

Creating an Online Version of an Environmental Geotechnics Course: Pedagogical Opportunities

Marina Pantazidou

National Technical University of Athens, Greece, mpanta@central.ntua.gr

Kyriakos Kandris

National Technical University of Athens, Greece, kkandris@gmail.com

SUMMARY: This paper describes the changes prompted by transforming a lecture-based course to an online version, as well as the intended and some unintended outcomes resulting from these changes. Changes implemented are discussed in two separate categories: (1) logistical changes, i.e. modifications imposed by the constraints of studying online educational materials and (2) pedagogical changes, i.e. changes stemming from research-based learning principles, which, for presentation convenience are further subdivided in (2a) methodology-driven changes and (2b) content-related changes. The overarching aim of the implemented changes was to make transparent the major decisions involved in course design. The immediate goal of the paper is to make explicit the relationship between good instructional practices and the research evidence that supports them. The ultimate goal of the paper is two-fold: to enable sharing of educational material in the belief that material developed to address stated instructional needs can be useful to other instructors and to encourage engineering instructors to contribute their work to the communal instructional resources.

KEYWORDS: course design, civil engineering, evidence-based practice, case study.

1 INTRODUCTION

This paper belongs in the genre “Case Study of Designing a University-Level Course” and describes the redesign of an elective course on environmental geotechnics. Course design includes the methodology of selecting the building components of a course and associated decisions along the process. The object of Environmental Geotechnics is the protection of the subsurface (soil and groundwater) from potential pollutants related primarily to waste management (e.g. landfills) and to transporting, storing and handling toxic raw materials (e.g. petroleum products, solvents).

The course has been taught for several years in the 9th semester of the 5-year integrated civil engineering curriculum at the National Technical University of Athens (NTUA), Greece (<http://www.civil.ntua.gr/courses/119/>). The first author of the paper is the course

instructor and the second author is the graduate student teaching assistant. The online version of the environmental geotechnics course is in Greek and it is meant for self-paced study (<https://ocw.aoc.ntua.gr/courses/CIVIL115/>).

The incentive for the redesign was offered by the NTUA-wide project for the creation of open online courses. Separating the live version of the course from its static, online counterpart gives an opportunity to bring to the fore the essence and the logic of the subject taught and keeps instructors backstage, where they cannot use personal traits to keep students engaged. Absent instructors have to be more organized and more attentive to their imagined students; hence, the online version required targeted changes, which ended up benefitting the live version of the course as well.

The environmental geotechnics course has been evolving through the years within the framework of scholarship of teaching (Borrego

et al. 2008; Pantazidou and Steif 2008; Pantazidou 2009; Pantazidou 2010). The single most important aim for the version described herein is to make course design decisions transparent to students and colleagues. In addition, this paper strives to make explicit the relationship between good instructional practices –the pedagogical opportunities of the title– and results of research on education.

Good pedagogy typically originates from two sources: the intuition of the instructors, drawn from their experiences as students and teachers (Jamieson and Lohmann 2012), and instructional practices grounded in research results from the science of learning (Ambrose et al. 2010). Although the two sources of inspiration may often converge to similar results, it is unlikely that every required instructional intervention will originate from experience alone. Hence, familiarity of instructors with elements of the literature on education is highly recommended (Pantazidou and Frost 2012), as there is evidence of positive correlation with their students' achievement level (Sadler et al. 2013).

Within this context, this paper uses the opportunity of the redesign of the environmental geotechnics course to give examples of (a) the guidance instructors can find in research on learning and (b) how they can readily apply this guidance to their courses.

To this end, the paper starts with introducing the main principles that underpin the changes made during redesign (Section 2), as they are presented by Ambrose et al. (2010) in “How learning works: 7 research-based principles for smart teaching”. Then, it gives examples of changes made, starting from the changes necessitated by the online format (Section 3.1), which are referred to as logistical, because they were mainly driven by ease-of-use. Lastly, the paper gives examples of pedagogical changes (Section 3.2), largely inspired by research-based teaching practices.

