

Supporting Engineering Education with Instructional Design: The Case of an Introductory Module on Biogeotechnical Engineering

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Abstract

This work describes the instructional design process used by an interdisciplinary team of engineering and education faculty working together, at a NSF-funded Engineering Research Center, to create an introductory module on biogeotechnical engineering. We describe how the principles of learning theories and instructional design were applied to provide an introduction to a complex engineering domain using direct instruction, multimedia, and numerous instructional activities to explore technical topics. In addition, informative slides on geotechnical career trends and career options were included to spark student interest in the emerging field of biogeotechnics. The promising instructional design strategies outlined here address a few critical issues related to building engaging and effective content for incoming students and could be applied to other domains.

Keywords

Interdisciplinary, instructional design, introductory module, biogeotechnics, freshman module

Introduction

This work describes the instructional design process used to create an introductory module on biogeotechnical engineering. Biogeotechnical engineering is an emerging subfield of geotechnical engineering which is inherently multi-disciplinary. It embraces biology and geochemistry with engineering mechanics and earth sciences to influence the soil behavior, which in turn helps design and build more sustainable civil systems.

In 2011, a NSF-sponsored workshop called for the need to train a new workforce in the fundamentals of biology, microbiology, chemistry, geology, and engineering mechanics to produce geotechnical engineers to work across disciplines.¹ As a response to this call, in 2014, an Engineering Research Center, Center for Bio-mediated and Bio-inspired Geotechnics (CBBG) was established with a partnership among four universities - Arizona State University (ASU), New Mexico State University, Georgia Tech and University of California, Davis. With the idea of learning from nature, the CBBG aims to transform the engineering of geotechnical systems and address infrastructure-related challenges using biogeotechnics. The ultimate vision of the CBBG is to provide the critical mass needed to integrate the necessary disciplines, bridge knowledge gaps, and educate a new generation of engineers through education and outreach activities. To accomplish this vision, an interdisciplinary team of engineers and educators was

formed with two main goals: 1) to design specialty courseware at the university level for biogeotechnical engineering and 2) to create activities that engender excitement and enhance attitudes toward biogeotechnics among K-12 and pre-college students.

Our interdisciplinary team has five core members and two peripheral members. The core team includes:

- Subject Matter Expert (SME), also the Deputy Director of the Center from the School of Sustainable Engineering and the Built Environment
- A professor from the Teachers College who is the Education Director of the Center
- An instructional designer, also the Education Coordinator for the Center
- A graduate student from the Teachers College
- A graduate student from the School of Sustainable Engineering and the Built Environment

The peripheral members include: (1) the Director of the Center who is a professor in the School of Sustainable Engineering and the Built Environment and (2) the Industry Liaison Officer of the Center. They were available for consultation and reviews throughout the design and implementation process.

Since the immediate task for the team was to create generalized awareness about the new field of biogeotechnics among the student population, it would be best addressed by an instructional program². Thus, to encourage freshman civil engineering students to learn about, become interested in, and consider careers in biogeotechnical engineering, we designed an introductory lecture on biogeotechnical engineering. We used what Smith and Ragan³ called the “pragmatic” approach of instructional design. While we followed the Kemp model⁴ for the step-by-step instructional design process, the design and development phase united cognitivist approaches derived from Merrill’s first five principles of instruction⁵ and constructivist strategies outlined under 4C/ID model.⁶

The remainder of this paper describes the step-by-step instructional design process as well as preliminary findings from formative evaluations. We emphasize that the aim of this work is not to examine the results of the instructional delivery of the module per se, but to describe the instructional design process we followed to develop the material. Finally, the paper discusses pedagogical and design approaches used to make this introductory module an engaging lecture for the freshman engineering students.

What is instructional design?

Instructional design is a systematic design process to “facilitate intentional learning”.² The instructional design process assimilates learning theories, information technology, systematic analysis, and project management.⁴ While the content is provided by the SME, the instructional designer adds the experiences of learning and offers opportunities to practice within the content to enhance learner engagement and to improve learning gains.

Steps of instructional design

With the need for an introductory module focused on biogeotechnical engineering, the team started the instructional design following the Kemp model⁴ as shown in Figure 1. The Kemp model⁴ is an instructional design method⁷ to create an instructional program. Though the model has nine separate core elements, they are interdependent and ultimately provide a holistic approach that renders significant flexibility in the design process. Next, we describe the application of the nine steps during the creation of the instructional module on biogeotechnical engineering.

