinate their discussion or couple them with professional contents.

Dimensional modelling considerations

Undergraduate courses for structural engineers focus on constructions compiled from simple structural parts (such as rods, beams, plates, walls). Mechanical behavior of these elements, as a rule, can be described by 1D stress and 2D stress models treated in the introductory treatise of mechanics. Homogeneity, isotropy and linearly elastic constitutive response of these bodies are common assumptions. Theory of structures concentrates on the questions (such as large strains or spatial stability) connected with the 3D displacement freedom of 1D or 2D elements. Advanced models assume more and more sophisticated structural behavior.

Except from some important plane strain problems geo-engineers are facing structural configurations embedded into 3D regions from the very beginning. Surrounding ground of the engineering structure is inherently problematic with respect to the mechanical simplifications applied commonly in the undergraduate curricula. Extension itself of the ground region to be considered is a question to be answered at the model creation stage. Inhomogeneity and anisotropy, inclusions (either reinforcing or weakening ones), arching phenomena appear in the region of interest. Estimated earth pressure or bedding coefficient distribution on soil-structure interfaces serve as lumped proxy for actual loads.

Complexity

Professional attention of the geo-engineer has to be extended to the mechanical behavior of the surroundings of the engineering structure. Full exploration of the ground profile (including its geological origin and constitutive characteristics) in the vicinity is possible but exceptionally. Multiphase soils can be saturated with water, or – as a worse case – with contaminating substances.

Construction technology impact on the undisturbed initial state of the ground has to be considered. Its response is temporal, consolidation and other time-dependent processes occur.

All these problems and circumstances can be illustrated with the Burland-tetrahedron (Figure 1), where the vertices represent the four main perspectives the geotechnical problems have to be analyzed from.

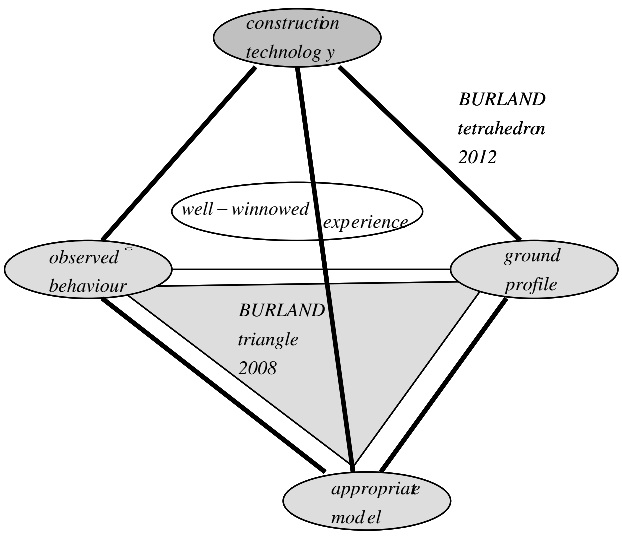

Figure 1 The Burland tetrahedron (Ray et al, 2013)

Of course, there are many conventional problems and works where one or more of the perspectives are easy to handle. Ground profile can be homogeneous, well-established computational methods can be available to cope with a simple mechanical behavior, construction technology can be determined by market considerations or by the developer's interest. Most of the models, geotechnical structures and technologies taught at the BEng level belong to these classes of problems.

It is interesting to realize that in cases, where problematic soils are to be dealt with, one of the vertices gets a primary importance. Well-winnoved experience suggests, however, that all the three perspectives displayed in the other vertices of the tetrahedron obtain importance, at the same time. That is one of the reasons why it is worth clarifying from the very beginning in the undergraduate curriculum how long and labour-consuming is the way to gain a good command on the knowledge of professional, economic and attractive geo-engineering solutions.

2. LEVELS OF EDUCATION

Researchers exploring artificial intelligence have been for decades investigating the learning and experience building mechanisms that are typical for the learning and validation of a profession. They found that different levels of professional knowledge and preparation can be suitably described by the number and complexity of cognitive structures associated with each, as well as their organization.

In the technical sciences the complexity of the problems and steps of their solutions can be structured in accordance with very general schemes as follows (Mérő, 2001, Scharle, 2005):

- observation, understanding, and anticipation of the phenomenon, situation, and process;
- recognition and description of tasks related to the progression;
- identification and analysis of the necessary and possible interventions;
- clarification and handling of expectable consequences;
- determination and technical execution of intervention steps.

Along this sequence of stages (and in accordance with the technical "jargon") model is probably the most expressive concept. It encompasses all mathematical, physical, technological and material-tectonic relationships that approximate reality and its behavior to an extent acceptable in the given circumstances.

From this perspective the essence of higher education in the engineering fields is the introduction of technical models of phenomena and processes. The curriculum includes theories and relations that more or less describe reality, explores the validity and applicability of these models, and discusses the prerequisites, methods and steps of application.

A well-educated professional is familiar with the most common and important phenomena, knows the relevant models, and is able to apply them to solve particular technical problems. Here it is sensible to differentiate between levels of professional expertise from the perspective of their relationship to the inventory of models (Scharle, 2008).

The levels can also be described by competencies as follows:

Bachelor – BEng

- Recognizes frequently occurring phenomena.
- Is familiar with the profession's simpler models and their application.
- Correctly selects the models that can be employed for simple phenomena.
- Is able to involve the apprentice in model application by creating simple subtasks.
- Understands and executes the steps according to the model selected by the master.