2 LEARNING PRINCIPLES

Ambrose et al. (2010) write for the instructors

who want the gist of research on education and the implications of this research translated into readily-applied good teaching practices. They focus on seven learning principles, identify the main implications of these principles expressed as goals, i.e. teaching practices meant to support desired student activities and attitudes, and offer a large variety of teaching strategies to achieve these goals. Table 1 lists five of the seven principles, their implications expressed as actions on the part of the student (s) or the instructor (i), a small subset of associated strategies that were salient to the design of the environmental geotechnics course, and indicative examples of implemented strategies. For ease of reference throughout the paper, each principle is assigned herein a number and a short name. These principles, goals and strategies are introduced briefly in this section, while their specific connection to the design of the environmental geotechnics course is described in Section 3.

2.1 Prior knowledge principle: “Students’ prior knowledge can help or hinder learning”

When students connect what they are learning to relevant prior knowledge from another or the same course, they learn and retain more. In addition, there is evidence that when recall is triggered (e.g. with the aid of quiz questions), the process of retrieval itself contributes to further learning (Karpicke and Grimaldi 2012). However, if prior knowledge is inaccurate and remains undetected, it will hinder learning. Hence, the goal for the instructor is to first identify the inaccurate knowledge and then develop educational material to address it. Ambrose et al. (2010) appear to assume that inaccurate prior knowledge is always apparent to instructors. But this is not so, at least in engineering, where knowledge builds on prerequisite understandings, often from other disciplines. For example, students may hold inaccurate prior knowledge from physics or chemistry (e.g. Ben-Zvi et al. 1986), as discussed in an example in Section 3.2.2.

Table 1. Learning principles, major goals originating from each principle and selected strategies to achieve goals, adapted from Ambrose et al. (2010).

Description of learning principle (exact phrasing from Ambrose et al. 2010)		
Principle number and short name	Main goal for student (s) and instructor (i)	Selected strategies†
Students' prior knowledge can help or hinder learning		
1 - Prior Knowledge	Activate prior knowledge (s)	Link material from other courses and within the course (trigger recall) ^a
	Identify-address prior inaccurate knowledge (i)	Ask students to justify their reasoning (uncover prior beliefs) ^b
How students organize knowledge influences how they learn and apply what they know		
2 - Knowledge Organization	Build dense and meaningful connections (s)	Provide organization structure of subject matter, course, lectures
To develop mastery, students must acquire component skills, practice integrating them, and know when to apply what they have learned		
3 - Mastery	Practice component skills (s)	Break complex tasks into component tasks ^c
	Practice integration (s)	Scaffold complex task performance
Students' motivation determines, directs, and sustains what they do to learn		
4 - Motivation	Increase subjective value of goal (s)	Assign authentic, real-world tasks
	Hold expectation for successful attainment of goal (s)	Align objectives-assessment-instructional practices, Articulate expectations, Use rubrics
Goal-directed practice coupled with targeted feedback enhances the quality of students' learning		
5 - Communication	Practice towards specific goals (s)	Be specific about goals, State learning outcomes ^d
	Provide feedback (i)	Provide feedback at the group level

† Indicative examples of applied strategies - Supplementary material is available at:

users.ntua.gr/mpanta/Teaching_EN/EnvironmentalGeotechnics for the following topics, ^a Quiz questions from unit “subsurface flow”, ^b Beliefs and analogies for the nature of solutes, ^c Contribution of dispersion-sorption-degradation to contaminant transport, ^d Detailed learning outcomes for unit “contaminant transport in groundwater”.

