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Case Studies — Pavement of the Educator's Road

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ABSTRACT

One of the lessons of educational strategies in geo-engineering is to inspire the students' motivation by telling them how the geo-engineer thinks and why is it worth attaining. The Geotechnical Triangle developed by Burland proved to be a useful conveyance to deliver essentials of the geo-engineers' habit of mind. Slight extension of this simplex to a tetrahedron brings into the framework the construction technology, equivalent of importance with ground profile, observed behavior and appropriate model. Case histories retain their central role within this 3D simplex. In this perspective geo-engineering proves to be analogous with medicine where concepts such as symptom, syndrome, diagnose and therapy appear and case histories in teaching have a central role, as well. This role has got an institutionalized representation in Eurocode 7, the new standard for geotechnical design brought into force in the EU by 2010.

INTRODUCTION

Issues about engineering education emerged into the focus of academic interest for the last decade. Particular attention has been paid to the professions where the general principles, techniques or good practices do not work without specific refinements. Geo-engineering seems to belong to this set. Probably that is why so many conferences open space for the discussion on teaching and learning issues.

Case histories appear in these forums as natural "public vehicles" conveying common knowledge and experience about exploration, observation, design, construction activities in geotechnics. At the same time, they prove to be indispensable tools of teaching and learning.

As a consequence, combined interest focused on both case histories and education inspires advanced research concerning particular features involved in geo-engineering, outstanding studies reporting good practices in composing curricula, courses and subjects, suggestions for teaching techniques proven successful.

Participants of a recent conference (*Shaking the foundations of geo-engineering education*, Galway, Ireland, 2012) had got and gave each others an extensive and comprehensive, up to date overview of the present state, questions to be answered and suggestions for future works. From considerations derived from cognitive sciences, across conclusions following from the measures taken by the institutional environment (concerning, for instance, accreditation and licensing), to actual educational activities the immanent case-interdependency has been reflected. This feature, even if not exceptional, is characteristic of geo-engineering. The paper outlines four contributions enhancing the comprehension.

BURLAND'S SIMPLICES

His first simplex, the Soil Mechanics Triangle had been developed by J.Burland in 1987 to identify some distinct but interlinked aspects as essentials of geotechnics. The prior intention was to enhance teaching of four concepts and activities placed at the nodes and the centre in comparison of several other aspects preferably called "very important" in soil mechanics.

During the years elapsed since then the configuration proved to be stimulating for educational and usable for other purposes (such as communicate with partners from other professions in expertise and design co-operation). The triangle represents the main aspects characterizing the geo-engineer's habit of mind, as described by the founders and masters of the profession.

Experience of two decades resulted in renaming and slightly modifying the simplex (Burland, 2006). The Geotechnical

Triangle (Fig. 1.) has been one of the most frequently referred schemes in the literature of geotechnical education. Indeed, there is a consensus in the content and the interdependencies reflected in the configuration.

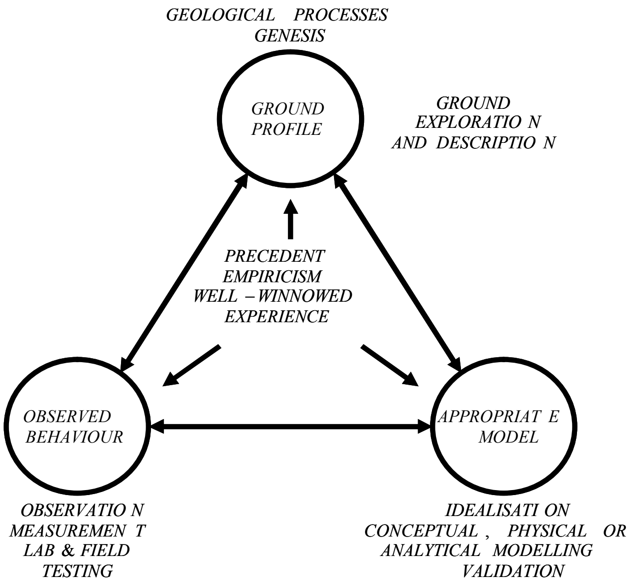

Fig. 1. The Geotechnical Triangle

Certainly, the Geotechnical Triangle is complete and compact with respect to the activities it covers. It does not reflect, however, a further aspect, appearing to be as essential as the other three: construction technology. The cluster of possible (reasonable, available, suitable, necessary, payable, etc.) implementation alternatives has a particular influence on and is interdependent with the other actions placed at the vertices of the Geotechnical Triangle. Even development and research are considered in the professional literature as technology-driven activities.

