Title: Establishing Disciplinary Foundations with Various Pedagogies
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Summary: A professor redesigned a 300/500 level course on soil geography to isolate and correct misconceptions among students, as well as to engender students' integration, research, and problem-solving skills.

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Background:

Soil Geography (GEOG 335/535) is an introduction to the properties and processes of soils as they occur in their environment. In the first week, we discuss the nature of soil as it functions as a body (soil morphology) and then move to discuss individual soil materials and soil profiles as one-dimensional columns. In this context, the course is divided by the major sub-disciplines of soil science, including the formation and genesis of soils (pedology); nature and properties of soil solids, especially clays and colloids (soil mineralogy); chemical composition, properties and reactions of soils (soil chemistry); interaction between solid, liquid, and gaseous components of soils (soil physics); plant, soil, and water relationships (soil fertility); and biological interactions with soil (soil biology). Toward the end of the semester, we discuss the classification of soils (soil taxonomy) as a way of putting all the information about soils back together into an integrated whole and to give a sense of proportion about how the individual soil properties and processes contribute to the overall behavior of a particular soil. Finally, we take a three-dimensional perspective and discuss the distribution of soils on the landscape (soil geomorphology).

This course typically enrolls 12-16 students largely from environmental studies, geology, and geography. The course also serves graduate students (enrolled in 535, and typically a third of the class) in geography, geology, and anthropology. An introductory geology course is a prerequisite; in addition, an introductory biology and introductory chemistry course are recommended. Our department has recently restructured its BA and BS programs in geography and proposed a new Master of Science degree in physical geography. This course is now one of five required foundational courses of the restructured BS degree, and most of the material covered in this class is used in virtually every physical geography class above it. In addition, it serves as a foundational course to graduate students in anthropology, geology, and geography who have come from programs that do not offer a rigorous introductory soils course.

Grading for the course in previous semesters (fall of 2008, 2009, and 2010) was based on four homework assignments distributed throughout the semester, weekly laboratory exercises, participation in a Saturday field trip, three exams over lectures, and a comprehensive final. The homework assignments were designed to give students practice with the mechanics of how to set up and solve problems in soil geography. The goal of the laboratory exercises was to give students hands-on experience with how to measure soil properties and observe soil phenomena.

The field trip, which was taken in the first two to three weeks of the semester, was meant to give students a physical context in which to place the information they were learning in class. This trip was also used to sample the soils that students used in the laboratory for the remainder of the course. Exams were designed to focus on a conceptual understanding (less mechanics) of the material presented in the course and to assess students' ability to integrate their learning.

Because there is so much material that is new to students in this course, lectures and assignments are compartmentalized by the various sub-disciplines as a way to systematize the subject. Although I try to emphasize the connections between these sub-disciplines in the context of individual problems, one of the biggest challenges for students in this class is to integrate their knowledge across the individual learning units. Students enrolled in this course at the graduate-level (535) were also responsible for completing an individually-run final project, which incorporated various techniques from the field and laboratory to answer a soils-related question of their interest. The goal of this project was to develop student skills in problem solving, integration, and writing.

The major goal of this redesign was to isolate and correct misconceptions about soil-related issues among students in the course and prevent those misconceptions from being propagated to upper-division courses. Three secondary goals were to increase participation during lecture while creating an environment where students take ownership of the concepts, to engender integration and problem-solving skills, and to improve student written communication skills.

My Guiding Teaching Questions: What are the best practices for discovering and correcting foundational misconceptions that lead to misunderstandings of more complex topics in soil geography and other upper-level physical geography courses? In addition, how can I most effectively engage students in the classroom to make lectures livelier and more productive? And, how can scaffolding exercises be used with students' final projects to help them clarify and deepen critical thinking and integration skills?

Course Goals:
When students finish my course, I expect them to:

1. Have gained an appreciation of and interest in the complex relationships that govern and shape soils in their environment.

2. Understand the questions that are tackled by the major sub-disciplines in soil science (pedology, soil mineralogy, physics, etc.).

3. Leave with a working knowledge of how they might approach a research question related to soils (e.g., what field and lab-based techniques might work with certain questions? What equations are relevant?).