2.2 Knowledge organization principle: “How students organize knowledge influences how they learn and apply what they know”

Instructors may assume that because they organize their courses in a certain way, this organization structure will be apparent to their students, or that students will be able to create their own structure. But, for students this is the exception, rather than the rule, since a highly organized structure of specific knowledge in a domain is a characteristic attribute of expert performance (Glaser and Chi 1988). Ambrose et al. (2010) too stress that the density of connections among concepts, facts and skills characterizes experts' knowledge organization. Students can use all the help instructors can give them to arrange what they learn. A neglected part of the organization is why students are learning something. Readily implementable changes include making explicit to students the organization structures at every level: lecture, course, subject matter.

2.3 Mastery principle: “To develop mastery, students must acquire component skills, practice integrating them, and know when to apply what they have learned”

This principle is partly linked to the previous, since it deals with assisting students with progressing along the novice-expert continuum. To this end, instructors should break complex tasks in their components and provide students with opportunities to practice component tasks. But, when experts attempt to identify component tasks, their own efficient performance becomes an obstacle in identifying steps and rules, aptly referred to as the “expert blind spot” by Ambrose et al. (2010). Hence, during fine-tuning of educational material, it is useful for the instructor to collaborate with a teaching assistant who can offer a perspective from an in-between expertise level. To avoid having the practice of component tasks result in rote learning (e.g. student memorizing solutions of standard problems), instructors should also

design opportunities for students to practice integration. This can be achieved by scaffolding complex task performance in a variety of ways, such as reducing the cognitive load of the complex task, supporting some aspects of the complex task, and providing rubrics specifying grading criteria.

2.4 Motivation principle: “Students’ motivation determines, directs, and sustains what they do to learn”

This principle and the next focus more on the psychological-behavioral aspects of learning, which support the cognitive. Ambrose et al. (2010) give a thorough overview of the motivational aspects of learning by first defining motivation as personal investment affected by (a) the subjective value of a goal and (b) the expectations of its successful attainment, or expectancies. Although instructors have little say in the goals students set for themselves, they can exert some indirect influence. Ambrose et al. (2010) offer a variety of strategies for instructors to establish values (which in turn can affect goals) and to build positive expectancies. Concerning the subjective value of the tasks, instructors can make material interesting by assigning authentic, real-world tasks, to the extent allowed by the subject matter. And, irrespective of the subject matter, instructors can make a significant difference by helping students hold positive expectancies by implementing strategies such as: clearly describing expectations, giving diagnostic tests to gauge class level and create assignments at appropriate level, and offering grading rubrics to show students what is important.

2.5 Communication principle: “Goal-directed practice coupled with targeted feedback enhances the quality of students’ learning”

The basis for this principle is communication, hence its short name. Most instructors, in their minds, have clear ideas on performance goals for their students. In order for these

performance goals to be the drivers of the course, they need to be clearly stated in writing as learning outcomes and communicated to students. Learning outcomes provide a more accurate picture of the identity of the course, compared to course contents, not only to students, but also to colleagues and program assessors.

3 COURSE REDESIGN

3.1 Logistical changes: Making online material more user-friendly

This section discusses the main changes made to the presentation of the course material in its online version. In the absence of a teacher who can clarify things, two priorities were set for the online course: reducing the cognitive load for the online user and outlining explicitly the connections between course topics and supporting material.

Cognitive load was reduced by a variety of modifications, such as:

(i) In anticipation of a future online version with videotaped PowerPoint presentations, existing presentations were broken in smaller subunits. For example, the core units of the course on groundwater flow, soil-contaminant interaction and contaminant transport broke in four presentations each, from the initial two, one, and two presentations, respectively.

(ii) A lot of thought went to assigning a meaningful title and subtitle to each subunit.

(iii) Each subunit ended with highlighting the main points, and each unit ended with detailed learning outcomes. Introducing and wrapping up subunits reduced the cognitive load for the live version as well, and ended up improving the teaching experience.

Moreover, each of the ten units of the online version was described by 1-2 paragraphs of text, which also explained the relationships between the main points of the unit and the unit material (PowerPoint presentations, case studies and solved problems).