This slight addition can be illustrated by extending the triangle to a tetrahedron (Fig. 2). The configuration remains symmetric (there is no need to rank the vertices). The centre remains the same. Case-generating role of construction experience (Peck, 2004, Orr & Pantazidou, 2012) becomes more plausible. Teaching practice justifies this attention even at the undergraduate level (Nash, 2012). Hence, authors of this paper were pleased with having the consent of Jim Burland to retain the name of the configuration as Burland-tetrahedron (Ray et al., 2012).

Due to the discussions inspired by the idea the interpretation of the Geotechnical Triangle's vertices has been developed and modified slightly, as well. Now we think the interpretation of the vertices, by and large, has to be related to the whole region (ground and structure in interaction) of geotechnical interest and has to signify its

- topology and genesis of the region,
- constitutive (material) and kinematic characteristics,
- idealization describing the expected mechanical behavior.

Certainly, other less or more general interpretations are justifiable and acceptable – this is one of the main advantages of these simplices.

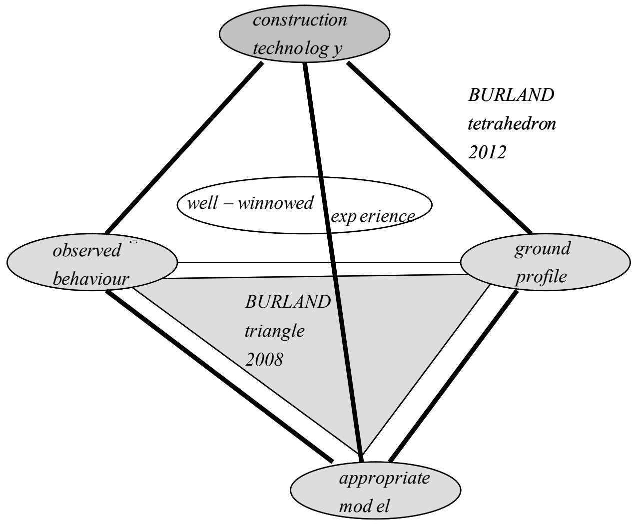

Fig. 2. The Burland-tetrahedron (2012)

EVOLUTION OF BACHELORS' AND MASTERS' HABITS OF MIND

Obviously, answers to the basic questions about teaching and learning outlined in recent papers (particularly those presented at the Galway-conference - McCabe at al., 2012) can not be derived directly from the Burland-simplex (let it be either triangle or tetrahedron). Even if we leave open the issues connected with teaching techniques (such as problem-based, project-based, case-based ones, for instance), there exist many alternatives to determine the structure and content of geo-engineering curricula, both at undergraduate and graduate level.

Outcomes and grades

Felder (2012) outlines the traditional and the alternative paradigms of engineering education, as creatures of positivism and constructivism, two philosophical views of knowledge. His option is based on the constructivist (inductive) approach: the curricula should be integrated both horizontally (across subjects and disciplines) and vertically (across years), and have to balance content and skill (Prince, Felder, 2004).

This proposal, concerning engineering curricula in general, seems to be in perfect harmony with the conclusions arrived at in many papers about the geo-engineering issues. The constructivist (*aka* learner-centered) approach applies case history analyses extensively, as appropriate vehicles to convey knowledge. However, let the structure of the curriculum have a deductive or an inductive character, the distinction of the undergraduate and graduate curricula remains an open question at this level of general considerations.

Orr and Pantazidou (2012) draw the attention explicitly to the learning outcomes, with particular interest in the case studies to be used at undergraduate and master levels. Their list of learning outcomes achievable from geotechnical courses contains 10 points; it starts with "Identify potential critical modes of failure", and in increasing order of performance level ends with "Appreciate the ethical dilemmas in geotechnical practice". The list is presented "as an invitation to the wider geotechnical community to define key learning outcomes and suggest how these may be linked to appropriate courses".

There is an expectation that outcomes, competencies and skills (as much as they can be taught at all) can be brought into close correlation with the graduation levels. Case studies seem to be very adequate tools to enhance this effort.

That is why Orr and Pantazidou (2012) suggest establishing a geo-engineering case study repository having three features of

- clear purpose and learning outcome for each item,
- well-referenced on-line search availability,
- completeness with respect to the intended use.

