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Modeling Instruction in an Environmental Geotechnics Course

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ABSTRACT: Although modeling of physical systems is a key engineering task, the educational literature provides little guidance on how to systematically include modeling exercises in instruction. To this end, this paper presents work-in-progress involving the introduction of a framework of modeling in an environmental geotechnics course. The framework unpacks the components of the modeling process, placing particular emphasis on the simplifications made when considering relevant phenomena, determining parameters and variables, specifying geometry and boundary conditions, selecting and solving governing equations. Explicit modeling instruction required modification of learning outcomes and corresponding revisions of instructional material, example problems and exam questions. The development of a larger-scale term project is underway, designed so that students gain confidence when selecting different levels of approximations, through comparisons of numerical solutions at different degrees of idealization with simplified analytical solutions.

INTRODUCTION

The key role of modeling in geotechnical engineering has been identified by leading researchers and revered teachers in the field (Burland 1987, 2006; Lundell-Sällfors and Sällfors, 2000). Modeling of environmental geotechnics problems shares the complexities of geotechnical problems, with the additional difficulty of deciding to account for all or ignore some of the phenomena related to the release and the fate of contaminants in the subsurface. However, despite its importance, the process of modeling remains a “black box” for instruction purposes. While on the surface modeling appears to be a mainstay of engineering education, engineering instruction focuses much more heavily on model analysis than on model formulation.

With the aforementioned motivation, this article has the following two objectives. First, to review an existing modeling framework (Pantazidou and Steif, 2003; Steif and Pantazidou, 2004). Second, to propose possible applications of the framework in instruction, using as example its introduction in an environmental geotechnics course taught at the last year of a five-year civil engineering program. The aim is that this paper serve as catalyst for the kind of discussion that could both (i) advance further the proposed framework and its applications and (ii) bring forward alternatives, with the ultimate goal of increasing the instances of explicit instruction on engineering modeling.

ON MODELING IN GEOTECHNICAL ENGINEERING

The central role of modeling in geotechnical engineering was highlighted early on by Burland (1987). In this seminal address, Burland (1987) introduced a graphic where he placed at the apexes of a triangle three main aspects of soil mechanics, namely *ground profile*, *soil behavior*, and *applied mechanics*, with a fourth aspect, *empiricism-experience*, at the center of the triangle, intertwined with the other three. Regarding *applied mechanics*, he noted that it includes "idealization, modeling and analysis". In a later revision of the, now known as, "Burland triangle", *applied mechanics* is replaced by *appropriate model* and is accompanied with the explanatory note "idealization followed by evaluation, conceptual or physical modeling, analytical modeling" (Burland, 2006). In the same vein, Lundell-Sällfors and Sällfors (2000) placed particular emphasis on the use of realistic problems in instruction as means for students to acquire experience with the demanding task of translating a real-life situation into a well-defined engineering problem.

Problems in environmental geotechnics naturally share similar difficulties with geotechnical problems, e.g., same issues with approximations of geometry and properties, reductions of dimensionality and idealizations of boundary conditions. Moreover, geoenvironmental problems offer a larger menu of phenomena (to take into account or ignore) and of corresponding parameters. In addition, they are characterized by a wider variety of initial conditions, e.g., types of contaminant releases at the source. Hence, as in many applied engineering courses, it becomes a challenging task for the instructor to bring rich "solvable" problems in class.