Implementation:

To address the primary goal of this redesign (i.e., to isolate and correct misconceptions about soil-related issues), I implemented two pre-lecture exercises: 25-word précis and decoding-the-discipline questions. The précis were meant to emphasize important concepts through focused reading of the required supplementary text, while the decoding questions were designed to directly target misconceptions that were observed in previous iterations of the course. Both types of pre-lecture exercises were also used to better prepare students for lecture, pique their interest by discussing their pre-lecture answers in class, and deepen in-class discussions.

Additionally, the scaffolded exercises that led into the final project were used with students enrolled at the graduate-level to improve critical thinking, integration, and writing skills. The 25-word précis were also used to enhance writing skills by making students intentional and exact about the words they used to construct their statements.

25-word précis**:** When I taught this course in the fall semesters of 2008, 2009, and 2010, students did not seem to be engaged with the material they were learning. In order to promote discussion and active thinking during lecture, I decided to implement an assignment that required them to fully engage the material before class during the Fall 2011 semester. (I have also taught this course since then [Fall 2012] and have continued to implement the following exercise.)

Once per week before lecture, students wrote out a statement containing exactly 25 words summarizing the required reading for that day. The 25-word requirement is designed to make students carefully choose their words in summarizing the main point. The ultimate goal is to promote more informed discussion and questions by introducing students to the topic before lecture.

I gave students very specific reading/writing instructions for each précis. For example, "Describe what information is contained in a water characteristic curve (Section 5.4) in a sentence containing exactly 25 words." Students were then required to compose or copy and paste their 25-word précis directly into the textbox in the active Blackboard assignment. The web link for the assignment was visible to the students 24 hours before the start of lecture; this link was turned off automatically at the start of lecture. Although I was unable to grade or provide direct feedback before lecture, since they were able to submit assignments up to the start of class, I spent five to 10 minutes in the hour before lecture looking over any submitted answers and getting a sense of how well students understood the concept from the reading. This allowed me to focus my lecture time on any misconceptions from the reading that seemed to be common among the students. I was explicit about this just-in-time teaching strategy with the students, mentioning what errors or misconceptions I might have seen in a précis although never directly calling out students by name.

These précis were efficiently evaluated and graded using the following simple rubric:

Criteria				Score
1/1 (High-quality)	**0.9/1 (Average)**	**0.8/1 (Below average)**	**0.7/1 (Inadequate)**	
Content accurately reflects the reading; writing is clear and precise without grammatical or spelling errors; submission is within one word of the target word count	One of the following problems: content does not accurately reflect the reading (e.g., mistaken association or definition); writing is slightly ambiguous or may contain grammatical or spelling errors; submission is more than one word from the target word count	Two of the following problems: content does not accurately reflect the reading (e.g., mistaken association or definition); writing is slightly ambiguous or may contain grammatical or spelling errors; submission is more than one word from the target word count	More than two of the following problems: content does not accurately reflect the reading (e.g., mistaken association or definition); writing is slightly ambiguous or may contain grammatical or spelling errors; submission is more than one word from the target word count	

In addition, personalized feedback was given on the précis via the feedback option in Blackboard so that students could see their grade and learn how to improve future submissions. Selected samples of these précis are given via a link in the Student Work section.

Decoding-the-discipline questions (or counter-intuitive questions): In the past, I had occasionally surveyed students at the beginning of class to see what they thought the answer was to a particular problem. When most students answered the question incorrectly, I had noticed that they seemed to take ownership of their own responses and want to understand why their initial answer was incorrect. This made them better engage during lecture, because when students learned that they got a problem wrong, especially when they really trusted their intuition, they paid closer attention to the explanation, which generated interest in the complexity of soils (course goal 1) and the need to understand and approach soil questions from multiple angles (course goal 2). In the explanation of the counter-initiative example, I led the class in a quick but explicit discussion about how a soil scientist goes about answering that question in research (course goal 3).

In order to channel this reaction to such questions, I created a list of questions that challenge common misconceptions in various topics of an introductory soil geography course. These questions were answered on our course Blackboard site the day before lecture. In order to introduce the topic represented by the question they answered, I presented their collective responses in class. Afterward, we spent seven to 12 minutes in class discussing the answers and the reasoning behind them.

