Intellectual synergy in the education of geo-engineering

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ABSTRACT: Cognitive psychological considerations can help to understand the essential differences between the levels of BSc, MSc and PhD. Complexity of the interrelationships experienced in geo-engineering parallels those in medicine, i.e. concepts such as symptom, syndrome, diagnosis and therapy. The analogy makes it easier to identify some perspectives and approaches used in geo-engineering, rather different to several other fields of engineering where the problems are treated with well-established models and managing technologies which are much better defined or more deterministic. In this regard, the importance of using case studies in geo-engineering education turns to be as natural as it is in clinics. Geo-engineering is one of the professions where experts comprehending the interplay of academic knowledge, design practice, construction skill, even communication are predestined to co-operate in developing the inventory of case studies for the education curricula of different graduation levels. Simultaneously, students have to be advised clearly about the challenge they are facing and have to engage at their competence level.

1 INTRODUCTION

1.1 Survey of preliminaries

By the end of the last millennium, European education policy makers reached the conclusion that the traditional higher education system has to be restructured. The Bologna declaration (1998) opened a new era where the linear structure of bachelor and master levels dominates. Significant efforts were made to establish a European system for accreditation of engineering educational programs based on a network of spontaneous agreements between national and regional institutions (Augusti 2006).

Nowadays 40–50% of age groups enter undergraduate courses and some 15% make a further step to the master level. The system works; albeit diversity of courses, differences in requirements, impact of declining secondary school performance have been, and will continue to be discussed. Several educators share the opinion that most of the accreditation models developed regionally or internationally “seem to be non-uniform, too complex, non-transparent and, moreover, non-precise” (Patil & Codner 2007). There is room for further work.

In particular, the content of the professional subjects became less plausible, for at least four reasons:

- There is a conflict of interest between the faculty knowledge and the actual industry needs.
- There is a time-lag between the waves of education supply and employment demand.
- Higher education institutions try to attract as many students as possible with popular courses.
- By and large, secondary education seems to be unable to prepare its pupils for the competencies needed for traditional university entrance.

Since the main goal of restructuring is to become more competitive globally via more practical knowledge of more people, educators, politicians and researchers are continually occupied with questions such as:

- How long should bachelor and master programmes be when separated, or built together?
- Should there be different tracks of bachelor programmes preparing students for employment versus preparing for graduate work?
- To what extent should bachelor programmes prepare for master programmes in the basic sciences?
- What financial quotas should be allocated for bachelor and master programmes?

In this academic environment the clear identification of the undergraduate and graduate levels becomes more important than before, even in those cultures where the linear structure of higher education is a tradition (Ilic 2007). Additionally, there arise the questions of how the role of case studies must be reinterpreted, and how their content and presentation style could be developed to better support the practical side of academic education.

An effort to keep pace with this progress and with the development experienced in construction and computing technologies means that the issue of geo-engineering education is covered at many conferences, seminars and in periodicals. Recent historical surveys (Burland 2008 and many others) explain how
the Fathers of the profession stressed the importance of educational aspects and combined their expertise in soil mechanics, structural engineering, and construction technology in teaching via case studies. Not exclusively, but probably most consciously, Peck’s courses discussing one-page case studies are referred to as best practice (Rogers 2008).

There seems to be no lack of case studies on geo-engineering activity available for use. By and large, 40–70% of papers presented at regional conferences discuss cases. A series of conferences on case studies in geotechnical engineering will have its 7th instance in 2013 (Prakash 2008) and several collections of case studies are also readily available. The International Journal of Geo-engineering Case Histories has appeared since 2004 and has been accessible free of charge.

While the role of case analyses in engineering education is not particularly significant, it has been of high importance for teaching economics, medicine or law – and geo-engineering. Participants and authors of recent conferences, seminars and studies (e.g. Manoliu 2008) agree the reason is that geo-engineering differs in several aspects from other civil engineering activities. Burland states, that “… geotechnical modeling involves much greater explicit uncertainties and complexities in idealizing both the geometry and the material properties than in structural engineering.” An understanding of the differences results in different teaching methods. Advanced techniques (such as problem-based learning, enquiry learning, case-based teaching etc.) are reported as being applied successfully (Papadimitriou 2011). However, it seems to be a question open for further discussion, how the cases are to be tailored for educational purposes; even if some general recommendations exist.