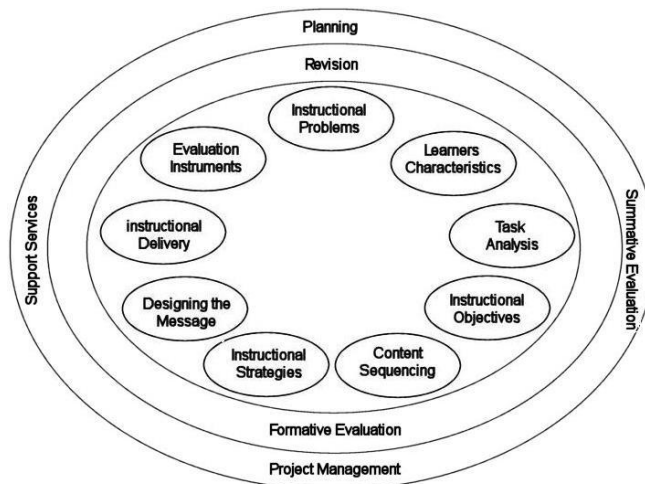


Figure 1. Kemp instructional design model

Image sourced from <http://educationaltechnology.net/wp-content/uploads/2016/02/Kemp.jpg>

Instructional problems

Morrison et al.⁴ suggest that the first step in the instructional design process is to identify the need and to ensure that the need will be best addressed by instruction. Apart from the vision of the CBBG to create awareness about the emerging field of biogeotechnics, some of the recent research related to the field of geotechnics^{8,9} illustrate and reinforce the need for specialized instruction in the early years of engineering education. For example, a recent survey of U.S. geotechnical faculty⁹ highlighted the need to introduce new specialization fields within engineering disciplines at the undergraduate level. This work suggests that early exposure will pique student interest in the emerging fields. The new geosciences workforce report⁸ urged academicians to create a relatively bigger and steady pipeline of students into the geotechnics specialty, alerting them of a significant short fall of approximately 90,000 geoscientists and geotechnical engineers by the year 2022. Thus, to spark interest, create awareness, and motivate students to consider careers in biogeotechnical engineering, we decided to create an introductory module for freshman civil engineering students.

Learner characteristics

Defining the characteristics of your target audience helps with design decisions⁴. Our target population was freshmen planning to major in civil engineering. To understand learner

characteristics, the student member of the design team interviewed a faculty member in the School of Sustainable Engineering and the Built Environment at ASU. While the demographic composition of students planning to major in science and engineering has become more diverse over time¹⁰, the participation of underrepresented minorities in geoscience university programs remains poor at 10%, compared to 23% representation of minorities in other engineering fields.⁸ ¹⁰ In engineering, the gender ratio is also poor. For example, in 2013, only 19.3% bachelor's degrees in engineering were awarded to female students.¹⁰ We also learned that while most incoming students are familiar with general civil engineering work such as transportation or construction, few have awareness regarding the field of geotechnics and potential career opportunities in geotechnical engineering.¹¹

Task analysis

Task analysis is an important element of the instructional design process as the designer determines the knowledge and procedures to be included in the instruction.⁴ This was a challenging task for the following reasons: 1) The entire technical field of biogeotechnical engineering had to be explained in the confines of a few slides without overwhelming the students, 2) the material had to be compatible for use by other universities nationwide, and 3) the material had to be engaging to pique student interest. After an initial consultation with the engineering faculty, two members of the design team met multiple times and created a content outline as shown in Figure 2. To further spark student interest and motivation, a conscious decision was made to include information on geotechnical career trends as well as future research and career options.

