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Cognitive psychological structure of education and research in geotechnics

La structure psychologique-cognitive de la formation et recherché en géotechnique

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ABSTRACT
Post secondary education provides an introduction to models, and develops model selection and application skills. Recent developments in cognitive psychology offer good possibilities for differentiating between levels of knowledge. It is prudent to define four levels of preparation in the technical-engineering professions, particularly in their relationship to models. As a conclusion, it turns out that professional geotechnicians are required to have MSc level of competency. The approach also yields answers to some debated questions of modelling and solving geotechnical problems in the framework of engineering mechanics.

RÉSUMÉ
La formation post-sécondaire établit la notion de la modèle et développe la capacité de choisir entre plusieures modèles. Les résultats récentes de la psychologie cognitive offrent une possibilité pour la différencier cettes capacités. Basé sur l'aptitude pour utiliser des modèles, il est possible d'identifier quatre niveaux de formation dans les professions d'ingénieur-technique. Une déduction qui s'en suit c'est qu'un géotechnicien diplômé doit atteindre le niveau de compétence de Mâitre de Science. En outre, cette approche offre des reponses sur l'application des modèles mechanique-ingénieure aux problèmes géotechniques.

1 INTRODUCTION

In many fields of civil engineering the planning procedure of structures with complex purpose involves

- learned selection in the treasury of standardized loads, sophisticated mechanical models and powerful computational techniques at the level of designing,
- the best possible constructional realization of the structural arrangement in accordance with the assumptions and limitations of the selected model.

Rich assortment of materials, numerical methods, and building technologies are at hand to realize complicated structural models. Slender steel trusses, double curved concrete shells, light cable bridges are planned and built this way. Professional papers of highly scientific approach discuss the mechanical and mathematical problems connected with the models applied.

Most problems of planning in geomechanics are paradigmatically different. Considerations related to the functional arrangement of the object are influenced, even constrained by the subsoil conditions and geotechnical construction technologies. Prudent assumptions and estimations are to be made before arriving at an acceptable model describing the soil-structure interactive behaviour complicated both in space and time. Papers and conference lectures discuss case studies and describe, analyze, interpret the particular models chosen. Importance of monitoring and interactive construction is stressed as a regular component of planning practice in geotechnics.

Geotechnics seems to be a technology-driven profession with a few scientific scent only, for its ordinary approximations with respect to the kinematic behaviour, mathematical simplifications and physical uncertainties, even in the age of sophisticated constitutive soil models and high degree of freedom computational methods.

The difference between the structural and geotechnical approaches, however, does not establish any difference in intellectual quality or pretension. Cognitive psychological considerations prove that understanding and modelling of complex engineering phenomena might be as great intellectual challenge as the ingenious application of difficult mechanical and mathematical models for structural arrangements of well-known kinematic behaviour. A recent example (failure of the new London pedestrian bridge) shows what may happen when the kinematics of the structure was not well known in advance.

Consequently, both the equivalence in mental challenge and difference in the approaches of problem solution must be reflected in the BSc and MSc level education. Significance of knowledge about mechanical phenomena, assortment of the models taught and skill of their application may have different importance depending on the level and the civil engineering specification. Multidisciplinary perspective, for example, is neither a privilege nor an obligation at the different levels, but an overall attitude to understand the real phenomena and to select adequate models to complex problems. As a matter of fact, it is an obligation of greater importance for geotechnicians than for structural engineers.

Society demands professional knowledge at its every possible level. It is in its interest that educated professionals become capable of utilizing and further developing the accumulated and expanding human knowledge. The higher education system gives the foundations for this capability and may be classified (among other things) based on the type and proportions of knowledge content at each educational level, and by the application competencies that can be obtained at each level. At all times and places it is the expressed objective of education to introduce, teach, and practice how to use various models that approximate reality (phenomena, processes, relationships). Recent papers concerning about the engineering education pay due attention to this issue (Steif, Pantazidou, 2004).

Obviously, besides education, experience gained through the application of models plays an important role in a professional's productivity. There are different levels of individual need, as well as changing societal-economic pressures to increase one's level of competency (among others this is where the concept of life-long learning is rooted). In order to stay on track though, this paper will not discuss these obvious connections. Rather, it will be seeking conclusions regarding the use of the concept of models, with particular attention to their role in geotechnics.

2 COMPLICATIONS OF THE BOLOGNA-PROCESS

Determining the need for higher education is a persistent problem for all societies and economic models. It is a problem in two aspects:

- in defining content, there is a conflict of interest between the traditions and knowledge offered by higher education institutions and the often dissimilar need of society;
- the market value of elements of knowledge is unstable, there is a considerable time-lag between the waves of education and employment demand.