1.2 Some questions of interest

One of the questions worth discussing is how to identify the bachelor, master or doctor levels of competence defined either in the academic environment (with respect to courses) or in practice (connected with licensing and other professional qualifications). Some levels of academic graduation (such as BEng, MEng, PhD) seem to be determined in the long run, since the European system has been reorganized to this scheme by the Bologna-process. Nevertheless, there exist difficulties of implementing the idea (this might be one of the reasons why the European credit transfer system does not always work seamlessly).

Most branches of civil engineering have accustomed themselves to the Bologna-classification easily. Geo-engineering seems to have some difficulties. A better understanding of the educational purposes and demands of the practice may help to clarify the reasons and to comply with socio-political constraints.

The question of adequate case study selection and tailoring is not independent of education level classification (Orr 2011). Efficient usage of the existing case analysis inventories can be supported this way.

To answer these and similar other questions, there exist several well-elaborated conceptual frameworks. Bloom’s taxonomy (1956) of six educational objectives (knowledge, analysis, comprehension, application, synthesis, evaluation), for instance, was selected by ASCE to establish 28 outcomes, all of them defining knowledge, skill and attitude. Compilation of the Civil Engineering Body of Knowledge (describing minimum cognitive levels of achievements for each outcome) with the distinction made between undergraduates’ knowledge, experience gained in practice and master’s knowledge in this system is an advanced alternative (ASCE 2008).

The authors think that their views merge into the mainstream paradigms of geo-engineering education. With less bumptiousness than the title of the paper would suggest they apply some general concepts and analogies accepted in other professions, and this way hope to contribute to the discussion.

2 LEVELS OF HIGHER EDUCATION

2.1 Cognitive psychological background

For decades, researchers exploring artificial intelligence have investigated 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 schemes associated with each, as well as their organization. The system of these schemes building on each other provides a good framework for a number of considerations regarding the mechanisms of cognition (a more detailed discussion of the conceptual framework can be found elsewhere, Méro 2001, Scharle 2008b).

Levels of professional expertise must be qualified according to their complex knowledge bases and paradigms. 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.

Despite these differences, in most instances three or four levels can be characteristically defined, and this classification proves surprisingly applicable for a great variety of professions. Obviously, small differences can result from the nature of individual profession’s paradigms and their stability. However, the road leading to knowing the rich collection of complex schemes and to using professional and everyday language adequately and at a high level can be recognized even in such particular fields as architecture, economics or law.

2.2 The model – an extended understanding

In the engineering sciences, a whole group of concepts parallel the ideas applied in 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.

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 behaviour 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 broader than that of the right bottom circle meant by Burland (2008) in the geotechnical triangle.

2.3 Model inventory – knowledge and selection

From this perspective the essence of higher education in the engineering fields can be perceived as the 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.

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.

The significance of differentiating between these levels lies in their relationship to recognise phenomena and processes, and to the models used for their understanding and intervention. They can be described by competency as follows.

Assistant – understands the main characteristics of models conveyed by the bachelor or master; may participate in the application of models under guidance with simple steps.

Bachelor – 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 – recognizes phenomena and correctly appraises their complexity; knows the profession’s inventory of models and the prerequisites and limitations of their applicability; 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.

Doctor – is able to identify and analyse complex phenomena; knows the profession’s model inventory and the limitations of their precision and applicability; expands the range of validity of models, improves and develops methods for their application; attaches models to new phenomena, and if necessary, supplements or creates new models.

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 routinely at the bachelor level of expertise while a good grammar school teacher can make his/her 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/her. The traditions of institutions and the cultural patterns of societies can greatly influence the stratification of entire disciplines.

Furthermore, most readers may know top-notch consultants having no academic degrees or titles but a splendid 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. This consideration might be extended to the basics needed from mathematics, mechanics and reach out to the theories, models and applications to be discussed in the course. Simultaneously, 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,
professional 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 conclusions to be derived 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. Nevertheless, to keep the attention close to the point, in what follows, the argument will be focused on the questions related to the undergraduate and graduate levels only.