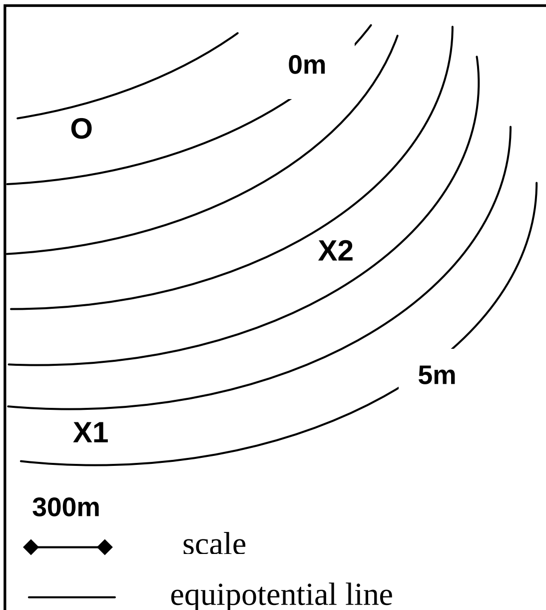
A MODELING FRAMEWORK

The aim of developing a framework for modeling was to articulate its constituent components. The motivation was to come up with guidance, in the form of a framework, to assist instructors with teaching the modeling process and help students practice modeling. Pantazidou and Steif (2003) and Steif and Pantazidou (2004) discuss in detail the background of framework development. This section summarizes the main premises and features salient for instruction.

Seeking the constituent components of a complex mental task, like engineering modeling, rests on the assumption that such components exist and can be found. The literature of cognition and instruction provides evidence that this indeed is the case [e.g., see work by Goel and Pirolli (1992) on design]. What is more, there is evidence that explicit task decomposition improves student performance [e.g., see work by Lovett and Greenhouse (2000) on statistical modeling].

Constituent components of cognitive tasks can be determined by following either a prescriptive or a normative approach. Developers of prescriptive frameworks focus on what a particular task *should look like*, judging from their experience as either seasoned instructors or experts in the respective discipline, or both. In contrast, normative approaches are based on studies of subjects performing the task and hence their results may come closer to what a cognitive task *actually looks like*.

The authors followed the normative approach, using interviews and protocol analysis. For this purpose, three open-ended sample problems were constructed, all involving a real situation or object. The problems were drawn from the areas of mechanics, soil mechanics and contaminant transport. The contaminant transport problem can fit very well in an environmental geotechnics course. It is drawn from an actual project and addresses the common question of confirming or discarding the possibility that a spill at a particular location is the source of contaminant detections in groundwater. The data for this problem consisted of an air photograph and a contour map of the groundwater table elevation, marked with the locations of the potential sources and the contaminant detection. Figure 1 provides a zoomed-in sketchy version (due to space limitations) of the contour map and a summary of the problem statement.



A trichloroethylene (TCE) spill took place in 1970 at one of two possible locations, **X1** or **X2**. In 1995, TCE is detected in a groundwater sample from location **O**. It is difficult to obtain additional samples between the **X'**s and **O** because there is an airplane landing strip between them. Could you make a first estimate whether **X1** or **X2** could be a potential source?

X potential TCE source
O TCE detection

FIG. 1 Sample modeling problem used in student interviews (spill problem).

During interviews, graduate students were asked to "think aloud" about how they would go about formulating and solving the problems. The interviews were tape-recorded and transcribed. These transcripts are often referred to as protocols. Protocol analysis consists of (1) developing a coding scheme (i.e., deciding on suitable labels that describe the categories of subtasks on which subjects focus), (2) segmenting the protocol (i.e., grouping related utterances) and (3) coding (i.e., labeling) the segments. A following short excerpt from a transcript of the spill problem (Figure 1), coded as *qualitative solution*, serves as an example: [Since I know it is going in this direction, I know it would be a spill here (Note: student sketches contour) and then with time it would be growing (Note: student sketches wider contours), it would be traveling, but then it would also get longer and wider … so the question would be in some time could it spread big enough…].

The developed coding scheme includes ten categories of focus corresponding to the hypothesized components of the modeling task, some of which can be grouped together. The ten modeling components are indicated with italics on Figure 2, where they are numbered for reference purposes.