Although most of the above changes were made for the convenience of the user, only in

retrospect it became apparent to the instructor that they make sense from a pedagogical view point as well. For example, meaningful titles are in agreement with the knowledge organization principle No 2 and distilling each course unit in its essentials provides an example of expert understanding (3 - mastery principle).

3.2 Pedagogical changes: Applying research-based good practices

3.2.1 Methodology-driven changes

As already mentioned, the major aim driving the changes was to make more transparent to students the way the course was designed (5 - communication principle). This was done in a variety of ways:

(i) Course-level general learning objectives are supplemented with detailed learning outcomes for each course unit, as already mentioned (see also note ^d in Table 1). The live version of the course also highlighted the relationship of the detailed learning outcomes to assignments and the term project (4 - motivation principle).

(ii) Contents were reordered to make clearer to students the necessity of certain course units, thus rendering unnecessary the approach of: “you will see later the usefulness of what I teach you now” (2 - knowledge organization principle). Specifically, the technical part of the course starts with a qualitative introduction on pollutant spreading in water, in order to stress the important role of groundwater velocity and, thus, motivate the unit on groundwater flow.

(iii) Qualitative description of phenomena precedes their quantitative-mathematical formulation. This also helped with revisiting topics and, thus, reinforcing key concepts. (2 - knowledge organization and 3 - mastery principles). This qualitative-quantitative sequence is implemented at two critical junctures of the course. As already alluded in (ii), the mechanisms of contaminant transport in water (advection, diffusion, mechanical dispersion) were introduced at the beginning of the course qualitatively, with the help of videos,

analogies and simple experiments, before equations were introduced in the unit of contaminant transport in groundwater. Likewise, after completing the unit on mass transfer and sorption, the manifestation of sorption as contaminant retardation is introduced with an analogy explained with an in-class “transport experiment”. The experiment involves chocolates that move through classroom tables with specific rules towards the back of the classroom and demonstrates how “sorption” affects the mobility of chocolates passed on (Pantazidou 2010). The concept of sorption manifested as retardation is further reinforced qualitatively with the results from the first solute transport experiment conducted at Borden (Roberts et al. 1986), before introducing the retardation factor in the transport equation.

(iv) The importance of key topics is stressed by visiting them often: key concepts are introduced during the first half of the course and are later reinforced several times in different applications (2 - knowledge organization principle). Such a key skill is estimating hydraulic gradient from the potentiometric map (i.e. hydraulic head map) of a real site and, with this information, calculating seepage velocity. Students do this in a homework assignment in the unit on groundwater flow, they repeat it when they need the advection velocity as input to the solution of the contaminant transport equation, and they have one more opportunity to practice in the unit on remediation technologies, in problems where they calculate the required width of a permeable reactive barrier.

A second systematic change was to supplement every lecture with multiple choice quiz questions in order to trigger recall (1 - prior knowledge principle) and also, for the live course version, to provide feedback at the group level (5 - communication principle). The intent of these questions is primarily diagnostic. Most of them require that the students think critically of course content (e.g. Do you agree with the statement “In general, we worry less about naturally-occurring substances in soil and groundwater”?). A few are meant to uncover or prevent misconceptions (see also note ^a in Table

1), e.g. the question shown in Figure 1 about calculating hydraulic gradient between two points using distance (L_1 or L_2) or flow path length (L_3 – the correct answer) between the two points.

