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Streamlining Case Studies for Education

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ABSTRACT

Recent results of cognitive psychology seem to confirm that post secondary education in civil engineering can be conceived as introduction to the world of models, and to the model selection and application skills. From this perspective, case study analysis turns to be one of the most efficient approaches used worldwide by educators teaching geotechnics. BSc and MSc levels of knowledge and competency are easy to distinguish and characterize plausibly in this conceptual framework. Significance of the MSc level thinking in geotechnics proves to be a consequence. Plenty of case studies, in principle, can be selected to meet the educational purposes, since conference proceedings and periodicals contain a treasury of informative, instructive and illuminating case studies. Nevertheless, there are faults and shortcomings hindering the educators from using these publications effectively. There is some room to improve this situation. Priority aspects can be defined and offered to case study authors ready for considering educational points. Case study treasuries can be evaluated *a posteriori* with regard to the same priority list. Pilot selection results and informal discussions with prolific case study authors show that it is worth putting some effort into this work.

INTRODUCTION

Tradition of using case studies in the geotechnical engineering education is as old as this profession itself. Even Terzaghi, founder and father of the academic approach was one of the greatest case analysts. Needs for and supply of well-written case studies is maintained continuously, either for educational, scientific or simple practical purposes. Both alternatives of the observational method defined by Peck (1969) as "ab initio" and "best way out" can be interpreted as real-time case studies, as well. Full semester courses of geotechnical curricula are based on case analytic approach in several universities.

Plenty of case studies published in journals and conference proceedings seem to satisfy all needs. Yet, there are at least two recent challenges demanding more conscious preparation, selection, application and development of case studies to be used for educational purposes in geotechnics:

a) The Bologna process launched in Europe and discussed for introduction in other parts of the world (Ilic, 2007) combines the Prussian and Anglo-Saxon experiences of dual and linear higher education. Educators and politicians are occupied with the definition of degree 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 etc. (Scharle, 2005). Hundreds of studies analyze the stimulants, objectives and dynamics of the Bologna-process, discuss questions such as:

- 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?

Reconsideration of the abilities, skills and attitudes needed by the civil engineer of the 21st century are on the agenda in the US, as well (ASCE, 2007).

Independently from the societal and institutional environment, on the more professional level of scrutiny the role and application of case studies arise. Their selection must not be separated from the level of competence, and their efficient presentation is one of the preconditions for the adequate knowledge.

b) Previous distinctions made between the sophistication of structural and geotechnical engineering knowledge are getting less and less justified. Functional diversity and multipurpose character of structures (e.g. complex airports with high speed rail terminals, underground garages, conference centers and public spaces) makes it unavoidable to understand each others designing principles, modeling considerations and simplification constraints. Instead of prescribing forces and displacement restrictions at interfaces the computational models are extended to count with the soil-structure interaction. Partial ("greenfield") knowledge becomes inadequate, particularly in urban environment (Burghignoli et al., 2007). Case analyses are the best conveyances to disseminate prompt information about the experiences gained in this developing area of geotechnical engineering.

Unfortunately, large part of the case studies published recently does not support adequately the higher education to face the challenges. Some of them are simple narratives, others miss the signs of background knowledge and serve as examples for structural engineers to qualify geotechnical engineering as a technology-driven profession using simple models with poor mechanical education (let's accept the first, reject the second argument). Papers appear in professional journals, 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 structures involved in the case are stressed ("the runway was highly wanted by the regional industry");
- derived variables are used instead of physical state or material properties;
- statements are made about safety, economic evaluation or efficiency 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 finite element method"),
- inadequate illustrations are attached to the case (the street with a multi-storey glass and steel office complex is shown to demonstrate the successful action against settlements caused by a tunneling shield passing beneath the building in the depth of 20 m; successful treatment of collapsible soils is illustrated with the view of the hotel protected).

Experienced case study writers and users can easily add further items to this list, even if we know that only a few cases allow a perfect study with all the necessary features but without shortcomings.

Beside the common characteristics, there are particular points, too, worth mentioning. For instance, a few of the case studies written by geotechnicians stress only an essential issue related to the convergence of structural and geotechnical perspectives.

- The structural engineer's goal is to identify an optimal model (structural arrangement) for a function and find the best construction technology to realize it. Imagine a bridge where all efforts made by the constructors have to correspond with the demands raised by the most advanced dimensioning theory. Case studies provide examples of technology development serving the application of the best theories.
- Geotechnicians are more anxious about their models extended beyond the engineering structure to its surrounding. Imagine a tunnel or a concrete reservoir dam where adequate assumptions about the interaction between structure and soil or rock are a part of the modeling lesson, but there is no way to gain enough information with regard the expectable kinematical behavior of the latter one. This is why the proceedings of geotechnical conferences open so large a space for case studies: they pay more attention to explaining their modeling considerations.