Final project/scaffolded assignments:
Work for the final project was divided into four scaffolded assignments throughout the semester. The first assignment (due during the 5th week of the semester) required students to choose a title and write an abstract for their individual projects. The assignments had detailed instructions and contained an example of work graded as excellent; the students were required to email their assignments to me in Word format. The following week, I returned the files via email with

detailed comments about the feasibility of the study, methodologies employed, writing, and formatting using the track-changes feature in Word. I was particularly strict about the formatting as this assignment was meant to mimic the submission of a technical note to a peer-reviewed journal (in Fall 2011 we used *Geoderma*). Students were required to make or address the changes I recommended (simulating the peer-review process) and resubmit the second draft of the title and abstract by the 7th week.

The second assignment had students turn in a writing sample in the form of a paragraph from either the introduction or materials and methods sections, along with several references that were cited in the sample paragraph. The specific goals of this assignment were to ensure that students continued to work on the projects and did not wait until the end of the semester to frantically attempt the observation, experiment, and/or modeling project; to provide students with further writing assistance; and to guide the formatting of their references to conform with the guide-for-authors from *Geoderma*. As with the first scaffolded assignment, students were required to submit their writing sample in Word via email, in this case by the 10th week and a second draft that addressed my previous comments was required by the 12th week.

The third assignment was a “figure/table check” that was done in my office by appointment. Students were assessed by whether or not they had stopped by to have the figure and/or table checked. Students were required to prepare and print off at least one figure or table (depending on how they chose to best represent the data) by the 15th week (when they had completed their observation, experiment, laboratory analyses, or model run). I sat down with students for 10-15 minutes to discuss their method of displaying the data. I would also provide them with handwritten feedback on their printout to guide them in preparing the figures and tables in conformity with *Geoderma*. Because of the disparity in types of projects, I found it more efficient to assess and provide feedback to the students one-on-one as opposed to attempting to write out instructions that would cover all possible ways of representing their results.

The fourth assignment required students to submit a draft of their entire final work (at least 10-pages of text, double-spaced; at least 10 references most of which had to be peer-reviewed journal articles; and properly formatted figures and tables) by Stop Day. After quickly going through each one over the weekend, I provided feedback in the form of track changes via email. This gave the students guidance in making final changes in formatting, content, writing or figure/table representation. The final drafts of their final projects were due the last day of finals week. The final project was assessed with a detailed rubric.

A summary chart of these three implementations (i.e., précis, decoding-the-discipline questions, and the final project/scaffolded assignments), along with their targeted goals and details, is provided via this link.

Student Work:

The success of my implementations were formally evaluated by tracking scores on the 25-word précis assessed with the assignment rubric, as well as exam questions that mimicked the concept represented in the decoding-the-discipline questions assigned before lecture. My goals were also informally evaluated on the quality of the discussions and questions during lecture. The discussions during the Fall 2011 semester were much more organic and lively than the three previous semesters. In addition, the success of the final project scaffolded assignments were assessed on the quality and depth of the final written reports, which were also exemplary compared to the three previous semesters where the scaffolded assignments were not implemented.