Master – MEng

- Recognizes phenomena and correctly appraises their complexity.
- Knows the profession's inventory of models and the prerequisites and limitations of their applicability.
- Is aware of the limitations of her/his own competency.
- Is able to cooperate with masters of other fields in the solution of a complex problem.
- Is able to select the optimal model to solve a particular problem.
- Grasps the complete process of intervention, and is able to incorporate in particular steps the expertise of the apprentice and bachelor according to their skills.
- Recognizes phenomena that require the further development of the model inventory, understands the way doctors think, and can utilize their recommendations.

All these competencies may appear at all levels of education and there can be broad overlaps for a number of reasons. The educator's preparedness and perspective has an obvious role (many faculty members teach graduate students rather simple models extensively and with routine at the BEng level of expertise while a good grammar school teacher can make his interested pupils acquainted with pretty complex models using the master's perspective).

In this perspective credits can be tied to the size of the taught inventory of models. Undergraduates are prepared for the use of a relatively simple set of models accepted and "broken in" for the solution of already largely known, recurring problems. Perception and identification of the unconventional, problematic phenomena, selection and application of the adequate models assume MEng competence, as a rule (Ray et al, 2012).

Interdisciplinary skill is the entrance to be gained for coping with the challenges in this field. Consequently, engineering education must offer all its courses at all levels consciously and openly stressing this compound demand.

4. INTERACTIONS AND ANALOGIES WITH OTHER DISCIPLINES

In communications with structural engineers difficulties may arise from the difference in attitudes of modelling the problem. Works dealt with by structural engineers are mostly modelled with well-defined boundary conditions (prescribed loads, support displacements).

Geotechnical models involve explicit uncertainties, both in the field of interest and at its boundary. The ground, as an open space, has to be truncated at a range where the kinematical state can be assumed to remain undisturbed. This difference is essential and has to be consciously taught.

Burland (2008) explains how a structural engineer encounters the geo-engineers' habit of mind when working on an ancient building to be reconstructed or rehabilitated. This activity is analogous with that of the geo-engineer. One has to track down the genesis of the building, to find existing discontinuities, determine constitutive parameters for materials used many decades (even centuries) ago, to reinforce or replace existing elements at site, to scrutinize expectable interactions with other constructions in the vicinity. That is why structural engineers involved in tunneling are the most understanding partners in co-operation with geo-engineers.

There exist several less plausible or tangible analogies worth mentioning. Student learning can be supported by explaining correspondence between sport and soil mechanics (McCabe, Jaksa, 2012). Complexity, multidisciplinary character and ways of solving problems establish another analogy, that of with medicine (Ray et al, 2013).

Physicians – in particular, internists – start with collecting symptoms, medical reports and findings, maybe complaints of the patient, all information about prior sicknesses and treatments. Then they try to connect, interpret, organize the data to identify syndromes, using the experience drawn from previous cases. The next step is to conclude one diagnose and then follows the therapy. In complicated (or problematic of any reason) cases observation continues, sometimes multidisciplinary council is chosen with partners having communication skill.

Medicine, being as complex profession as engineering has specifications. Some activities (such as surgery) are more straightforward, follow well-established protocols, work in specific or well-defined circumstances. It may turn out that surgeons' habit of mind is closer to that of the structural engineers than to that of their fellow internists (not to mention dermatologists).

Role of cases in medicine is like in geo-engineering. Cases serve as resources of collective experience. In university clinics medical students at the bedside learn to understand uncertainties, complexity, alternatives of treatment and risk of the possible complications of intervention. Therapies may follow simple or regular protocols or singular specifications.

Without overstressing the analogy it seems to be clear that geo-engineering follows the same approach. Geotechnicians have to correspond with a similar immanent structure of their lesson: to face the problem as a whole, to look at the subject as embedded into its interacting environment. This analogy is a genuine argument for those stating that geo-engineers should be (even might be exclusively) educated for the master level; no real BEng competency exists or can be defined, since all geotechnical works are problematic in some sense.

Authors think this conclusion remains disputable. Plenty of daily geotechnical lessons can be solved at the BEng level. Even the medicine analogy is available here: medical advisers, family doctors are working in the health service system with due competency to cure simple complaints according to established protocols, and with responsibility to identify and direct more complex or complicated cases to specialists. Systematic educational stages in medicine (where obligatory trainings result in particular specialist competences) correspond with this rating mechanism.

5. CONCLUSIONS

Interdependences illustrated in the Burland-tetrahedron are worth explaining and teaching already in the undergraduate geo-engineering curricula from the very beginning. Understanding of the 3D character featuring in the geomechanical problems could be supported by harmonization of geo-engineering subjects with preparatory basics (mathematics and mechanics).

Undergraduates can be qualified, as a rule, for treating conventional geotechnical problems with standard protocols. Graduate education can (and should) result in established habit of mind needed to identify the problematic phenomena, complexity of lessons and select adequate solution methods. This difference in the levels of competence can (and probably should) influence the content, methods and evaluation techniques applied in the education.

Explanation of the apparent analogy with other professions of similar complexity and interdisciplinary features (in particular with medicine) may contribute to conceive and understand better the geo-engineer's mentality.

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