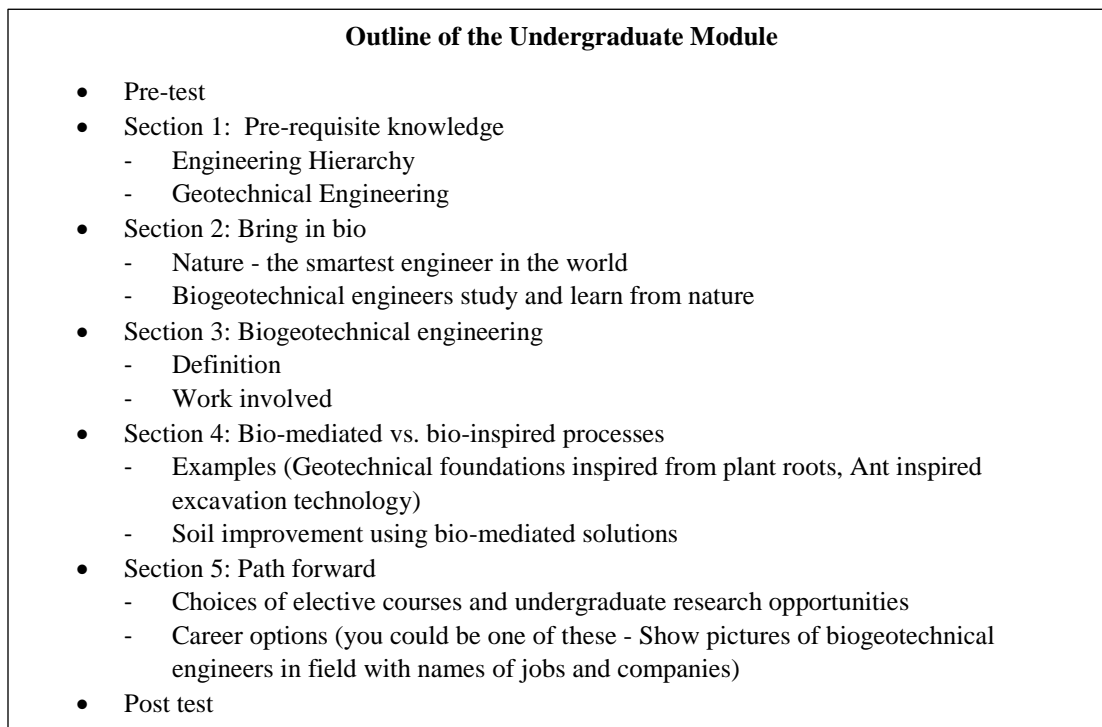


Figure 2. Snapshot of task analysis

Instructional objectives

With the topic analysis on hand, the next step was to create specific, measurable learning objectives² not only to guide the designing of the instruction, but also to develop the assessments on learner performance. The learning objectives for this module were as follows: At the completion of the introductory lecture on biogeotechnical engineering, the learner will be able to

- Define the field of biogeotechnical engineering, describe its fundamental principle, and name various disciplines involved in biogeotechnics.
- Differentiate between bio-inspired and bio-mediated processes.
- Describe opportunities available in the field and acquire positive attitude toward biogeotechnical research and career.

Content sequencing

The order in which information is presented, plays a crucial role in helping the learner understand the content in efficient and effective manner.⁴ Taking cues from Merrill's first principles of instruction⁵ and cognitive learning theories^{12, 13} that recommend activating existing knowledge and starting with simple problems, we created a logical sequence of topics and examples to be covered. To create a lasting impact, we decided to end the lecture with a slide outlining elective courses and undergraduate research opportunities for students.

Instructional strategies

In order to promote engagement and facilitate retention of knowledge, we included practice, reflection, or review activities in each section of the module (Table 1).

Table 1: Technical content paired with instructional activities in the module

Section	Detailed Topics	Student activity
1. Defining geotechnics	<ul style="list-style-type: none">• Hierarchy of civil engineering fields• Meanings of words geo and technics to define geotechnics• What does a geotechnical engineer do?	Working in pairs, identify real world systems made with, on, and in the earth, a resource extraction activity and one remediation problem
2. Bringing in bio (nature)	<ul style="list-style-type: none">• Examples of engineered geosystems• Problems with these systems• Solution to these problems• Why study and learn from nature	Small group discussion on potential solution(s) for the problems that occur with man-made geosystems
3. Biogeotechnical engineering: Definition and principle	<ul style="list-style-type: none">• The emerging field of biogeotechnics in the civil engineering hierarchy• Formal definition of biogeotechnics• Job of a biogeotechnical engineer	Practice activity for students to write the definition of biogeotechnical engineering in their own words
4. Difference between bio-inspired and bio-mediated Processes	<ul style="list-style-type: none">• Two different roles of nature in biogeotechnics<ul style="list-style-type: none">- Bio-inspired processes- Bio-mediated processes• Various examples of both processes	Practice activity of identifying given examples as either bio-mediated or bio-inspired processes
5. Education, research and career opportunities	<ul style="list-style-type: none">• The multi-disciplinary nature of the field• Annual salaries of geoscience workforce• Industry sectors that hire geotechnical engineers• Elective courses in junior & senior years• Undergraduate research opportunities	Reflections on sustainable engineering solutions

Moreover, notes were included below each slide for instructors suggesting how to conduct these activities and provide feedback to the learners (Figure 3). In addition, previous research^{14, 15} suggests that students see value in technology enhanced multimedia learning. As a result, we included couple of videos, one on the tunneling activity of ants and another showing tree-root systems. These videos conveyed some of the nature's processes which are not readily visible to us but help understand the concept behind biogeotechnics.

