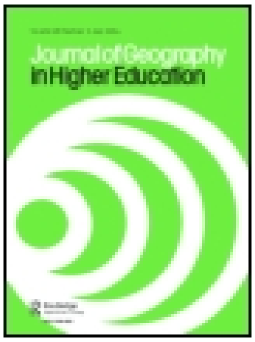

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Research-based learning for undergraduate students in soil and water sciences: a case study of hydropedology in an arid-zone environment

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ABSTRACT

This article reports the efficacy of a research-based learning (RBL) exercise on hydropedology of arid zones, with guided and open research projects (OPR) carried out by teams of undergraduate students in Oman. A range of activities and assessments was used to support student learning during the three-month course. Assessment included monitoring of field trip and lab activities, attendance recording, scrutiny by a panel of written reports and open oral presentations. Students' feedback through teaching evaluation is compared with other courses in the Department-College, illustrating high level of students' satisfaction. OPR best fit the scaffold of RBL.

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KEYWORDS

Research-based learning; soil science; teaching–research nexus; hydropedology; field trip

Introduction

This paper presents an exercise started in 2009 on development of a final year, compulsory, two-credit course, Soil and Water Tour (SWAE 4110) in a 4-year Soil Science Bachelor program (total of 126 credits) in the Department of Soils, Water and Agricultural Engineering (SWAE), College of Agricultural and Marine Sciences (CAMS), Sultan Qaboos University (SQU) as a comprehensive, research-oriented national, government-funded university, first in Oman in all available ranking schemes. SQU was the only university in the country since 1986 until early 2000. From 1986, a joint "Soil and Water Management" B.Sc. was offered until 2008 when a separate "Soil Science" program was established. This program is connected with the "Water Technology" B.Sc., offered in the same department. The graduates of both programs are locally employed by the Ministry of Agriculture and Fisheries, Public Authority for Electricity and Water, Ministry of Water Resources, Ministry of Environment and Climate Affairs, and even oil and gas service companies like Occidental, Petroleum Development Oman, Sohar Aluminium Company, and Schlumberger. One of the advantages of the "Soil Science" degree is its integral, multidisciplinary character, and geo-theoretical background juxtaposed with dexterity and readiness to "put dirt on the shoes." Using Spronken-Smith and Walker (2010) taxonomy, the course presented in this paper can be classified in two categories: open inquiry and guided inquiry, within a prevalently discovery-oriented inquiry framing (see also O'Steen & Spronken-Smith, 2012).

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Research-based learning

Research-based learning (RBL, synonym: inquiry-based learning), links research and teaching in the academic environment (Yeoman & Zamorski, 2008). Healey (2005) and Healey, Jenkins, and Lea (2014) advocated engagement of students with research activities that enables them to recognize the variation and complexity of constructing knowledge in different disciplines which ultimately improves their innovative abilities. Scholars express serious concerns about the traditional research-teaching nexus at universities. For example, Barnett (2003, p. 157) said that "The twentieth century saw the university change from a site in which teaching and research stood in a reasonably comfortable relationship with each other to one in which they became mutually antagonistic." At SQU, such a nexus is declared in the University Strategic Plan 2040 and is supported by several internal funding schemes, as well as programs of The Research Council, a national funding agency (similar to National Science Foundation (NSF), USA). For example, Faculty Mentored Undergraduate Research Award Programme (FURAP), which supports faculty-guided year-long undergraduate research projects comprising small (3–5 person) teams of students who get up to 2400 Omani Rials (1 OMR = 2.56 US$). However, SQU faculty are often pressurized by the "publish-or-perish" dogma; many, especially in applied sciences disciplines of CAMS and SWAE are lured by contracted work offers from the private sector; some are dormant as both researchers and teachers.

SWAE students, during their university study, are exposed to practical activities in the form of field trips and laboratory sessions as part of the undergraduate curricula. In the Soil Science program of SWAE at CAMS these practical components, albeit not of RBL type, are in the courses including compulsory fieldtrips: Introduction to Geology 1 (ERSC2101), GIS for Environmentalists (SWAE3001), Land Surveying (SWAE3005), Water Quality (SWAE3315), Irrigation Principles (SWAE3402), and courses including laboratory sessions: Soil Chemistry (SWAE3002), Elements of Hydrology (SWAE3303), Soil Physics (SWAE3311), Soil Microbiology (SWAE3411), Hydropedology (SWAE4401), Management of Salt-affected Soils (SWAE4412), Internship (SWAE4800), as well as in some of 13 elective courses. The prerequisites of SWAE 4110 are Soil Genesis and Classification (SWAE4404) with its own prerequisites, all basic science courses (biology, physics, chemistry) and CAMS required courses (Introduction to Food and Resource Economy, CAMS2003, Seminar and Presentation Skills, CAMS3000, Biometry CAMS3001). Unfortunately, the program does not have a compulsory capstone project with integral assessment of the learning experience of students and, tacitly, SWAE4110 and SWAE4800 are considered by the faculty as surrogates of comprehensive evaluation of the final product of the program.