Besides these timeless factors, in the process of integration and globalization the advantages and shortcomings of various traditional national education systems become more visible. The supporters and opponents of the two basic systems customary in Europe, dual and linear education, have been long clashing their arguments, looking for alternatives in which the advantages can be amalgamated and the shortcomings limited. Since 1998 the discussion has been institutionalized into the Bologna process, a framework aiming at a common European BSc-MSc system.

The scope of the debated questions is broad. Practicing educators, politicians and researchers are continually occupied with the definition of education levels, their building upon each other, the content of knowledge to be obtained at each level, the time period of education, the framework for the practical application of obtained competencies.

Rich literature and hundreds of studies analyze the stimulants, objectives and dynamics of the Bologna-process. Foregoing the presentation of even some more important questions we mention only a few much discussed issues as an example:

- How practical should bachelor's programs be?
- To what extent should bachelor's programs prepare for master's in the basic sciences?
- What financial quotas should be allocated for bachelor's and master's programs?
- What optimal enrollment numbers can be assigned to each education level?

Reaching of a general consensus is hindered by the paradigm differences of various disciplines, as well as the differences in the national and historical roots of the culture of a decade and a half of (or now *lifelong*) learning for from childhood on. In addition, admitted or veiled prejudices, to be protected employment positions and professional hegemonies, and direct existential interests are articulated in the debates.

This paper does not cast a vote for or against any known viewpoint. It does not wish to analyze or qualify value or interest relations. Its purpose is to outline considerations using some recent findings of cognitive psychology, based on which a number of the debated questions could be answered with relatively little bias.

3 LEVELS OF KNOWLEDGE – AN EXAMPLE

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. The system of these structures building on each other provides a good framework for a number of considerations regarding the mechanisms of cognition (Mérő, 1990). A more detailed discussion of the general thoughts can be found elsewhere (Scharle, 2004). Here some basic concepts and considerations are introduced only, using *chess* as an example.

Individuals with chess skills rated through tournaments all see the same board, the moves of the pieces are governed by strict and unambiguous rules, the number of possible positions is large but finite. The players, regardless of the extent of their experience or expertise, cannot influence these conditions – in this sense chess is not a life-like game (for instance, real life games often involve the determination, even the modification of their rules – Shubik, 1982, Carse, 1987). However, because of the high number and variety of possible positions, and since the knowledge, experience, mental state and even the physical condition of the players are greatly varied, using the conceptual framework of cognitive psychology we may distinguish characteristically different knowledge levels. Mérő highlights four of these: the *beginner*, the advanced, *second class* chess player, the *master candidate* and the *grandmaster* (Table 1).

The chess players perceive or comprehend the positions in the patterns and schemes they understand. The grandmaster does not necessarily figure out more moves and combinations in a more complicated middle game, but he is able to judge with greater certainty when such actions are truly required. Sometimes he will make a fast move precisely because he can see considerably fewer reasonable moves than a beginner. The application of certain complex schemes well known at more advanced levels may become obvious to the lower-rated player if a detailed explanation is given. However, he would not be able to judge its applicability in other instances.

4 LEVELS OF PROFESSIONAL COMPETENCE

The measurable differentiation between various levels of chess playing competence is an important starting point for cognitive psychology, because the results of these considerations can, in an analogous sense, be transferred to very different fields from medicine to the command of a language. For example, by and large the master candidate level can be equated to a university degree (while there are considerable differences in the content of professional knowledge, the number of professional schemes, and their organization and complexity).

Naturally, levels of professional expertise must be qualified more comprehensively in the cases of more complex knowledge bases and professional paradigms. At different levels, besides the number of cognitive schemes, their quality (simpler or more complex, everyday or more professional character), the handling of problems, 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.

Table 1: Classification criteria for chess players

	Beginner	*Advanced*	*Master candidate*	*Grandmaster*
Quantity of schemes	some 10	some 100	some 1000	some 10,000
Problem solving method	conventionally logical	illogical because mixed	professionally logical	synthetic
Professional language	none	clumsy/awkward	professional	“mothertounge”
Time of maturation	-	a few years	approx. 5 years	minimum 10 years
What is needed for it?	interest, some learning	continuous learning	school diploma	“talent”

It is an interesting fact that, despite these differences, in most instances the four levels introduced through the example of chess can be characteristically applied, and the classification (some of its criteria shown in Table 1) 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 or law. Particularly, it is worth considering the geotechnical activity as a profession, science and art, where the modelling ability, skill and practice is crucial, because

- the kinematics of the structures is to be identified more often than determined by the designer,
- constitutive parameters of the ground are extremely difficult to define and measure,
- measurements of the regions of interest are usually subject of problem description,
- the academic knowledge is "technology-driven",

and, as a consequence, the competence of problem identification and formulation – modelling – is at least of the same interest than the skill in solving complicated, but well defined problems.

5 LEVELS OF ENGINEERING EXPERTISE

The knowledge and competency, the content and nature of education necessary to obtain them, and the societal-economic need for different levels of attainable expertise in the technical sciences fields can be understood and rated in many different ways. The consistent system that can be constructed using cognitive psychology's considerations regarding chess skills and in general the levels of professional knowledge, fits within these possibilities.