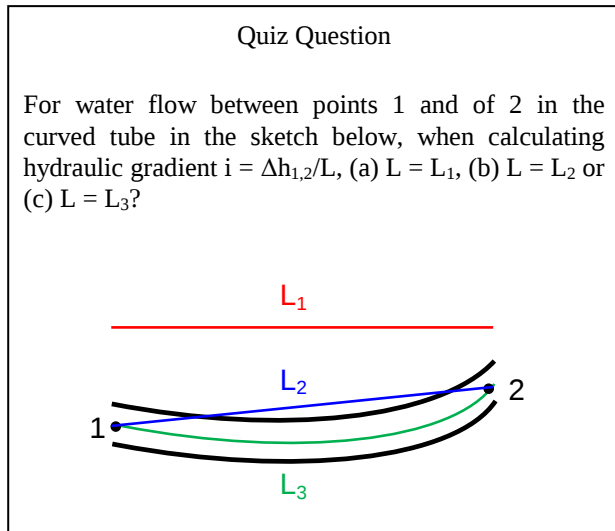


Figure 1. Quiz question concerning alternatives for calculating hydraulic gradient between points 1 and 2.

The difficulty in coming up with several meaningful quiz questions and phrasing them properly was a surprise to the first author. Part of the difficulty was due to initial inexperience with using multiple choice questions in exams, which was partly overcome after attending several massive open online courses (MOOCs) and getting ideas from the quiz questions used therein. For example, the experience of attending MOOCs revealed the usefulness of asking students to select from a list of statements all those with which they agree, without telling students how many may be true (could be only one, or all). In order to avoid misunderstandings caused by the phrasing of quiz questions, it was essential to run them by the second author (who has served for several years as graduate student teaching assistant of the course) for comments and modifications.

Given the difficulty of thinking quiz questions and ensuring their reliability, the first author would not have been that diligent with devising them, had it not been for the paper by Karpicke and Grimaldi (2012), which demonstrates convincingly the learning gains of students

when being asked questions. Familiarity with the literature of education provided the necessary encouragement for not giving up a practice that reinforces learning.

3.2.2 Content-related changes

This section gives some pointers on mostly new educational material developed to address teaching needs specific to the subject matter.

Environmental Geotechnics is an applied field. The course is designed so that students get the necessary background to address the central issues at a contaminated site, with emphasis on case studies (4 - motivation principle). The subject matter is introduced with cases and nearly every course unit includes one case study. For example, the unit on risk assessment presents the results from the risk assessment study performed in 1998 for the site Graces Quarters (USEPA 2004) and stresses that the carcinogenic and hazard indices would be different if the calculations were performed with the revised toxicity characteristics valid 15 years later.

The applied nature of the course facilitates connections with other civil engineering topics and courses (1 - prior knowledge principle). Obvious connections are to classic geotechnical engineering topics (groundwater seepage due to consolidation, clay-contaminant interactions). In one such instance, hydraulic conductivity is contrasted to the modulus of elasticity, in order to make the point that hydraulic conductivity varies over many more orders of magnitude – 11 orders of magnitude for soils-rocks – compared with most quantities common in civil engineering: e.g. modulus of elasticity varies by 2.5 orders of magnitude for soils-rocks, or 4.5 orders of magnitude if concrete is also taken into account. This comparison is useful also because it shows that while concrete and clay can have comparable hydraulic conductivities, clay outperforms concrete when low permeability is desired for contaminant barriers, e.g. landfill liners.

Because tasks that involve complex phenomena can be challenging for students, it

helps to support some aspects of the complex task (3 - mastery principle). One such example is the unpacking of contaminant transport by demonstrating with targeted graphics the effect of each one of the contributing mechanisms (dispersion, sorption, degradation), as shown in Figure 2 (see also note ^c in Table 1).