With all the field and laboratory baggage of our students we, as well as several other educators, are seriously questioning the pedagogical effectiveness of the practical courses (see e.g. Mamlok-Naaman & Barnea, 2012). The majority of courses are of a non-inquiry type and have a protocol-based approach that often fails to develop higher academic skills such as hypothesizing, design, and problem solving (Al-Hashmi & Al-Ismaily, 2013; Gunstone & White, 1981; Kotiw, Learmonth, & Sutherland, 1999). Studies showed that most science professors believe that the main purpose of conducting practical sessions is for students to gain skills in making accurate observations and interpretation, and making connections between practice and theory through direct implementation of concepts (Gunstone & White, 1981; Wilkinson & Ward, 1997). Wilkinson and Ward (1997) found that to give students training in solving problems and conducting investigations is of a minor importance. Conducting practical sessions in science courses was ranked seventh out of the ten items by the surveyed teachers. Bybee (2000), Stumpf, Douglass, and Dorn (2008) and Krakowka (2012) called for a reform of the practical curriculum in science teaching: RBL is considered to be vital and superior to Internet surfing or/and PowerPoint presentations in traditional lectures. Commingling project-structured and RBL-framed field work with laboratory practicals in soil sciences is one of the key components toward active learning (Field et al., 2011; Hartemink et al., 2014). Students have to discover, sense, and experience things, with a spirit of team work and camaraderie (Grabinger & Dunlap, 1995; Spronken-Smith, 2005; Stumpf et al., 2008). The scaffolding tasks (structured-guided-open ended modes of RBL), with corresponding spontaneous or instructor-enforced grouping of students, models the real situation and challenges during future professional carriers of all SQU and, in particular, Soil Science students. The best Soil Science graduates get jobs which often require high level of ingenuity, open-ended inquiry, and little expert support by superiors or colleagues. Moreover, our graduates rapidly ascend through the administrative ladder and become decision-makers in large-development projects, where research-sound experience of soil, water, and ecological systems in arid environments is vital.

Aims of the course

The aims of RBL development of SWAE 4110 were similar to ones of Spronken-Smith and Hilton (2009) and Spronken-Smith et al. (2011a, and b) in their undergraduate courses in physical geography and ecology courses:

- to improve employability of graduates as qualified practitioners, e.g. soil managers, geotechnical engineers, environmental consultants, and extension officers advising farmers, among other employment paths in Oman;
- to fascinate students by research projects at two levels of RBL, open and guided learning;
- to enhance the teaching-research nexus at SWAE and appetize instructors in other courses to follow the RBL paradigm as a way to improve the learning outcomes for students, their level of satisfaction and chances of employment;
- to illustrate to the CAMS course instructors the collateral benefits for their own disciplinary research (free-of-charge utilization of students field and lab work in funded research projects);
- to ensure the quality of SWAE graduates via open presentation and defense of the final written report, both subject to scrutiny of a SWAE panel;
- to detect and cultivate the best undergraduate students, reaching the acme of RBL scaffold, as potential candidates for the MSc and PhD studies at SWAE;
- to secure jobs of instructors via documented evidence of students' post-university employment and careers' excellence (in case of no evidence programs and departments are relentlessly closed and instructors are sacked).

As such, this course meets the criteria of constructive alignment (Biggs, 1999), which says that well-designed courses have students actively involved (the constructivist part) and the outcomes are well aligned with the teaching and learning methods and the assessment regime

Physical setting and context of the course

Oman is an arid country of 315,000 km^2 and the geography of its soils is extremely diverse, varying from mountain soils to coastal sabkhas (Al-Ismaily, 2014). Genesis and evolution of soils in Oman has been studied by the well-known concepts of external (driving) factors (Huggett, 1998; Jenny, 1941), which determine both physical and human geography. These, commonly classified factors viz. climate (including hydrology), relief (or topographical gradient), biota, parent rock, anthropogenism, and time (age) counted from the moment of deposition of sediments at a particular geographical locus that determines soil's maturity are well represented to different degrees in terraces, oasis, urban soils, primary and secondary salinized soils of Oman. Soils geography has a broad holistic role in society and is a unique discipline as it combines related environmental/ecological and social sciences, with a new paradigm of "soil security" intertwined with the common food security as put forward by McBratney, Field, and Koch (2013). This paradigm is of unique value for Oman which has a relatively low population density and misconception of a "vast land" to be developed, while in reality soil resources suitable for agricultural production are limited in general and by the aridity of the climate in particular. This is aggravated by the fact that a significant proportion of food is imported. Therefore, teaching soil sciences in Oman through project-based courses with field work, where the students communicate with farmers and land owners, has not only academic advantages but also collateral benefits of fostering relations with a broader community and educating the community by students accomplishing both RBL course tasks and public outreach mission. This is well in line with the McBratney et al. (2013) Bouma and McBratney (2013) call for education reform which would lead to intensive and effective experiential learning as a roadmap to students' "connectivity."

Soil (also called "pedosphere") is a critical zone, in which complex and dynamic interactions involving the hydrosphere, biosphere, atmosphere, and lithosphere exist (National Research Council [NRC], 2001, p. 154). Hence, soil scientists must engage with a variety of experts of different disciplines, viz. farmers, geologists, hydrologists, environmentalists, and engineers. Consequently, soil science students have to learn how the information, advice, practices and expertise, pertinent to food security, water shortage, climate changes, land use and planning, construction and other engineering projects, amalgamate (Hartemink & McBratney, 2008). In the specific conditions of Oman, this multidisciplinarity of soil investigations and teaching soil geography to university students is amplified by a relatively limited data-set: the first soil survey was only completed by the local Ministry of Agriculture and Fisheries in 1990 and the soil geography research started with establishment of SQU and CAMS.