Templates can help to build up this repository, according to the specific outcome characteristics.

We believe this program is worth implementing and it may become even more beneficial than it is foreseeable now. At the same time, the connection between case studies, education outcomes and the geo-engineering *habit of mind* could and should be tightened, not casually with respect to the points stressed by Felder.

Actually, outcomes and competencies provided by the BSc and MSc curricula have to be defined, checked and qualified for practical purposes. Reasonable and justified distinction between undergraduate and master courses is a demand for accrediting a course, licensing a graduate at a Body of Engineers, operating a student mobility and credit transfer system, too. Simultaneously, however, Burland (who resisted to derive a curriculum from the Geotechnial Triangle – 2008) and others conceptualize the habit of mind top-notch geotechnicians may and seem to have. Maturation of this trait is very individual an not necessarily goes with academic results.

Practically, separation of the levels assumes step nonexistent in the mind of the student. Some of them are able to think as to-be-masters already at their undergraduate period. Others (who knows how many) never reach the genuine master habit of mind, even if they hold their well-deserved MSc degree. Orr and Pantazidou call the attention to this problem when matching 10 outcomes with undergraduate and master courses.

Modeling skills and grades

Following Felder's thoughts a somewhat sophisticated but inspiring possibility to distinguish professional knowledge and skill can be derived from cognitive psychological considerations. Number and complexity of cognitive schemes attained can be associated with the levels of BSc and MSc curricula. The system of these schemes building on each other provides a good framework for a number of aspects regarding the mechanisms of cognition (Mérő, 2001, Scharle, 2005).

In general, at different levels, besides the number of cognitive schemes, the jargon, the extent of consciousness of thinking can vary from profession to profession. The number of competency levels worthy of distinction may also vary by professional fields. However, despite these differences, in most instances two levels of bachelor and master can be characteristically defined, and this classification proves surprisingly applicable for a great variety of professions.

In the engineering sciences, a whole group of concepts parallel the ideas applied by the cognitive psychology. To this group belong, among others the

- observation, recognition, 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.

These nouns, albeit not active verbs, are in harmony with those qualifying the learning outcomes listed by experienced educators and in the related documents.

For the technical wording *scheme* can be translated as *model*. With this interpretation, the core of professional knowledge can be conceived as model selection skill based on these elements.

The definition of model in this regard is very broad. It may consist of simple or compound elements. It can be simple or complex. It also encompasses all mathematical, physical, technological and material-tectonic relationships that approximate reality and its behavior to an extent deemed acceptable in the given circumstances. The application of the model may consist of simple steps, or form a closely related sequence of steps. Indeed, this extended perception is somewhat broader than that of the right bottom circle meant by Burland (2008) in the geotechnical triangle.

From this perspective *the essence of higher education in the engineering fields can be perceived as introduction of technical models of phenomena and processes*. Particular curricula include theories and relations that describe reality more or less reliably, explore the validity and applicability of these models, and discuss the prerequisites, methods and steps of application.

Professions have their inventories (or treasuries) of models as well. Simpler or more complex models can describe (but approximate only) simpler or more complex phenomena. 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 a particular technical problem. We think this habit of mind is the right answer to the problems connected with the immature beliefs about the certainty of knowledge, stressed by Felder (Orr, Pantazidou, 2012).

It is sensible to differentiate between levels of professional expertise from the perspective of their relationship to the inventory of models. Certainly, it is not possible to assign one "natural" classification. However, it seems practicable to accept a four-level classification system.

Significance of differentiating between these levels lies in their relationship to recognizing phenomena and processes, and to the models used for their understanding and intervention. They can be described by competency at all levels (from assistants to doctors – Scharle, 2005, 2008a,b,c). Here we recall the BSc and MSc levels only, as follows.

*Bachelor*s
- recognize frequently occurring phenomena;
- are familiar with the profession's simpler models and their application;
- correctly select the models that can be employed for simple phenomena;
- are able to involve the apprentice in model application by creating simple subtasks;
- understand and execute the steps according to the model selected by the master.

Masters
- recognize phenomena and correctly appraise their complexity;
- know the profession's inventory of models and the prerequisites and limitations of their applicability;
- are able to cooperate with masters of other fields in the solution of a complex problem;
- are able to select the optimal model to solve a particular problem;
- grasp the complete process of intervention, and are able to incorporate in particular steps the expertise of the apprentice and bachelor according to their skills;
- recognize phenomena that require the further development of the model inventory, understands the way doctors think, and can utilize their recommendations.