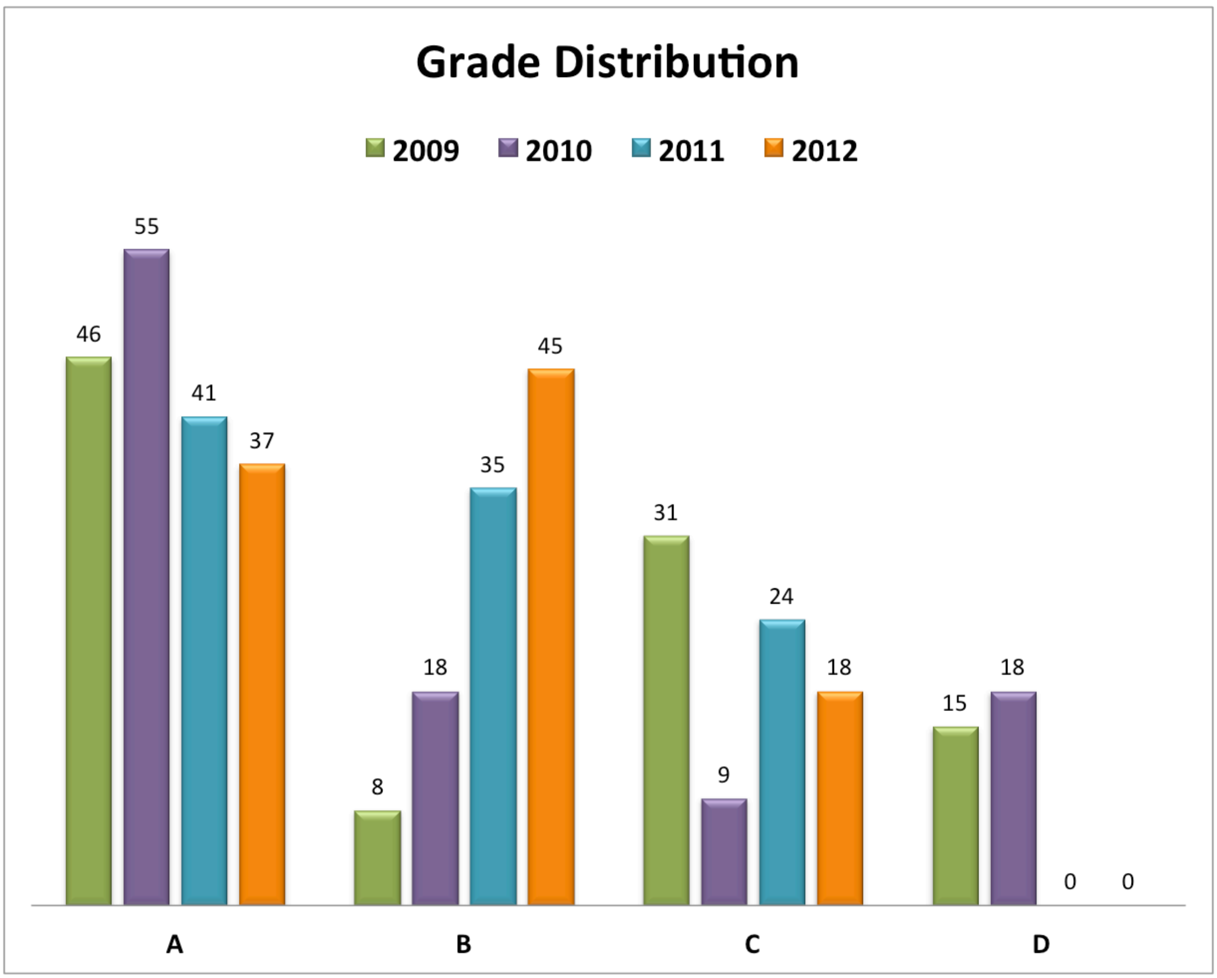
The evolution of in-class discussions during the semester revealed that student understanding of the material had deepened and that many initial misconceptions had been successfully reversed. The difficulty of the decoding-the-discipline questions assigned towards the end of the semester hinged on the integration of several sub-disciplinary concepts covered earlier in the course. Students seemed to quickly recall relevant soil processes and integrate their understanding of these processes on the fly in lecture by the end of the semester. For example, one of the early decoding-the-discipline questions for this course was:

"As a body of magma cools, there are minerals that crystallize at high temperatures and pressures, and others that crystallize at lower temperatures and pressures. Which minerals are more stable at the Earth's surface?"

Most students immediately and incorrectly associate minerals that precipitate at high temperatures and pressures (T and P) with minerals that have a higher stability (i.e., less weatherable) at the lower temperatures and pressures of the Earth's surface. Minerals are generally more stable, however, in conditions closer to their crystallization temperatures and pressures, which means that those minerals that precipitate at lower temperatures and pressures as the magma cools (e.g., quartz) are more likely to be stable under the typical weathering environments in the soil. As the course progresses, we discuss the effect of parent material on the genesis of a soil and compare and contrast soils formed on granitic rocks (containing a significant content of minerals that formed at low T and P) with those formed from gabbro (dominated by minerals formed at high T and P). Although students initially struggled with the relationship between crystallization conditions and stability at the Earth's surface, they were able to understand and clearly discuss why, and in what way, soils formed from the two parent materials would differ with respect to their morphological, physical, and chemical properties.