Therefore, effective teaching in soil sciences in Oman must be assimilated with other related natural sciences and engineering disciplines, as well as with "geographical" discoveries of new soil zones which have never been studied/described in the past using modern tools and instruments. Enriching soil sciences students with multidisciplinary research-oriented skills is a key toward enhancing their abilities in finding and proposing solutions to different issues in related fields such as agriculture, environment, hydrology, land use-planning, irrigation-drainage, geotechnical and hydrologic engineering (Field et al., 2011; Ramasundaram, Grunwald, Mangeot, Comerford, & Bliss, 2005). In Oman, there are specific challenges for soil science graduates, requiring a host of multidisciplinary research skills and integrated geographical vision which includes: increasing soil salinity (Victor & Al-Farsi, 2001); water scarcity and catastrophic floods (Al-Ismaily & Probert, 1998) which cause soil cracking and erosion; artificial recharge of aquifers (Matter, Waber, Loew, & Matter, 2006) and reuse of treated wastewater (Abdel-Rahman & Abdel-Magid, 1993); siltation of recharge dams (Al-Ismaily et al., 2013); and socio-economic ties with the country soil and water problems (Ahmed, Hussain, & Al-Rawahy, 2013).

Hydropedology and field trips as key course components

The course presented in this paper addresses the "Hydropedology" concept as an emerging interdisciplinary science that bridges soil sciences and hydrology, along with other related bio- and geosciences, such as geomorphology, stratigraphy, hydrogeology, hydroclimatology, ecohydrology, landscape ecology, and many others (Bouma, 2006; Kutílek & Nielsen, 2007; Lin, 2012; Markham, 1998; Pachepsky, Gimenez, Lilly, & Nemes, 2008). It embraces both a holistic study of complex landscape–soil–water–vegetation relationships across space and time and atomistic Francis-Baconian analysis of the elements of this bricolage by standard techniques of soil physics, soil genesis and classification, soil chemistry, and vadose zone hydrology, among others. The NRC (1996) has stressed the significance of integrated soil and water studies in the context of agriculture, groundwater vulnerability, watershed management, earth sciences, water resources, and environmental sciences as a response to the rising challenges in soil and water resources for many parts of the world. Noy-Meir (1973) pinpointed the crucial role of soil layering and textural contrasts on the status (motion and storing) of the root zone water and plant ecology in arid zones. Since this seminal contribution, hydropedologists–hydroecologists understood better the intricate relations between pedogenesis-pedomorphism and essentially transient water/moisture motion through the surface–subsurface compartments of the hydrological cycle. Hydropedology by its nature blends together fieldwork, laboratory experiments, and computer-based technologies into an integrated approach to understand landscape–soil–water patterns and dynamics across scales (Lin, 2012).

Herein, we present a practical course that combines "skill learning," "skill experience," and "extended problem solving tasks" for undergraduate students pursuing a soil science degree. The course comprises the descriptive-explanation (by developing students observational skills) and analytical-prediction learning approaches (via the facilitation of experiential learning), as defined by Fuller, Rawlinson, and Bevan (2000). Our practical curriculum emphasizes collaborative learning and integration of classroom knowledge into field research, facilitates the cross-application of the theoretical courses, and engages students with a taste of "real" scientific research experience that involves conducting literature review, designing a research question, setting up field and laboratory experiments, sampling and data analysis and interpretation in a way providing evidence to answer the research questions.

This paper presents a case study, which highlights how to amend a routine, conventional practical session in a B.Sc. program with an RBL exercise closely linked to research interests of the course instructors (Al-Ismaily et al., 2013; Al-Maktoumi et al., 2014). The RBL exercise reported here therefore also serves to develop the research-teaching nexus by connecting students with staff research interests (cf. Fuller, Mellor, & Entwistle, 2014; Spronken-Smith & Walker, 2010).

Fieldwork in general represents one of the most effective and enjoyable forms of teaching and learning for both staff and students (e.g. Al-Ismaily & Al-Maktoumi, 2011; Boyle et al., 2007; Hanson & Moser, 2003; Hofstein & Lunetta, 2004; Kent, Gilbertson, & Hunt, 1997; McEwen, 1996; Mellor, 1991; Moore, Kerr, & Hadgraft, 2011; Stumpf et al., 2008; Weil, 2003; Yeoman & Zamorski, 2008). According to a study on soil science teaching principles by Field et al. (2010, 2011), analyses of students survey responses showed that 79% of the ranked field-work and laboratory activities as the two top most effective learning environments compared to other activities, such tutorials, lectures, and presentations. Three categories of field trips are distinguished and ranked according to the resources (instruments, technical personnel involved, consumables-time required): "look and see," "participatory," and ones involving intensive research projects (see e.g. Hefferan, Heywood, & Ritter, 2002; Krakowka, 2012). Our field trips were of the third type and 5 days of duration, unfortunately not as long and geographically diverse as ones reported by Kasimov, Chalov, and Panin (2013) and Hartemink et al. (2014).

Course design

The number of students for each class was: 2009 (n = 25), 2010 (n = 21), 2011 (n = 29), 2012 (n = 26), and 2013 (n = 28) i.e. the average class size is 26 students. All students were Omanis, of the same age group (21–22 years old), about 60% are male, and the language of instruction is English. Also, during the practical work the students communicate among themselves in Arabic (the mother-tongue). An average number of faculty and technicians involved was 3–4 and 2–3, respectively.