The elements of all 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 (plenty of faculty members teach graduate students rather simple models extensively and with routine at the bachelor level of expertise while a good grammar school teacher can make his interested pupils acquainted with pretty complex models using the master's perspective).

There is also a great variation in individuals' ability to learn. The same lecture may leave a much greater impression on one student than on the other sitting next to him. The traditions of institutions and the cultural patterns of societies can greatly influence the stratification of entire disciplines.

Furthermore, most of the readers may know top-notch consultants having no academic degrees or titles but a splendid habit of mind always ready to develop or invent original models for complex and sophisticated phenomena. Considered either conscious or serendipitous, these achievements are *artistic* in a sense and seem to reflect the highest level of „competency", even if it was not obtained by learning, by exams or gained by election.

Despite all these sources of uncertainty, in constructing any engineering curriculum it seems to be worth considering its content in accordance with the cognitive categories entailed. Undergraduates are educated to see the most fundamental configurations nested in the Burland-tetrahedron only. Masters' competence involves the whole panorama of the picture. Doctors keep under control the range of validity of the complex models and try to extend the inventory of models if needed. Either aspects may have the same importance for the practice.

Plausibly, actual content, presentation techniques (including case histories) and student performance evaluation methods are worth discussing and harmonizing with the qualification rules and licensing procedures applied by the professional engineering chambers or authorities. Efforts of educators, professionals and bureaucrats based on the neutral classification provided by the cognitive psychology may result in a higher synergy and more consistent career visions presentable for the students and the society.

This perspective allows deriving conclusions for all levels defined above. For instance, it can be conjectured that genuine geo-engineering expertise has much to do with the doctor's level.

ANALOGIES WITH STRUCTURAL ENGINEERING AND MEDICINE

Applying the Geotechnical Triangle in communication with structural engineers Burland realized that the roots of the problems lie in a difference in approach to modeling the mechanical behavior of the object. Works dealt with by structural engineers are mostly modeled with well-defined boundary conditions. Geotechnical models involve explicit uncertainties, both in the field of interest and at its boundary (Burland, 2008).

The difference is essential. Burland explains how a structural engineer encounters the geo-engineers' habit of mind when working on an existing, accidentally ancient building (such as to be stabilized, modified, reconstructed, etc.). S/he finds the activity needed analogous to that of the geo-engineer: to track down the genesis of the building, to find existing discontinuities, determine constitutive parameters for materials used many decades ago, to scrutinize expectable interactions with other constructions in the vicinity.

An additional feature geo-engineers are facing is the region of their interest (as interpreted when discussing the Burland-tetrahedron). As a rule, it is an open space. It is an important (and often crucial) part of modeling to identify or determine its boundaries at a range where the mechanical (preferably the kinematical) state can be assumed to remain undisturbed.

For instance, limit depth can be determined, underneath which no compression has to be calculated, or the position of a quasi-rigid layer has to be identified with the same kinematic characteristic. Designers and consultants using field models for computing soil-structure interaction problems with Finite Element Methods are well aware the difficulties of bounding the domains to be discretized and calibrate their boundaries' response to prevent spurious displacement modes.

Importance of the skilled habit of mind in modeling structures of kinematic sensitivity is well known for structural engineers, of course. The case of the Millennium-bridge in London is but a delicate example of situations geo-engineers are involved in much more frequently, particularly of those connected with underground structures. That is why probably the structural engineers involved in tunneling are the most understanding partners in cooperation with geo-engineers.

Complexity, multidisciplinary character and ways of solving its problems establish another analogy, that of with medicine. Physicians – in particular, internists – start with collecting *symptoms*, medical reports and findings, information about prior sicknesses and treatments. Then 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 cases *observation* continues, sometimes multidisciplinary *council* is chosen with partners having efficient communication skill.

Role of cases in this profession is like in geo-engineering. They serve as resources of collective experience. In university clinics professors are teaching their medical students by walking from bed to bed. Education is saturated with listening to and looking at symptoms, scrutinizing the findings provided by laboratories, interpreting syndromes. Alternatives are assumed, checked, accepted or rejected. Diagnoses are defined and therapies are determined. Continuous observation is a natural part of the medical intervention here.