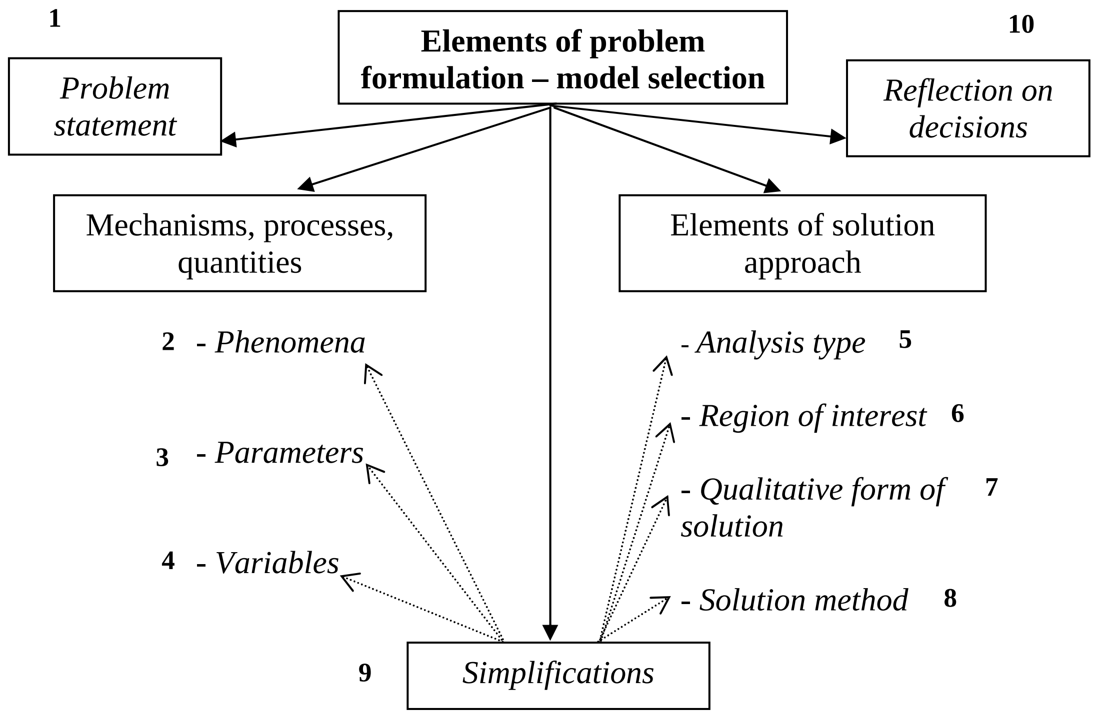


FIG. 2 Constituent components of engineering modeling.

Transcript analysis indeed showed that subjects attended to subtasks suitably described by the chosen focus categories, thus providing confirmation that the selected coding scheme is meaningful and an indication that the coding categories represent the constituent components of modeling. It is worth noting that various attempts at simplifying the problems were explicitly mentioned during the interviews. *Simplifications* were thus acknowledged as a separate component, despite their necessary relation to the other modeling components (e.g., simplifications of parameters, simplifications of analysis type, etc.).

The ten categories were accompanied by detailed annotations, developed both to clarify each category and to reduce ambiguity during coding. Because the annotated version of the coding scheme is two-page long, annotations of only two categories, *phenomena* and *simplifications*, are included as examples next.

2. Phenomena

- statements about what is happening physically
- causal relationships or interactions between effects or events
- related physical effects that would be relevant if present (often not obvious from problem statement)

• statements about what can go wrong (failure modes or critical conditions)
• proper names for physical phenomena.

9. Simplifications

• Idealization, approximation, estimation, or neglect
• Must include recognition that a relative simplification has been made
• Simplifications are always with respect to another element, such as:
    • Phenomena: idealize operative phenomena or neglect phenomena
    • Parameters: approximation (replacing a known complex variation with a simpler one), estimation (rough quantification of the value of an unknown parameter), neglecting the role of a parameter
    • Variables: neglect the variation with an independent variable or idealize the variation with respect to a variable. Can involve anticipating whether or not a quantity has a magnitude to be of further concern.
    • Analysis type: Simplification of mathematical relationships, including idealized relations (e.g., linear) between quantities, bounding behaviors (such as rigid body, potential flow) with specific mathematical consequences, approximate or partial implementation of principles
    • Region (or subsystem) of interest: neglect of a region as not being worth investigating, simplify geometry of subsystem, simplify external interactions
    • Solution method: each method can have a variety of simplifications.