On average, a regular CAMS student during the spring and fall semesters has a load of 15 credits/semester but during the winter break, when the course is offered, the students have no regular classes. The total field work in 5 days is 40 h that includes transportation to the site from the campus and field activities for students' groups. Approximately 6 h/day of supervised field work in January are followed by the laboratory experiments and analysis, which last for 3 months. Submission of the written report is in week 14 of the spring semester where students officially register for the course. The oral presentation to a departmental committee is in week 15, the last week of the spring semester.

Intended learning outcomes

The main learning objectives of all students were

- designing a research question (including its several iterations, reformulations, tuning up and amendments during the field and laboratory work),
- set up needed experiments, in particular, how to construct a soil pedon, examine soil at pedon's faces and identify different horizons simultaneously with conducting infiltration experiments using both double-ring and tension infiltrometers,
- collect and interpret data,

- make connections and relationships between the various soil science sub-disciplines (soil physics, soil chemistry, pedology), and to other disciplines such as physical geography, hydrology, and geology,
- write, present, and defend a technical report.

The field component includes observations, sampling, and experiments. This was followed by analysis of collected data samples in the SQU research labs and interpretations, including verification of theoretical concepts (Al-Ismaily & Al-Maktoumi, 2011). Field-lab activities, stitched to earlier material from the above-mentioned Soil Science courses enrich the students with the essential skills at the end of the whole B.Sc. program.

Each year the whole class consisted of students' groups (3–5 students per group with one student assigned as a leader). The instructors articulated clearly to each team that developing teamwork skills is a key outcome and a component of the final grade of individual team members.

Each group is exposed to a well-demarcated general research question or theme formulated by the instructors who later mentored specific groups. For instance, research assignments given to different groups in one class were:

- Assessment of soil fertility and agricultural practices in a selected farm in the Seeb area, close to the SQU campus (within 10 km).
- Analysis of soil catena in the South Batinah region.
- Assessment of irrigation efficiency in the traditional Aflaj system in the Batinah region.
- Hydropedology in the vicinity of a recharge dam in Oman.

This paper uses the research task on hydropedology as a case study. The corresponding narrowed research question raised by the hydropedology group of students was: "How strong is the influence of construction of the Al-Khoud recharge dam (Figure 1), as a human (geotechnical) factor, on the soil properties (texture, soil layering) and infiltration rate through the reservoir bed and recharge basin?" Another example of a focused question raised to a team of a previous cohort: "How is the flood intensity measured through a hydrograph of the gauging station correlated with observed sequences of sediments in the pedons?" and "What is the relationship between the measured wadi (stream) current and suspended sediment load sampled at different points of the channel cross-section?".

The task is very important for water resources and land management in Oman where more than 43 dams of this type were recently constructed.

During the field-work session the instructors give introductory, on-site lectures lasting for in average 30–60 min, with the help of a portable white board). The following topics were overviewed for all students soil catena (Al-Ismaily & Al-Maktoumi, 2011; Weil, 2003), soil survey and morphological description of pedons, sampling and physicochemical analyses of soil horizons (Figure 2(a)), hydrological properties (e.g. measurements of soil permeability; Figure 2(b)), sedimentology (Figure 2(c)), water resources management, along with laboratory experiments for further investigation of impact of soil layering on water movement (Figure 2(d)). The students had to revise the basics of 2000–4000 level relevant courses listed above. On topics which were not covered in the program-prerequisite courses (e.g. geotechnical engineering) the instructor gave basic terminology, short review of the concepts and practices in Oman, followed by students' self-reading during the whole semester.