The paper describes an effort to clarify some concepts and relationships to prove that the academic world has valuable reserves for creating and using better geotechnical case studies in higher education.

LEVELS OF INTELLECTUAL COMPETENCE

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 questions regarding the mechanisms of cognition (Mérő, 1990, 2001). Without discussing the general thoughts it is sufficient here to introduce those basic concepts and considerations only that are deemed necessary to understand our argument, using chess as an example (as discussed in depth by Mérő).

Competence in chess

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* chess player is familiar with the rules and recognizes the possible moves in a given position. He is able to calculate the immediate (or possibly up to two-three more steps) consequences of his move, and whether it is to his advantage or detriment. He knows and uses a few dozen simple schemes.

An advanced, *second class* chess player is familiar with those low-degree-of-freedom positions (openings, endgames) in which the options of the players can be calculated, and applied as the results of calculations already done by others. The outcome of his matches in these simpler situations now depends rather on his obtained knowledge than on judging each and every position. Number of the schemes employed is a few hundred.

The *master candidate*, as a result of having played hundreds of matches and analyzed the games of others, is able to assess the middle game positions unfolding from openings. He is familiar with position improving options and recognizes similar or analogous precedents. Weighing these he maneuvers to improve his position, to achieve a preferred (because familiar) endgame. The number of known and employed schemes is several thousands, a large percentage of which is complex.

The *grandmaster* also knows the strategic principles of manipulating games. Knowing hundreds of general patterns for various position options, he judges positions based on the opportunities of folding one into another. He sees the possibilities for improvement and damage (for example, he may give up or offer a draw when the positions are still confusing for a beginner or advanced player). He formulates strategic plans that encompass entire games, utilizing several tens of thousand complex schemes embedded in one another.

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	according to common logic	illogical because mixed	according to professional logic	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”

The players perceive or comprehend the positions in the patterns and schemes they understand. They weigh their options over the collection of these. 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. These facts are reflected directly in the results of matches played by chess players of differing levels of ability: the *Élő*-rating points indicate playing strength which give a reasonable estimate of the expectable outcome of the contest.

Studying or learning chess *via* case analysis is a common exercise (and, probably, amusement) for players of any level. Beyond the professional books (Benko, 2003) and magazines presenting thousands of conducted games with expert comments daily newspapers publish chess game analyses written by acknowledged masters, as well.

Competence in engineering

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 (10 semester MSc) 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. 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. The Table 1 includes some of the criteria for classification.

This classification proved surprisingly applicable for a great variety of professions. Small differences can result from the nature of individual profession’s paradigms and their stability (thus it may matter whether a profession’s interrelatedness and models are rooted in the deterministic laws of nature, statistical economic principles, or in man-made laws that reflect societal conditions). 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.

According to an especially important observation, reaching a certain level of proficiency in a given field can make changing fields considerably easier (Mérő, 2001). This fact is worthy of attention from the perspective of retraining associated with career changes (necessary or desired).

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 fields – or in a broader sense the natural sciences – 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, as a rule, 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" *model* is probably the most expressive among common expressions such as outline, script, model, pattern, sample, and prototype that are analogous with the concept of scheme and are also used by professional languages. The essence of professional knowledge is the model selection based on the above detailed elements.

The definition of model in this regard is very broad. It is far from being a simplified (or even palpable) copy of an object, establishment or phenomenon, such as the scale model of a building. It may consist of simple elements, it can be simple or complex. It also encompasses all mathematical, physical, technological and material relationships that approximate reality and its behavior to an (in the given circumstances acceptable) extent. 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 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 in light of the considerations offered by the cognitive psychology. 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:

Apprentice – ASc

- Understands the main characteristics of models (of phenomena) 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.

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 – the debate over dual or linear education is often unproductive because the parties perceive qualitative differences where the causes of discrepancies are of a completely different nature.

Table 2. Four level 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

Neither the creativity of the doctor 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.

Obviously, the presented framework is but one of the possible classifications available. 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 undergraduate's knowledge, experience gained in practice and master's knowledge in this system seem to be compatible with the bachelor-master separation described above.