In the case of professional knowledge in the natural sciences, a whole group of concepts parallel the chess concepts of position, analysis and move in terms of a problem. In 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;
- the determination and technical execution of intervention steps.

For the technical "jargon" the essence of professional knowledge is the model selection based on these elements. The definition of model in this regard is very broad. It may consist of simple 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.

From this perspective the essence of advanced 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. Simpler or more complex models can describe 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 those to solve a particular technical problem. A recent analysis (Pantazidou, 2003) draws the attention of the geotechnicians to these educational aspects with well selected examples taken from the practice. She proves that in this profession the structure of competency is particularly complex.

It is sensible to differentiate between levels of professional expertise from the perspective of their relationship to the inventory of models. Probably it is not possible to assign one "natural" classification. However, in order to answer the posed questions it seems practicable to accept a four level classification system that can be described as follows in various languages (Table 2).

The 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. Without striving for completeness, the levels can also be described by competencies as follows:

- *Assistant* – ASc (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* – BSc (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* – MSc (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).
- *Doctor* – PhD (is able to identify and analyze 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).

Table 2 : Four grade classification of professional expertise

Common language	Apprentice	Journeyman	Master	Doctor
Professional language	Assistant	Technician	Professional	Top-notch consultant
Chess	Beginner	Advanced	Master candidate	Grandmaster
Educational level	Associate	Bachelor	Master	Doctor of Philosophy
Abbreviation	ASc	BSc	MSc	PhD

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 BSc 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.

Neither the creativity mentioned in the introductory section of this paper is alien to engineering. Most of the 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 or gained by election.

Despite all these sources of uncertainty, the presented levels offer a serious opportunity: in the prescription of education requirements and for the perspective of instruction it establishes the definition of levels that are in accordance with the findings of cognitive psychology. The model inventory of any particular technical-engineering field can be appraised regardless of education considerations. The questions about its content and quantity can removed from the focus of the debate and the attention can be drawn to the nature of relationship between students and the inventories of models.

This approach allows for and necessitates some particular considerations in disciplines where the nature of the model inventory is different from the usual. *Architecture* is an example of this kind, as much as it is defined as the *art of building*. The field of European (continental) *law* appears to be unconventional in a different way. In this field a single, though complex, model is the subject of education, one that is man-made and reflects societal values, interests and power conditions. Here even the five years long university course may result in a BSc level expertise). Somewhat more detailed discussion of this issue is given elsewhere (Scharle, 2004).

6 CONCLUSIONS

The broad and complex definition of the model inventory as the content of professional knowledge, on the one hand, and the different relationships to its understanding and use, on the other hand, provide a suitable framework for analyzing the levels of higher education, its requirements at each level, and the rational system of degrees superimposed on one another. The clearly outlined education levels and graduation competencies can be defined on this basis for the society, the economy and the individual.

The approach of cognitive psychology primarily enables the rational differentiation between the bachelor and master (in analogy to the *advanced* and *master candidate* chess player) levels of professional knowledge, but it can also be used as a guiding principle to other levels. Thus it is worth drawing some further conclusions, even if otherwise we would doubt that the transparency and accessibility of the higher education system is of greater value than the mechanisms that make career selections easier.

- Geotechnics related knowledge is of highly complex character. Perception and identification of the phenomena, selection and application of the adequate models assume MSc competence, as a rule. Moreover, interdisciplinary skill is the entrance to be gained for coping with the challenges in this field. Consequently, civil engineering education must offer all its geotechnical courses at all levels consciously and openly stressing this compound demand. This conclusion is in complete accordance with the statements of a very recent report prepared by the ASCE Committee on Academic Prerequisites for Professional Practice (Civil Engineering, 2004).
- Concerning the relationship to models, the higher education curriculum is very diverse and the differences are wide-ranging. According to the author's own experience, the majority of textbooks, notes, and lectures strive to introduce a vast quantity of models and their application in great detail. This practice makes realizing the true objective of education more difficult. Students are often mislead and confused by the notion that they will learn the practice of a profession rather than the understanding and use of models. Success of excellent examples prove that there is a "golden middle-ground" that is probably best illustrated by the attention given to the introduction of simple and concrete models at the bachelor level, while in working toward a master's level the focus changes to the complexity, selection, principles of application and relationships of models.
- In the field of geotechnical expertise several accountability, public safety and health issues cannot be ensured by a competitive entrepreneurial environment only, and professional guilds and chambers award here licenses, certifications and re-certifications. The knowledge of models, and their applicability and range can be used as a sound basis for professional certification and licensing requirements. It is an important question whether and to what extent formal education covers the licensing requirements. In this sense it is a timely and serious undertaking to synchronize the content, perspective, and requirements of professional examinations and the higher education curriculum.

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