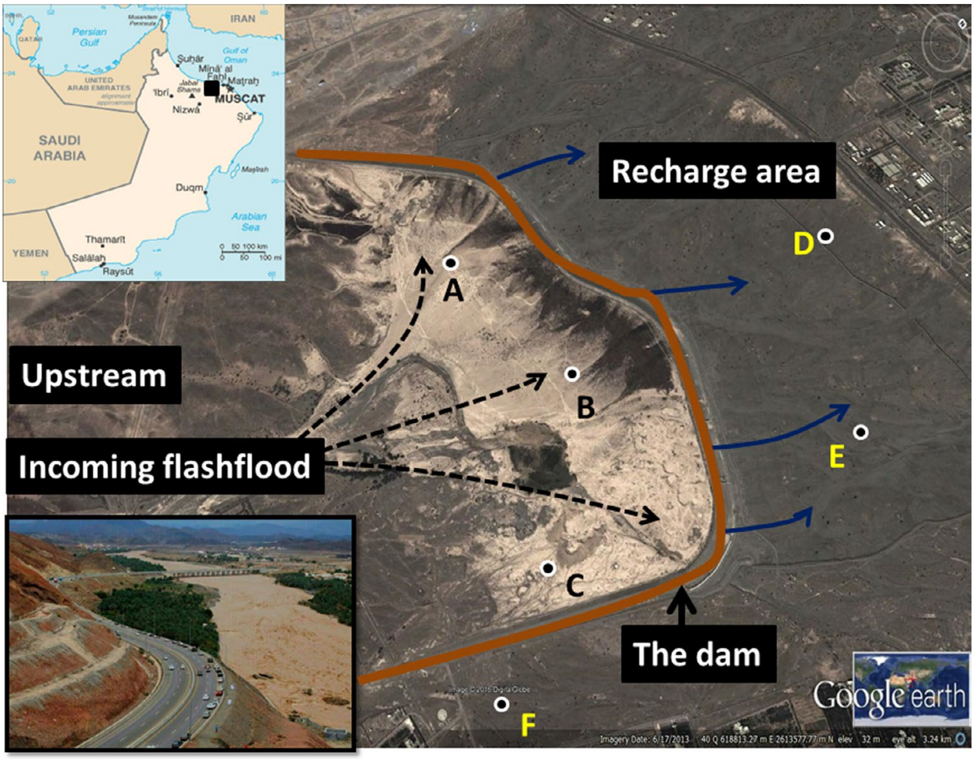

Figure 1. Satellite image of the study area (retrieved from Google Earth –Digital Globe). The left-bottom window shows the flashflood in the upstream heading towards the dam area.

The group leader's responsibilities were to submit short but frequent progress reports and to provide feedback about the performance of the group and its members. Each group was assigned an appropriate faculty member from the department, depending on the nature of topic, and a technical staff, both to act as facilitators. Setting objectives, designing field and laboratory activities, data analysis and interpretation, and communication of the findings through writing-up a technical report, and a final oral presentation (open to the public) are evaluated by a special panel appointed by the department.

Evaluation of the oral presentation is done by a departmental committee (usually seven members, both faculty and those technicians who were involved in field and laboratory experiments). The members of the committee complete the form presented in Table 1.

The final grades are discussed and approved by a Departmental Board. This Board includes only faculty members, i.e. the technical staff – members of the evaluation committee are not members of the Departmental Board.

For this specific group the learning outcomes were amended as following:

- Do textural analysis of soil samples from different horizons using a laboratory hydrometer.
- Study the water movement within a layered soil using a laboratory column, which mimics the field layering of the reservoir bed.

Figure 2. Students' activities in the field and laboratory: (a) physicochemical analyses of soil horizons, (b) infiltration test, (c) reconstruction of sedimentological events (reservoir fillings), (d) laboratory column experiment. (Source: Dr. Said Al-Ismaily)

- Upscale the field-laboratory experiments to the level of a sub-catchment (Figure 1) and ponder of water management of the whole Batinah region of Oman, which is characterized by pedological and hydrological conditions similar to the Al-Khoud dam area.
- Forecast the consequences of damming and observed rapid sedimentation and soil evolution for the human geography, primarily, with respect to potential competition-conflicts between the farming sector and urban development of the area, adjacent to the embankment.

The research exercise

According to the guided inquiry classification (Spronken-Smith & Walker, 2010), the sampling regime was initially designed by the teams, followed by meetings with instructors. After modifications and endorsement by instructors, the final sampling schemes were pursued.

The study area was divided into three major zones: dam bed, downstream recharge zone, and upstream area. In total, six soil pedons were excavated to represent the three different zones, pedons are labeled with uppercase letters in Figure 1. Students identified soil horizons and collected soil samples from each horizon (in total 65 samples). Double ring and tension

Table 1. The assessment form for oral presentation.

Soil & Water Winter Tour-SWAE 4110

Group (Project) name:______________________________________

Evaluator:____

Quality Index: 5: Excellent, 4: Very Good, 3: Good, 2: Needs Improvement , 1: Needs lot of improvement

Quality of Presentation

	Comments
Well Prepared, convincing, persuading	
Organization - logical order and transitions	
Focused on important issues	
Demonstrated knowledge	
Good use of time – ended on time.	
Good conclusions for ending	
Quality of visuals	
Loud and clear	
Faced the audience, no reading from screen	
Adequate level of detail	
Lively & Interesting	
Use of professional language	
Avoiding verbal filters, ah, eh, om, etc.	
Overall quality of communication	
Adequately answering the questions	
Total Mark (%)	

infiltrometer devices were used at sites close to the pedons to measure the infiltration rate. Then in the lab, students analyzed physical and chemical characteristics of the samples.

Infiltration tests illustrated that the infiltration curves have blips which are not in standard theories of infiltration and textbooks of Soil Physics and Hydrology. Provocative questions and explanations (similar to ones in Spronken-Smith, Bullard, Ray, Roberts, & Keiffer, 2008) were formulated by the instructors, like "Is it plausible that the in-field infiltration rate oscillates due to oscillations of the gravity field or diurnal variations of the topsoil temperature?" Frankly, the instructors themselves did not have a sound theoretical explanation of these blips, they learned the phenomenon with the students.

A close inspection of the soil texture variation with depth and pedon loci was correlated to the infiltration pattern. Relation to surface hydrology (Figure 1) was contemplated: hydrographs of flash flood events, detected levels of ponded water inside the reservoir, sediment load deposited from the still reservoir water, and fast drying of the top soil when all reservoir water vanishes from the surface. The students observed on pedons' faces the propagation of the infiltration front affected by thickness and sequence of layering.