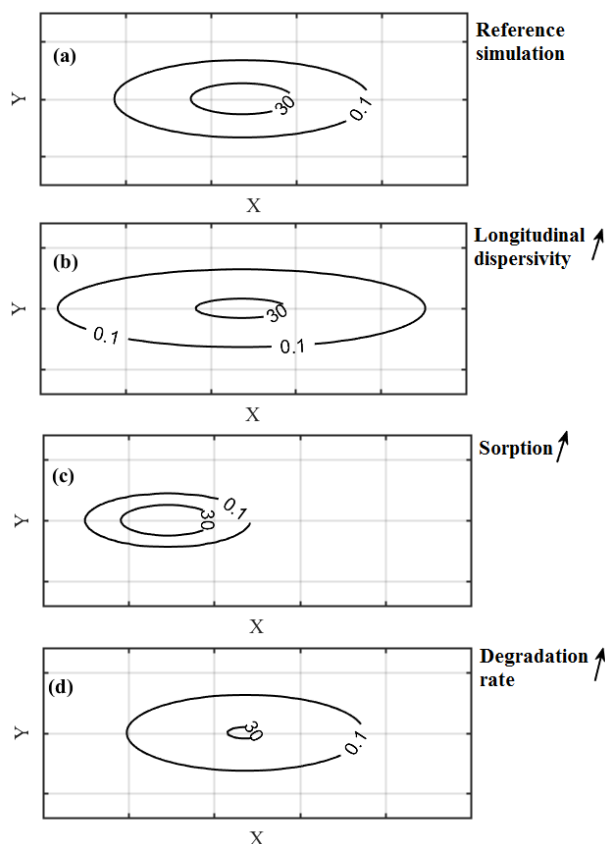


Figure 2. (a) Reference simulation for contaminant spreading following an instantaneous release from a point source at concentrations 0.1 and 30 $\mu\text{g/l}$ and illustration of the effect from increased (b) mechanical dispersivity, (c) sorption and (d) degradation.

Lastly, the ongoing effort to identify problem areas of inaccurate understanding continues (1 - prior knowledge principle), by crafting suitable qualitative questions, as described for the concept of soil structure by Pantazidou (2009), and continuous monitoring of students' work for possible cues. Knowledge of the literature on common misconceptions helps instructors not miss such cues and better understand the origin of inaccurate conceptions, gives an idea of their pervasiveness, and may offer guidance on how to address them in instruction.

For example, one misconception came up

during a lecture break, in a discussion on a comment by a student. The discussion revealed that the student was envisioning for solute transport "solid" molecules of a contaminant in water (e.g. chromium, which is solid in its natural state). In the mind of the student, the contaminant, although in solution, had preserved its solid properties and was travelling like tiny beads suspended in water. This misconception is discussed in the paper by Ben-Zvi et al. (1986) "Is an atom of copper malleable?", which concerns the, apparently common, fundamental misconception of extending properties of matter to the molecular and atomic level, e.g. believing that each atom or molecule of a solid substance is also solid.

Knowledge of the pervasiveness of this misconception helped in two ways. First, in identifying other instances of it in students' work. For example, in the answer to a conceptual question asking students to describe letting clothes dry indoors vs outdoors using analogies from environmental geotechnics, one student wrote: "The drying of clothes primarily consists of liquid water molecules turning to gaseous water molecules". Second, the knowledge of the pervasiveness of the misconception helped in deciding to attempt to address it in class: knowing that deeply held misconceptions often persist despite direct instructional interventions (Ambrose et al. 2010), analogies related to the coffee culture of Greece were used hoping for increased retention (see also note ^b in Table 1). A slide clarifying that solid-liquid-gaseous states are emerging properties of assemblages of the same molecules is accompanied by a picture of instant coffee (the ubiquitous "nescafé" of Greece), which visibly loses its solid state when mixed with water. Hence, nescafé is recommended as a model for an aqueous solution. Nescafé is contrasted with Greek (or Arabic) coffee, which, with coffee grounds settling to the bottom of the cup, is a better model for transport of particles in suspension rather than solute transport.

4 CONCLUDING REMARKS

This paper attempted to answer the question “If I am familiar with the education literature what can I do better in my course?” by giving examples of implementing teaching practices that are supported by evidence-based learning principles. It is probable that experience will eventually guide instructors to many of these practices, but certainly not all. It is also probable, that instructors who are familiar from the literature with these teaching practices will be able to improve their courses faster than if they draw inspiration from experience alone.