USING THE MODELING FRAMEWORK IN INSTRUCTION

Including modeling instruction in a course starts with stating the corresponding learning outcomes. The instructor is required to describe what modeling is and decide on levels of modeling performance for purposes of assessment. For all these decisions, the modeling framework can serve as a useful guide. The instructor then has to create instructional materials compatible with the aforementioned decisions. This section describes the evolution of course modifications made by the first author while introducing modeling instruction in an environmental geotechnics course, an advanced undergraduate course taught at the fifth year of the civil engineering program at the National Technical University of Athens (NTUA), Greece.

Learning outcomes

The overarching goal of the course is to develop environmental thinking related to risk assessment, recognition of the mechanisms affecting the fate of a contaminant release in the subsurface, and selection of suitable remedial measures and/or technologies. The goal of the course is mapped to the learning outcomes below, i.e., the goal is achieved if at the end of the course the students:

• can locate reliable data on the effects of contaminants on human health,
• are confident in applying principles of mass transfer, groundwater flow and contaminant transport to problems of contamination and restoration of the subsurface,
• are able to address the geoenvironmental aspects of landfill and clay barrier design,
• are familiar with a wide range of remediation technologies,
• are able to take initiatives related to modeling, i.e., related to the formulation of a

simplified problem that admits solution,

- are aware of some social or public policy dimensions of the problems of subsurface contamination and restoration.

The statement of the learning outcome related to modeling may correspond to levels of student performance ranging from attending to a few or most aspects of modeling of an open-ended problem to producing a fully-defined problem statement accompanied with the information necessary for its solution, the solution itself and reflections on decisions. Based on the pervasiveness of explicit references to simplifications in the protocols and given the supporting role of modeling in the course under discussion, a decision was made to focus performance expectations primarily on familiarity with the simplifications aspect of modeling.

Instructional materials

The materials produced for the purposes of modeling instruction consist of a handout with guiding questions for problem formulation and model selection. These questions correspond to shorter versions of the annotations produced for the constituent components of modeling. The guiding questions are accompanied with the schematic of the modeling framework depicted in Figure 2. The questions originating from the annotations for *phenomena* and *simplifications* listed earlier are included as examples next.

2. What is happening here?

- Which phenomena are relevant to the problem?
- The consideration of which mechanisms may contribute to setting up the problem?

9. Can I make any simplifications? Can I approximate something? Ignore something? Specifically, can I…

- simplify or neglect some phenomenon?
- approximate/estimate/neglect some parameter?
- neglect the variation of some variable?
- simplify some mathematical relationship?
- neglect some region, some system?
- simplify the geometry?
- simplify the solution method?

The modeling handout is introduced in class at an opportune time, following discussion of a few groundwater-flow problems solved with alternative ways, producing answers of different accuracy. References are later made to the handout throughout the duration of the course, both in the presentation of the theory and during in-class solution of problems. Apart from the modeling-specific instructional material, the emphasis on modeling prompted modifications of the presentation of the subject matter. Contaminant transport is an ideal topic to introduce aspects of modeling, as there are many closed-form solutions to the advection-dispersion equation for one, two or three dimensions, for specific conditions at the contaminant source and accounting (or not) for various phenomena (e.g., sorption, degradation). To this end, a handout was prepared with different versions of the advection-dispersion differential equation and alternative corresponding solutions, depending on the boundary conditions, phenomena considered, etc. It is important to stress that the inclusion of modeling instruction offered the opportunity to enrich contaminant transport instruction.

Without the prospect of using the material in modeling-related exercises, the compiled equations would make a dry mathematical handout for reference purposes. On the contrary, given the emphasis on model selection, the thinking behind transport equation choice enhances the understanding of contaminant transport phenomena.

The problems solved in class and assigned as homework were also modified accordingly. Fully-defined problems were restated as partly open-ended, paying attention to eliminating as much as possible references to variables and parameters that invariably point to a unique "right" solution. It should be stressed here that in curricula that give students few opportunities to practice the decision making required by open-ended assignments, it is expected for students to feel discomfort with such assignments. The discomfort often prompts questions of the type "what do *you* want me *exactly* to do?", i.e., implicit requests to fully define the problem. Students, understandably, will not welcome the responsibility of problem definition. Hence the gradual introduction of modeling components could perhaps be sound not only from a cognitive but also from a psychological point of view as well.