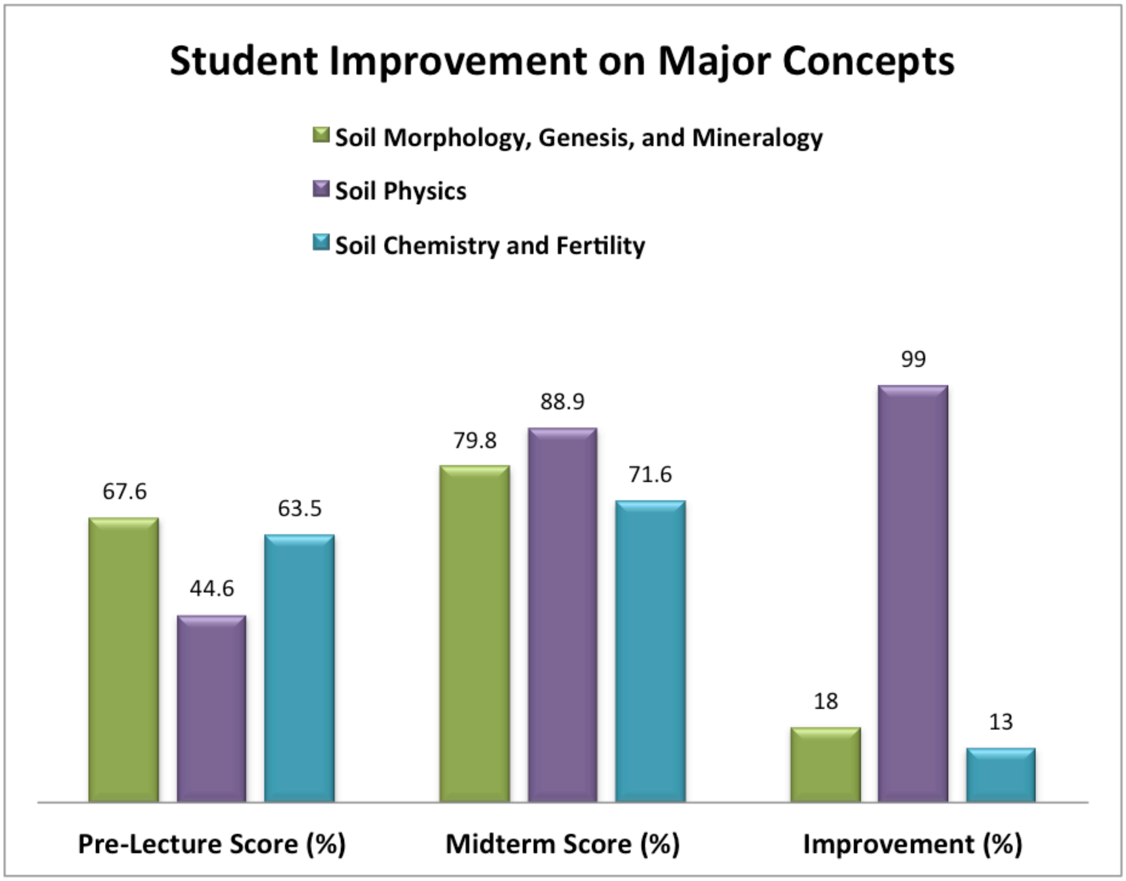
The quality of the discussions, improvement on the précis answers, and final project report outcomes far outstripped previous iterations of the course and, indeed, made teaching the course more enjoyable compared to those semesters. Student evaluations for this course were the highest in the department that semester, and were higher than any previous semester I had taught the course. Overall, my goals for the course appeared to have been achieved as students seemed much more knowledgeable about and interested in soils than at the beginning of the semester, they could both integrate their knowledge and discuss intelligently specific aspects of each sub-discipline, and they demonstrated their ability to answer a research question related to soils.