Medical students at the bedside learn to understand uncertainties, complexity, alternatives of treatment and risks of the possible complications of intervention. Therapies may follow simple or regular protocols or singular specifications. All stages and steps of the treatment depend on several conditions known up to some uncertainty only. Interaction between other professions (e.g. those developing laboratory and curing technologies) are parts of the everyday practice.

Without overstressing the analogy it is clear that that geo-engineering follows the same approach, because of the immanent structure of the lesson: to face the problem as a whole, to look at the subject as embedded into its interacting environment.

Medicine, being as complex profession as engineering, has its 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 internist (not to mention dermatologists).

Recent talks with active hospital physicians seem to validate this analogy. Some good practices (including collection, classification and interchange of experience gained in cases) seem to be worth discussing and changing with them.

EUROCODE 7 – A CHANNEL PAWED WITH WELL-WINNOWED CASE STUDIES

Shaking the foundations of geo-engineering education, as an operation to contribute to the development of this segment in civil engineering as a profession can be considered as a small-scale action compared to another operation accomplished recently in the European Union: bringing into force a new standard for design of structures, Eurocode.

Generations of structural engineers using their national designing standards for decades (modified or amended only slightly over the years) have to comply with the new CEN standard since 2010. Understanding of the comprehensive system of its principles, aspects (such as the separate calculation of serviceability and ultimate limit states or partial factors related to several material parameters or designing situation) and getting experience in their application is a real trial for most of them, particularly for those skilled in the calculations connected with the abandoned standards only.

Geotechnics has a specific position in this process and the consequences were realized in due course. In particular, lessons to be learned in the education were outlined timely in many forms of papers, lectures, guides and books (Frank et al., 2004, Orr, 2008).

Not surprisingly, Burland-triangles served well in responding the challenge of understanding the philosophy of the whole system of structural standards (Eurocode 0 and Eurocode 1) and the differences specifying the geotechnical subsystem (Eurocode 7). Orr's paper (2008) on the relationship between

Eurocode 7 and geotechnical education reports how deeply influenced the coding process the educational and cognitive considerations, including the Geotechnical Triangle and the idea of using well-winnowed cases, and *vice versa*.

With respect to the *habit of mind* and *case-dependence* topics, and apart from many important details two essential points of the Eurocode 7 can be underlined here:
- Instead of well-defined constitutive relationships and calculation models available in the structural chapters of the series (Eurocode 2…6) geotechnicians are supplied with prescriptive rules and suggested guidance "only". This approach renders both freedom and responsibility to the geo-engineer to select an appropriate model for the given and expectable circumstances.
- Depending on the design situation, structural engineers and geo-engineers are obliged to co-operate at different levels. The not-so-good practice of tradition (to change information referring to the soil-structure interface) is allowed only in the very simple designing situations. The expected kinematic behavior, sources of risks and explicit or hidden uncertainties influencing the limit states (even possible in the stage of implementation) have to be imagined, assumed, discussed throughout as much as possible.

Geo-engineers have to be able to communicate the essence of this advanced approach rigorously, creatively and clearly. Instead of providing a couple of strength parameters for the structural engineer, they have to participate in the designing process in case of complex installations.

Both points are in full harmony with the ideas reflected by the Burland-tetrahedron. The second one, however, raise the question: which one of the partners should understand the other's habit of mind first and better? The answer, obviously, must be symmetric: both of them have to make steps. However, many geo-engineers think their position is harder. Burland mentions his experience of difficulties in communications between structural and geotechnical engineers (2006).

The case history of the Millennium-bridge, touched upon previously, can serve as an instructive example from this point, too. Having been opened for the public, an unexpected kinematic mode (lateral swinging) of the structure (without any risk of break) showed that the model used to design the bridge was not complete. Structural engineers had to reanalyze the dynamic behavior, in particular the frequency responses of the structure. Experiments were needed to determine the necessary damping and the best allocation of the pistons. The advanced theoretic and constructing considerations and solutions were discussed and published in professional papers. Since then, using the experience gained in the case, several bridges of similar arrangement have been built, some of them being equipped with continuous electronic observation system to keep under control any unexpected response.

Being informed at professional level about similar cases, interpreting properly the actions made rarely by structural engineers as analogous with those made regularly by geotechnicians may help the effective communication and result in efficient co-operation.

CONCLUSIONS

Case histories deserve the central place occupied in the Burland simplices. They incorporate the interdependence between the vertices, let these connections be relating to any goal, task or reason in geo-engineering activity. Therefore, they serve the education in a sense visualized by the title of this paper.

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