To closely investigate this field-observed effect, the students designed a laboratory column experiment for two-layered repacked soils subject to constant ponding. The students realized that this infiltration regime in the laboratory is only an approximation of real dam reservoir conditions where the ponding depth decreases with time due to evaporation, infiltration, and culvert discharge. Students also contemplated the relation between field tension infiltrometer tests and laboratory column experiments in the following sense. The field tests generate data which in standard theoretical simplifications assume a homogeneous soil massif. In reality, the students see from the pedons that the soil at infiltration sites is distinctly laminated. In the lab columns the students see a simplified system which only mimics the multilayered soil of the dam bed. On the other hand, in the lab, unlike field conditions, the students can see from all azimuthal angles in a transparent acrylic plastic column the wetting front, in particular, the preferential flow and capillary barrier, which are ignored in standard theories.

Capillary tension is taught as a concept in the prerequisite course of Soil Physics and Hydropedology. The students themselves decided to run an additional (not preliminary planned) experiment with the capillary rise, rather than infiltration, through the soil columns. In the capillary-ascent experiment, water moved into the soil upward from a constant-depth container, which students understood as a model of the real groundwater table. These cross-comparisons of infiltration and capillary rise illustrated to the students the theoretical concepts covered in Introduction to Soil and Water, Elements of Hydrology and Arid Zone Hydrology. Clearly, during the field trip the relatively slow capillary rise experiment is not feasible to conduct. Designing and conducting such experiments with laboratory models helps the students to understand the basic concepts of water behavior in a layered soil, which is important for the prototype study area (recharge dam).

Students examined the distribution pattern of electrical conductivity of soil extract and concentration of $CaCO_3$ with depth, across the layers. Then, the students attributed this to the capillary barriers under both ponding conditions during flood events and an intensive evaporation process after them (redistribution phase of infiltrated water). The students related arid climate characteristic to the long-term consequences of the observed caliche formation in the reservoir soil.

Student knowledge assessment

During the semester-long project, the students' performance was assessed through the following metrics (out of 100%):

(a) 10%: frequency/regularity (minimum once a week) of meetings with the faculty-group supervisor (individual record of students attendance and participation in the discussions during the meetings);

(b) 25%: students technical skills graded by the supervisor in both field and laboratory experiments (combination of group evaluation with tracking idle students and corresponding grade reduction);

(c) 25%: students' final presentations to the panel, presentations are formally evaluated using a form, which includes: knowledge of the subject matter (15%), PowerPoint presentation style, quality of the slides and appearance (eye contact, gesticulation, jerking when speaking) (20%), time management (5%), question and answer session (35%), and gained skills (25%). During the oral examination the group and individuals are subject to a cascade of numerous questions from the audience (faculty, technicians and students of different teams and cohorts) such that the corresponding grade is derived from assessment of both group's and individual's celerity and aptitude;

(d) 40%: final written report (judged by the quality of the technical content, punctuality of submission, level of academic English, format of the print-out, and potential plagiarism). Evaluation here is collective.

The SQU Academic Regulation has an official policy on misconduct of the students with respect to plagiarism. A spectrum of penalties is implemented, depending on severity: starting from a verbal warning to expulsion from the University.

Table 2 illustrates the time series indicating the trends of the four assessed elements (see the metrics in the text). From our experience in teaching various courses in this and other College programs, we know that the intellectual level of the students from different cohorts fluctuates. However, as apparent from Table 2, in three components students' performance improves. This can be attributed to junior students learning from the oral presentations.

In addition, the final technical report, especially the part concerned with data explanation, reasoning and nature of outcomes, is evaluated by the supervisor and a second faculty member in a "peer-reviewing" format, e.g. as a manuscript submitted to a journal. The mistakes and lapses are detected/annotated and brought to the public defense as "special questions." If a questioned student answers the deficiencies well during the presentation, the lapses are discounted and the student gets additional points for the "questions and answers" component. Moreover, the questions relevant to the "manuscript" may evolve to questioning on the concepts learned in soil physics, hydrology, and pedology connected to a practical application to the Al-Khoud dam area. In addition, the marked and graded report is also

Table 2. Trends of grades of four elements in the course assessment.

Assessed elements	2009%	2010%	2011%	2012%	2013%
Frequency of meetings with supervisor (10%)	60	65	95	90	70
Technical skills (25%)	73	88	98	96	90
Oral presentation (25%)	70	80	96	96	88
Final written report (40%)	60	73	83	85	73

used to determine the ability of expanding purely pedon-based, isolated, and "static," "fixed soil map" thinking to a dynamic 3-D soil mapping within a broader geographical context.

Student's evaluation and feedback

The student's assessment and feedback about the exercise is also important as it gives an idea about possible improvements. This is achieved through a standard course survey given at SQU in semester-wise electronic format for each credited course (Table 3). This survey is conducted by a unit under the Provost of SQU and statistics collected are used by SWAE-CAMS-SQU administration as tools in academic promotion, contract extension of the faculty, overall evaluation of academic programmes and Departments-Colleges at

Table 3. Summary of the Course and Teaching evaluation results for the course SWAE 4410 by students for the year 2012:

(a) Overall statistics of the student evaluation as released by SQU system academic affairs unit.