Comparing the distribution of grades from previous semesters reveals that the very lowest performing students were significantly helped as their grades tended to shift toward Bs and Cs in the two semesters when I implemented these teaching practices. The fall semesters of 2009 and 2010 had a considerable percentage of students performing in the D grade range. (Fall 2008 is not part of this comparison because the course did not take on its current form until 2009.) This is not totally surprising, since it is a piggy-back course where the graduate students tended to significantly outperform their undergraduate counterparts. However, the distributions were much more unimodal in 2011 and 2012, indicating that the undergraduate students in the course saw an improvement in learning and performance that was missing in the two preceding years.
Grades for the fall 2011 semester were 41% A, 35% B, and 24% C, compared to fall 2010 where grades were 55% A, 18% B, 9% C, and 18% D, or fall 2009 where the grades were 46% A, 8% B, 31% C, and 15% D. Also, grades for fall 2012 were 37% A, 45% B, and 18% C. I effectively removed the Ds using these teaching strategies.



Reflections:

For all three major concepts in the course, student learning improved on midterm questions when compared to pre-lecture questions. Average scores for the pre-lecture (decoding-the-discipline) questions, midterms, and percent improvement are shown below:



What was striking to me was the disparity of improvement across the major concepts. Clearly, the soil physics section showed the most improvement (almost 100%!) out of the three learning units. However, this is not totally surprising as, conceptually, the soil physics section appeared to be the most counterintuitive to students (lowest average pre-lecture scores) and, indeed, student questions and discussions during lecture corroborated this idea. Although all learning concepts were improved, my take-home lesson from this exercise was that the strategies I employed are best suited and most effective for the soil physics section. I am convinced that student learning in this section can be greatly improved by isolating misconceptions and directly addressing those through peer-to-peer interaction and discussion during lecture. Not every concept is equally difficult for most students; I expect this holds true for concepts in other classes I teach. Further isolating what concepts give students the most trouble and why is something I can use as an effective teaching strategy for this and other courses.

During the semester in which I implemented these new teaching strategies, I was initially concerned about the number of pre-class exercises I was requiring the students to complete.

Although a secondary goal with these exercises was to enhance discussion during lecture, which would potentially have a positive effect on final student evaluations, my concern was that the students would perceive the exercises as busywork, souring them to good discussion and ultimately having a negative effect on the perception of the class. To my surprise and relief, I never had a direct complaint about these exercises, and indeed the students seemed especially excited to answer the decoding-the-discipline questions. In fact, one of my students remarked on the end-of-semester evaluation, “The pre-lecture questions were a great way to keep the class involved and helped me focus.” Another student went so far as to say, “I also liked that there wasn’t ‘busy work,’ every question had a specific purpose.”

As a practice run, I had actually implemented both pre-lecture exercises (i.e., decoding-the-discipline questions and the 25-word précis) in several learning units of the same course the previous year. Through this experience, I learned several valuable and practical lessons about the options in Blackboard for administering these exercises.

I had attempted a few 25-word précis in the previous year’s class, but had not been exact with the topic I had asked the students to write about. Instead, I was too general, having them summarize, for instance, Section 5.4 instead of writing specifically about the information contained in a water characteristic curve discussed in that section. This implementation change allowed me to evaluate the student responses much more efficiently, and allowed me to focus more exactly on troublesome concepts.

Blackboard has at least two ways of administering the decoding-the-discipline questions. Both methods use Blackboard’s “Create Assessment” tool. With this tool, the instructor can either employ a “Test” or a “Survey.” During the previous semester, I used the survey option and polled my students’ responses to the pre-lecture decoding-the-discipline questions. As it turned out, this was not the best option to use, since Blackboard hides the individual responses to surveys and only reveals the aggregate data. This feature of the survey option prevented me from tracking the progression of individual responses at the end of the course. When implementing these exercises in fall 2011, I used the test option and was able to work with both the aggregate data for lecture and track individual responses at the end of the semester. This was important since I was interested in quantifying learner outcomes over the semester.

The scaffolded exercises were extremely helpful in saving time answering questions during the semester, by ensuring that each of the nine students enrolled in the upper-level course (535) had a systematic and consistent explanation of both my expectations and how to write a research paper in general. Most students needed less instruction and help as the semester progressed. These exercises had the secondary benefit of getting the students started early on their class project and led to richer and more in-depth projects (most were beyond the scope of the lecture or laboratory material). I was very excited to see those students pursue their research interests well beyond the level of the introductory soils course. In terms of the level of complexity of the research questions investigated, this class stood head-and-shoulders above the previous three years I have taught this course.