Competence in geotechnics

Classification of civil engineering competence levels might seem to be of overall validity. In this situation it would be possible to derive case study characteristics for all areas of structural, pavement, geotechnical etc. engineering. However, there are significant differences to be taken into consideration when specific areas are at stake. Particularly, this is necessary when structural and geotechnical engineering was compared.

In many fields of civil engineering the implementation 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.

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 modeling 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 in 2000) 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.

Because of this highly complex character, perception and identification of the geotechnical phenomena, selection and application of the adequate models assume MSc competence. Moreover, interdisciplinary skill is the entrance to be gained for coping with the challenges in this field. Consequently, higher education must deliver all its geotechnical courses at all levels consciously and openly stressing this compound demand. This conclusion is in complete accordance with the general statements of the ASCE Report on Civil Engineering Body of Knowledge for the 21st Century (2007).

ROLE AND ADJUSTMENT OF CASE STUDIES

For civil engineers, as a rule, it is almost impossible to possess all abilities listed for the BSc and MSc competency levels without a shorter or longer experience in practice. Nevertheless, during the higher education term, case studies are at hand to illustrate all points and arguments of the subjects engaged with model creation and application. Even more, analysis of case studies must be an indispensable part of engineering courses at both levels.

One of the most explicit outlines of the case analysis approach was given by Hagerty and Mohsen (2005). They list the objectives of incorporating a full semester case history course into the civil engineering curriculum as follows.

- Provide an educational experience that prepares students for the challenge of professional practice and promote problem solving skills.
- Foster an appreciation for professional development and life-long learning.
- Develop an ability to apply knowledge from math, science, and engineering.
- Develop an ability to analyze and interpret data.
- Develop student competence in the design of systems, components, and processes to meet specific needs.
- Give indirect guidance on working with and as part of teams with divers technical makeup.
- Instill an understanding of professional and ethical responsibilities
- Expose students to contemporary issues pertinent to the practice of civil engineering.
- Promote service to the profession and to society.

Through scrutinizing 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,
- understand, and execute instructions given by a master.

Case studies at the BSc level serve more or less as *examples* highlighting the essential features (concepts, relationships, simplifying assumptions, solution techniques) of a model.

Students of *master* courses 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.

On the master level *case studies* induce and frame considerations about alternative models, selection principles, verification and validation issues, highlight the essential features of modeling..

This perception of case studies, of course, is neither a new development nor a consequence of the Bologna paradigm. Yet, it needs to be stressed, as did a report released by the US National Academy of Engineering recently [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 BSc students, the second one for MSc students.
- Hegemony interests and to-be-protected employment positions can distort correct narrative descriptions or instructive explanations.
- Case studies can convey very simple business messages ("look how interesting is the problem we have solved", "we are skilled masters of our technology", "you can trust us to fulfil all your demands").
- Several case studies are overloaded with admitted or veiled prejudices about technologies or methods other than their own ones.

Even these types of case studies can help in stimulating the interest of the BSc students in the subject, can give impetus for the MSc student to think about the case itself but have a low value for teaching or learning. From the point of view of her or his purposes, the teacher has to scrutinize a case study whether it contributes to the course performance effectively or even might be obscure.

In any case, there is a general interest in increasing the number and improving the quality of case studies edited and written with attention to educational demands.

Efficient engineering case studies are characterized with features such as:

- 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 (strains, displacement and damage modes, constraints) of the mechanical behavior (both expected, and observed) is commented as clearly as possible;
- applied computational methods are described explicitly, with their assumptions and essential characteristic (constitutive laws, degrees of freedom data, specific finite elements used at interfaces etc.) ;
- failures, mistakes made in selecting and applying adequate models are considered and discussed openly.

Having surveyed five recent international conference proceedings of the ISSMGE with more than four hundred case studies the author estimates that not more than 20% of them can be used efficiently for educational purposes. Further debates and discussions about the competency levels and grading can result in more consolidated comprehension and practice. All points and examples seem to prove, however, that the academic world has valuable reserves for creating and using better case studies in higher education.

CONCLUSIONS

Discussion of case studies must be an integrated part of engineering courses, both at the BSc and MSc levels. There are many case studies available in the professional literature for such purposes, but only a few of them are written and documented in a well-rounded and streamlined form for educational purposes. New features could be added to and faults should be eliminated from most of them. It is worth paying particular attention to the different attitudes and outcomes related to the undergraduate and master levels.

Authors of case studies (often members of academic and research faculty) can improve the quality of their papers about cases with some effort and more attention if they are aware their own needs as users of such studies in higher education. Students of BSc and MSc courses would benefit from these efforts, too.

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