The guidance offered by the learning principles is domain-independent and, hence, is accessible to every interested instructor. This paper was written with the belief that the guidance will be more meaningful to instructors if accompanied with application examples drawn from their own or a neighboring discipline (4 - motivation principle).

The ultimate goal of this paper is to prompt other geotechnical engineering instructors to implement research-based instructional interventions in their courses and contribute to the literature of geotechnical engineering education by sharing their work and experiences.

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REFERENCES

- Ambrose, S.A., Bridges, M.W., DiPietro, M., Lovett, M.C. and Norman, M.K. (2010). *How learning works: 7 researched-based principles for smart teaching*, Jossey-Bass, San Francisco, CA, USA, p. 301.
- Ben-Zvi, R., Bat-Sheva, E. and Silberstein, J. (1986). Is an atom of copper malleable?, *J. of Chemical Education*, Vol. 63, No. 1, p. 64-66.
- Borrego, M., Streveler, R.A., Miller, R.L. and Smith, K.A. (2008). A new paradigm for a new field: communication representations of engineering education research. *J. of Engineering Education*, Vol. 97, No. 2, p. 147-162.
- Glaser, R. and Chi, M.T.H. (1988). An overview, In: M.T.H. Chi, R. Glaser and M.J. Farr (Eds.), *The nature of expertise*, xv-xxviii, Lawrence Erlbaum Associates, Hillsdale, NJ, USA.
- Jamieson, L.H. and Lohmann, J.R. (2012). *Innovation with impact: Creating a culture for scholarly and systematic innovation in engineering education*, American Society for Engineering Education, Washington, DC, USA, p. 77, <https://www.asee.org/member-resources/reports/Innovation-with-Impact>, accessed 4-4-2016.
- Karpicke, J.D. and Grimaldi, P.J. (2012). Retrieval-based learning: A perspective for enhancing meaningful learning, *Educational Psychology Review*, Vol. 24, No. 3, p. 401-418.
- Pantazidou, M. (2009). Student understanding of the concept of soil structure guides instructional interventions, *Proc. 17th Int. Conf. on Soil Mechanics and Geotechnical Engineering*, Alexandria, Egypt, October 5-9, p. 2758-2761.
- Pantazidou, M. (2010). The Scholarship of Teaching: A case in Environmental Geotechnics, In: *Inquiries into European Higher Education in Civil Engineering*, 9th Vol., Erasmus Thematic Network: European University Civil Engineering Education and Training (EUCEET), I. Manoliu (Ed.), p. 125-152.
- Pantazidou, M. and Steif, P. (2008). Modeling instruction in an environmental geotechnics course, *Proc. GeoCongress 2008*, New Orleans, March 9-12, ASCE *Geotechnical Special Publication No. 178*, p. 797-804.
- Pantazidou, M. and Frost, J.D. (2012). A tour through education sites for an engineering instructor: major stops and impressions, *Proc. ISSMGE Int. Conf. "Shaking the Foundations of Geo-engineering Education"*, Galway, Ireland, July 4-6, p. 231-242.
- Roberts, P.V., Goltz, M.N. and Mackay, D.M. (1986). A natural gradient experiment on solute transport in a sand aquifer 3. Retardation estimates and mass balances of organic solutes, *Water Resources Research*, Vol. 22, No. 13, p. 2047-2058.
- Sadler, P.M., Sonnert, G., Coyle, H.P., Cook-Smith, N. and Miller, J.L. (2013). The influence of teachers' knowledge on student learning in middle school physical science classrooms, *American Educational Research Journal*, Vol. 50, No. 5, p. 1020-1049.
- US EPA (2004). *Superfund Record of Decision: Aberdeen Proving Ground (Edgewood Area)*, EPA ID: MD2210020036, OU 21, EPA/ROD/R03-04/607.