	Course and teaching items	Means (out of 4.0)		
		Course	Department	College
	Course items			
Q1	Written instructional materials, e.g. textbooks and/or handouts, used in the course were helpful	3.39	3.25	3.23
Q2	The laboratory sessions were a valuable part of the course	3.78	3.44	3.42
Q3	Overall, I learned a lot from this course	3.72	3.33	3.3
	Summary	3.63	3.34	3.32
	Teaching items			
Q4	The objectives stated in the course outline have been met so far	3.5	3.26	3.26
Q5	Most of the lectures/labs/seminars started and finished on time	3.5	3.27	3.27
Q6	The instructor explained the course material clearly	3.61	3.26	3.25
Q7	The instructor was available during office hours	3.61	3.3	3.29
Q8	The instructor was helpful when I pointed out my difficulties in this course	3.61	3.28	3.32
Q9	The instructor encouraged me to think rather than just to memorize	3.56	3.14	3.11
Q10	The instructor stimulated my interest in the subject matter of the course	3.56	3.15	3.15
Q11	The instructor encouraged questions and discussions	3.56	3.23	3.25
Q12	Course assessments, such as tests/quizzes/assignments/reports, helped me find my strengths and weaknesses	3.44	3.17	3.12
Q13	Teaching aids, such as whiteboards/audio-visuals/ computers, were effective	3.39	3.22	3.27
Q14	The instructor provided helpful feedback about marked tests/ quizzes/assignments	3.44	3.2	3.11
Q15	Overall, This instructor is a good teacher	3.72	3.38	3.35
	Summary	3.54	3.24	3.23

(b) Collation of open-ended comments that helped and obstructed learning in the course.

Helping learning	Obstructed learning
Practical and field-work applications (11)	Course credits are too low (21)
Excitement and enjoyment (10)	Overload due to laboratory work and analyses (4)
Interesting and multidisciplinary topics (10)	Constrains in resources (2)
Working in groups (4)	Timing of the tour (2)
Working directly with soil (3)	Assigning groups members by the instructor (2)
Students–faculty friendship/cooperation (2)	Difficulties with group dynamics (2)
Involvement of several instructors (2)	
Opportunity for creativity (1)	
Self-directed learning (1)	
Enhancing critical thinking (1)	

the level of the whole University. One, main instructor (Dr Al-Ismaily) was evaluated each year, with the response rate always higher than 30% of registered students that is the cutoff level of validity of these surveys at SQU. This survey is conducted during weeks 12–15 of the spring semester. Each instructor, Head of Department, Dean and Provost receives the confidential results of the survey. In week 18 or 19 (after grades are awarded) the instructor receives the results of the survey. All courses are ranked within SWAE and CAMS, based on Questions 3 and 15 (see Table 3(a)). This course has been ranked as the 1st in 2010, 3rd in 2011, 4th in 2012, and 1st in 2013 within SWAE (among in average 22 courses usually offered by SWAE during the spring semester) based on students' answers to Question 3, i.e. "Overall, I learned a lot from this course."

As is evident from Table 3, the average students' evaluations of the course (based on a scale of 4 points, 4.0 as the highest evaluation) were 3.40, 3.48, 3.59, 3.63, and 3.78, respectively, for the years 2009–2013 (CAMS average point during the same period was 3.33 for all courses, see Table 3).

The presented absolute numbers and ranks quantify the high level of students' satisfaction. In a separate survey, conducted by the authors of this paper, the students were asked several questions including "what did you like best in this course?". The majority expressed their appreciation on the type of skills and team-work ethics gained, implementation of the theoretical concepts learned during classes on real problems, increasing of their confidence, and enjoyment. One of the students answered to the mentioned question:

> Every moment I had spent with the project was interesting, informative and beneficial. The most important thing that I was able to apply practically all concepts gained in lectures taught in other courses. I enjoyed the exercise with all the pain. After the field work, every day I liked to be close to my team, learning more and more. I benefited from all information provided by the facilitators and my team mates. It was unforgotten experience with a special group. From this experience I gained a lot of general skills e.g. work in groups and communication.

All three co-authors of this paper as instructors of the course are absolutely sure that the course is both extremely effective in achieving the above listed aims and in the joy of communicating and collaborating with the students. As an RBL exercise the course required greater efforts as compared with other standard courses. The appeal to join the team of course instructors voiced at SWAE's Departmental Board 2 years ago was positively received by only one more faculty member, despite obvious potentials to utilize final year students in research projects led by the SWAE staff.

Course challenges and avenues to improvements

Both logistic and pedagogical challenges were faced over the years with this course. Some are specific for Oman, others are generic:

(a) Approval from the University Provost's office was always necessary for getting financial support for transportation, accommodation, as well as complying with the safety regulations. Guarding female students and special permissions for them are necessary at SQU (separate transportation, female staff as guardians) and other universities with prevalently Muslim students.

(b) Several years ago, the course instructors and technicians had to stay with the students and guide them continuously throughout the whole day of field work and in the post-field lab experiments, monitoring even repetitive routines. Now, the students are almost independent: the teams self-organize and carry-out routine procedures such that the instructors only occasionally inspect the process, although their presence is still required according to the SQU safety and security regulations. The first batches of students were very reluctant and afraid of presenting and defending their projects in front of the public and panel.

(c) Although the problems in English of the written reports are not completely solved, with the advent of TurnItIn and other antiplagiarism software purchased by SQU, the students are more independent and academically honest. The practical nature of the course and combination of field–laboratory–theoretical components reduces the propensity to plagiarize, as compared with purely theoretical essays or other assignments.

(d) So far there were no special sessions dedicated to training in psychological or management aspects of team work. In 2015 SQU established a Centre of Excellence in Teaching and Learning. The experts from the College of Education can be requested to train instructors on better organization of students' team work.