3 GEOENGINEERING ASPECTS

3.1 Convergence and distinction

Convergence experienced between structural and geotechnical bodies of knowledge is reflected and will be explained in such points as:

– identification of kinematic behaviour deserves equal importance;
– developed constitutive models with more sophisticated strength parameters applied;
– designing principles (extended, for instance, to construction stages) are harmonized in continental codes (such as the Eurocode series);
– integrated computational models and construction technologies are available for design and implementation.

In spite of this convergence there are some aspects wherein the two bodies are expected to remain different (Orr 2011).

Structural engineers focus on the installation. Their models have boundaries where the interactions with the environment are characterized with variables and quantities (such as loads, spring constants or prescribed displacements) consistent with the structural model.

Geo-engineers notice the long-term and multidisciplinary interaction of structure and ground environment. More complex models with less-balanced approximations about the surroundings of the installation, possible impacts and responses are to be established.

3.2 Features of geo-engineering

The circles of the Burland-triangle, amended with a fourth circle representing construction technology, can be imagined as vertices of a tetrahedron. This framework visualizes the key aspects (and activities) pondered by the Fathers and have to be pondered since then by all top-notch geo-engineers. Their skill lies not simply in the knowledge about the strength and kinematic behaviour of soils, mechanics of structures or technologies, but about the interplay of these factors.

Bachelors are educated to see the most fundamental configurations nested in this tetrahedron only. Masters competence involves the panorama or the whole picture. Doctors keep under control the range of validity of the complex models and try to extend the inventory of models if needed. Either aspect may have the same importance for the practice.

It is interesting to find some analogy between geo-engineering and medicine. Physicians start with collecting symptoms. Then try to order and organize them to establish a syndrome. Their next goal is to identify a diagnosis, for they may have protocols to apply therapy.

Cases have their roles analogously. In clinics professors are teaching their medical students by walking from bed to bed. They listen to and look at the symptoms and scrutinize the findings provided by laboratories, interpret syndromes and define diagnoses. Finally, the therapy follows. Students at the bedside face questions, alternative models of sickness and possible therapies. Intrusions depend on the conditions (such as the patient’s state, facilities and medications available, etc.) and may be extended to possible treatments (from specific nurturing to surgical operation). Several days later students can face the results: the observation method works. Synergy is at stake when the professor calls a medical consultation with experts of their particular professional skills.

Without overstressing the analogy it is clear that geo-engineering follows the same approach, because of the inherent structure of the lesson: to face the problem as a whole, to look at the subject as embedded into its interacting environment. The example of stabilizing (or modifying) an existing, particularly an ancient building, as described by Burland (2008) helps to comprehend this attitude for structural engineers. In this regard, problem-based learning is not simply a possibility of inductive teaching with good practical results but a plausible constraint.

It is worth noticing here the role of communication, as well. Burland mentions his experience of difficulties in communications between structural and geotechnical engineers. Recent problems connected with the introduction of the Eurocode7 show the importance of this aspect. Again, geo-engineers have to be able to communicate rigorously, creatively and clearly the essence of the advanced approach. 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.

4 CASE STUDIES IN EDUCATION

4.1 Role and potential

Recent overviews clearly outline the educational role and potential of case studies in geo-engineering (Orr 2011). Therefore, some remarks are allowable here only, to help the understanding (Scharle 2008a).

For engineers, as a rule, it is impossible to possess all abilities listed for the bachelor and master levels without a shorter or longer experience in practice. During the education term, case studies are at hand to illustrate all points and arguments connected with model identification, creation and application.
Through scrutinizing well-rounded case studies, undergraduates can better prepare themselves to
- recognize frequently occurring facts and events,
- select correctly the models that can be applied for simple phenomena,
- execute instructions given by a master.

Graduates can accelerate and improve their development with case studies helping them to
- recognize and correctly appraise complex problems,
- select the optimal model to solve a particular problem,
- comprehend the complete process of intervention,
- understand the way doctors think, and utilize their recommendations.

This perception of case studies, of course, is neither a new development nor a consequence of the Bologna paradigm. It is stressed, for instance, by the US National Academy of Engineering (2005).

Obviously, adaptability and efficiency of a case study can highly depend on many conditions:
- Cases can be presented either as narrative descriptions or instructive explanations. The first alternative works well for undergraduate students, the second one for graduates.
- Hegemony interests and to-be-protected employment positions can distort correct narrative descriptions or instructive explanations.
- Many case studies convey very simple business messages (“look how interesting the problem we have solved is” and “we are skilled masters of our technology”).