The in-class discussion of problems includes first a lengthy stage of problem formulation, where students see how many modeling decisions does it take to transform a real-life question, such as:

- following a contaminant spill in a pond, there is concern whether a downgradient canal may be impacted if no measures are taken

to corresponding fully-defined assignment-type problems:

- what is the contaminant travel time between the pond and the canal?
- when will 1% of the concentration of the contaminant in the pond reach the canal?

In addition, several solutions are presented for most problems, each at a different level of simplification. The use of partially-defined problems enables selective attention to specific aspects of modeling, which is consistent with the learning outcome defined for the particular course. For example, some problems are good for deciding which phenomena can be ignored under certain circumstances. Others offer opportunities for considering reductions of the dimensionality of a problem. In future versions of the course, students will also practice anticipating the effects of simplifications, with the aid of numerical modeling and comparisons of numerical solutions at different degrees of idealization with simplified analytical solutions. For this purpose, a user-friendly web-based educational software (Valocchi and Werth, 2004) will be used for a term project.

Practicing modeling and assessment of modeling performance

As mentioned, modeling performance was more narrowly defined, in the particular course, as familiarity with the simplifications aspects of modeling. As a result, partially-defined problems were used not only during class discussions, but also in assigned homework and in exam questions. When assignments do not include information on parameters that directly point to phenomena, only then can students decide on their own which phenomena to include. Similarly, when maps of a wider study area are given (i.e., unlike the zoomed-in version of Figure 1!), students have to specify themselves the region of interest for the particular problem. These are examples of how to force students to model in the context of assignments. Modeling-type skills can equally well be assessed with "theory-type" questions that require anticipating general trends of phenomena or giving examples of certain simplifications (e.g., an example where steady-state transport conditions may apply).

CONCLUDING REMARKS

A modeling framework can guide both the instructor who seeks to introduce modeling instruction in a course and the student to acquire experience with modeling. While for both it will be a gradual process, the instructor must anticipate that incorporating modeling instruction in an engineering course will not simply add a new component, but will also alter the way the course is taught. Ideally, teaching of modeling should be part of engineering courses throughout the curriculum. One would rightly argue that modeling instruction takes up time from instruction on the subject matter of the course. However, it is time well spent: insight into differences between models has the potential to enhance understanding of the modeled phenomena.

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REFERENCES

Burland, J.B. (1987). "The teaching of soil mechanics: a personal view" Proc. of 9th European Conference on Soil Mechanics and Foundation Engineering, Dublin, Vol. 3: 1427-1447.

Burland, J.B. (2006). "Interaction between structural and geotechnical engineers", *The Structural Engineer*, 18 April 2006: 29-37.

Goel, V. and Pirolli, P. (1992). "The structure of design problem spaces", *Cognitive Science*, Vol. 16 (3): 395-429.

Lovett, M.C. and Greenhouse, J.B. (2000). "Applying cognitive theory to statistics instruction", *The American Statistician*, Vol. 54 (3): 196-206.

Lundell-Sällfors, L. and Sällfors, G.B. (2000). "Focus on real life problems facilitating learning and understanding", Proc. of 1st International Conference on Geotechnical Engineering Education and Training, Manoliu, I., Antonescu, I. & Radulescu, N. (Eds.), Sinaia, Romania: 425-431.

Pantazidou, M. and Steif, P. (2003). "Modeling of physical systems: a framework based on protocol analysis", International Meeting on Civil Engineering Education, Ciudad Real, Spain, Sept. 18–20.

Steif, P. and Pantazidou, M. (2004). "Identifying the components of modeling through protocol analysis", American Society of Engineering Education (ASEE) Conference, Salt Lake City, Utah, June 20–23.

Valocchi, A.J. and Werth, C.J. (2004). "Web-based interactive simulation of groundwater pollutant fate and transport", *Computer Applications in Engineering Education*, Vol. 12: 75-83, http://www.cee.uiuc.edu/transport/