(e) We do not have systematic evidence that students reflected on how they could have done their projects better, although there were examples when already graduated students, who got jobs, came to the oral presentations of junior cohorts and shared their past experience. In 2013 SQU started a program of annual gatherings of the alumni during which CAMS-SWAE fresh graduates can be approached with technical questions on the pitfalls/deficiencies of this course from the viewpoint of a young professional rather than a student.

At the beginning of the course, the students had no experience with team work. This course was instrumental in developing a culture of solidarity in group physical activities. The following explains how this was achieved:

(i) Delegation of certain authority: composition of the groups was left to the students, i.e. they aggregate by themselves. Also, they themselves select the leader of the whole class and each group. The class leader person is like a "general administrator" of all research activities and logistics of the groups from the side of the students (clearly, the administrative involvement of the faculty, instructors of the course, is overarching). The course instructor, based on factual data from prerequisite courses and assessment of personalities, endorsed the team leaders. The class leader encourages all students to be continuously reporting the progress to the instructors, helps to overcome technical obstacles (e.g. failure of instruments, loss of collected samples, arrangement of additional field visits when extra data are needed), organizes-coordinates the final oral presentations.

(ii) In a special gathering, insignia of the best research work with the names of the students and the course title engraved on medals (usually given to the best two groups). These trophies are highly appreciated by the students. Also, certificates of the best research teams are presented to these selected groups. The certificates are much appreciated by the students because they signify the practical skills of the students to potential employers. The whole Department (faculty, staff, and students) are attending this gathering.

(iii) Team experience in the research project is reflected in Letters of Recommendation written by the course instructors. The well-performing students receive these Letters. These Letters have high value in the professional career of the graduates.

First, they are taken into account when the graduates are interviewed for job vacancies. Second, when the best students continue with MSc and PhD studies, the research experience, hand-on skills and ability to work in a team, reflected in these Letters, are given weight during the interviews and evaluation of the candidates, especially, when scholarships are at stake.

(iv) The new batches of students are invited and encouraged to attend the public defenses of the more experienced student groups and to interact with them.

Summary and outcomes of the RBL exercise

The RBL exercise presented in this paper provides students with the necessary training in scientific research that enables them to understand the interaction between different branches of soil, water, and environmental sciences as strongly recommended by Ramasundaram et al. (2005) and Field et al. (2011). The approach used for the exercise provides students with an opportunity to practice their metacognitive abilities and foster critical thinking, abilities to make predictions, propose causative factors, and present constructive arguments. This is done/measured via/through oral presentations and final reports which all are the core components of any scientific research. The course instructors witnessed how, from the moment a general research questions were offered to the students or formulated by them, the level of students' inquiries deepened, focused (compare with Justice et al., 2007) and – in several cases – even rose to the level of attempts to refute the textbook knowledge and authority of godfathers in soil sciences. The habit to criticize was fostered and refined during formal and informal "team-instructor" meetings and conversation, as well as in final oral presentations. This kind of exercise is of great educational value if students have already been exposed to the concepts of soil sciences and basic hydrology courses, particularly, to the influence of soil physical properties (such as infiltration, capillary moisture movement, and capillary barriers across soil layers of different textures) on water dynamics in the subsurface system.

By the end of the research, the students clearly understand the difference in spatial scales of soil and water phenomena in a general framework of physical and human geography of Oman. They perceive how the catchment hydrology affects the pattern of sedimentation which in turn affects the dynamics of the infiltrated water, groundwater response, evaporation and, eventually, water resources management in arid zones of their home country, Oman.

Communication skills (both writing and presentation) of soil science graduates are found to be of concern to employers (Field et al., 2011). Providing opportunities for students to technically communicate ideas, information, data, and scientific findings can help the students in refining their understanding of different concepts. Enhancing students' abilities to communicate effectively, incorporated in the RBL exercise presented herein, was realized by the students who submitted a technical report, as well as an oral presentation, followed by technical discussions about the methodology and the findings.

The students in this RBL exercise solved real-world challenging problems of arid zone hydropedology, using knowledge obtained from a broad spectrum of interdisciplinary courses. The research skills acquired help the students reinforcing their understanding of theoretical concept through practicing.

Healey et al. (2014) mentioned one of the maladies of HE research done by the faculty: keeping students "at arm's length" from real projects and scholarly advances of the faculty.

Indeed in some "densely populated," "highly competitive" subjects with expensive and sophisticated equipment required for research, undergraduate students may be a burden. In our case, arid zone hydropedology is a relatively new topic with relatively few competing research teams world-wide. SQU has no RAE-REF-type rivals in Oman and faculty are receptive to engage undergraduates into real research projects, instruments, consumables and funding in general available for students' mini-projects from both University and National sources. The final year undergraduates are privileged to be on the front line of new knowledge generation as a part of RBL, two birds being killed by one stone: earning grades in required courses and receiving experience and kudos through fascinating and societally important inquiries. In our RBL example, we were co-learners and confirm that this, as Spronken-Smith and Walker (2010) pointed out, fosters the research-teaching nexus through stimuli for both parties, students and teachers. The open-inquiry approach is definitely the pinnacle of RBL, although the matrices and discrete ("linear," "abrupt") categories (e.g. 4 as in the theoretical scaffold) are, as any taxonomy, imperfect.

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