Even these types of case studies can help in stimulating the interest of the undergraduates in the subject, but have a low value for teaching or learning.

4.2 Quality of case studies

From the point of view of her or his purposes, the teacher has to scrutinize whether a case study contributes to the course performance effectively or even obscure it. Features of efficient engineering case studies are:
- correspondence between the problem or phenomenon and the model is controlled and straightforward;
- essential data of geometry, materials, constraints, impacts etc. are illustrated properly and quantitatively for understanding the problem;
- material characteristics and assumptions (linearity, time-dependency, etc.) are clearly explained;
- kinematics of the engineering behaviour (both expected, and observed) is commented on as clearly as possible;
- applied computational methods are described explicitly, with their assumptions and essential characteristics;
- failures, mistakes made in selecting and applying adequate models are considered and discussed openly.

Many case studies do not correspond with these demands. A lot of papers appear in professional periodicals, conference proceedings and corporate PR folders or leaflets distributed at exhibitions with shortcomings such as:
- data of marginal importance are given (“the site was at a distance of 4 km northwards from the capital”);
- information is unbalanced because of the primary competence or partial interest of the author;
- function, importance or attractiveness of the building involved in the case are stressed (“the runway was highly desired by the regional industry”);
- derived variables are used instead of physical state or material properties;
- statements are made without comparison with other similar constructions or alternative solutions (“the method we had applied gave a sound solution to the problem”);
- calculations are referred to inadequately (“displacements were computed with the FEM”),
- inadequate illustrations are attached to the case.

Experienced case study writers and users can easily add further items to these lists (Pantazidou et al. 2008). At the same time, one has to know that only a few cases allow a perfect study with all the necessary features but without shortcomings.

5 SYNERGY

Understanding the cognitive background, the concepts of the model inventory and education levels offer a space for further interdisciplinary co-operation. To the points mentioned previously several more can be added:
- basics from mathematics and mechanics (reduced to but selected for the inventory);
- methods of decision-making;
- conscious adaptation of advanced software;
- risk management.

6 CONCLUSIONS

1. It is plausible to differentiate two levels of education from the perspective of expertise in recognizing phenomena and processes, and from the relationship to the inventory of models, used by the profession for understanding and intervention.

   Bachelors are instructed to recognize frequently occurring problems, to select correct models for simple phenomena, to execute instructions given by a master. Case studies at this level serve as examples highlighting the essential features of a model.

   Masters are instructed to select optimal model for a particular problem, to comprehend the complete
process of intervention. Case studies at this level induce considerations about alternative models, selection principles, verification, and validation issues.

2. Models of the geo-engineer have to reflect the essential characteristics of the environment influenced by operations. High-quality models involve ecological, structural, geological, technological etc. considerations, both in design and construction.

3. This complexity appears in several analogies with economy and medicine. State and characteristics of the operated subject may have significance greater than canonical methods of the intervention. This is why the case-based methods are not just plausible but very natural and inevitable educating techniques for geo-engineering.

4. Depending on the competence level defined for bachelors and masters, case studies applied for education have to be differentiated by:
   - content (simplicity or complexity of the model involved);
   - uniqueness or variability of the technical intervention;
   - reliability of the observations and data used for establishing applicable models.

5. Scope of knowledge demanded in math, mechanics, construction technology, site or laboratory identification methods etc. can be determined easily for the bachelor level. At the master level, the scope is more open. Facilities (such as hardware, software, laboratory, tutorial competence etc) of the educating institution may influence the curricula.

6. Streamlining of the case studies available in the inventories is left for the educators. The result depends on their talent, invention and pedagogical skill. Advance in this field could be stimulated.

REFERENCES

ASCE 2008. Civil Engineering Body of Knowledge for the 21st Century: Preparing the Civil Engineer for the Future, 2nd edition, Committee on Academic Prerequisites for Professional Practice


Bologna Declaration 1999. www.ehea.info


Orr, T. 2011. What learning outcomes can be achieved by incorporating case histories in geotechnical courses, ERTC 16 Workshop on Education, XVth European Conference on Soil Mechanics and Geotechnical Engineering, Athens, Greece, Sept. 14