<p>Instructor Notes:</p> <ul style="list-style-type: none"> • Divide the students into groups of four asking them to discuss the question on the slide. • After two minutes, ask some groups to share their thoughts with the rest of the class. • Possible answers from students could be – better design, conservative structural engineering approach, use of stronger materials, regular inspections. • Prompt students to think about natural solutions and the possibility of learning engineering from nature. • Total time suggested for this activity is 5 minutes.
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Figure 3. Sample instructor notes for a group discussion activity.

To gain the attention of the students and to generate curiosity in the subject-matter, we suggested a simple demonstration (e.g., a small bucket full of sand and a biocemented block of sand) before the lecture, time-permitting. To help achieve this objective, information on a couple of simple biogeotechnical experiments was included with the module materials.

Designing the message

Designing the message involves specific and deliberate procedures and actions in arranging the text and pictures drawing from the cognitive theory of learning.^{15, 16} Table 2 shows some of the techniques we followed in the design process.

Table 2: Design techniques used in the module

Design Technique	Intended Outcome
1. Include learning objectives at the beginning of the lecture	Informs the students of what is expected at the end of the lecture
2. Create an appealing master-slide with colors that are friendly in various lighting conditions and color-blindness	Effective interface for communication between the learner and instructional material
3. Use side by side layout for content that requires comparison	Convey the contrast
4. Use typographical variations (boldface, italics, change in font size)	Draw attention of the learner and signal to a different structure of information
5. Use relevant pictures and direct learner's attention rather than simply placing pictures by the text	Reduce cognitive overload and facilitate retention

Development of instruction and delivery

Having completed the analysis and design, we developed customizable lecture material for a 50-90 minute class session. Figure 4 shows sample instructional slides prepared using the design techniques noted earlier. The design team ensured that the images used were either under

the CBBG license or the creative-commons license. While traditional instructional design process recommends creating learner and instructor manuals¹⁷, given the instructional context, we created a one-page handout (Appendix) for the civil engineering faculty delivering the lecture. The handout included brief information regarding the purpose of the lecture, organization of the instructional slides and timeline, supplies needed for the instructional delivery of the module, assessments, and finally, some suggestions for effective lecture delivery.



Figure 4. Sample Instructional slides

Evaluation instruments

Next, the team engaged collaboratively to create pre- and post-surveys to assess the learner's mastery of the objectives. We planned to collect data regarding learning outcomes, attitudes regarding biogeotechnics research and careers, as well as effectiveness of the instructional module and its delivery. The engineering faculty guided the formation of the technical questions, and the education faculty helped create the attitude and formative evaluation questions. After the detailed review by each member of the team, the instruments were transferred online for ease of dissemination.

Formative evaluations and implementation

We incorporated the introductory module as one of the lecture sessions for civil engineering section in the required Introduction to Engineering course at the freshman level. This course introduces incoming students to the engineering design process, working in engineering teams, and the profession of engineering. The course also exposes students to a cross section of topics in contemporary civil engineering disciplines to assist them with their education and career choices by arranging for guest lectures. Incoming students see value in this course and the introductory modules as they become familiar with concepts that they have not encountered before. Thus, there is high perceived utility of the course among students.

Though not part of the instructional design steps, formative evaluation is an integral part of the instructional design process that provides feedback to the designer for improving the instructional material.⁴ Essentially, it involves pilot testing and running field trials for the effective final version of the instructional module. We conducted two small group pilots – one with the student chapter of the American Society of Civil Engineers Geo-Institute and another with a small class of freshman students at ASU.¹⁸ With the feedback from these pilots, the

evaluation instruments were modified for specificity and the problem of soil-liquefaction was added under bio-mediated processes to strengthen the concept.

In addition, two field trials were conducted in freshman civil engineering classes, and results are under evaluation. Preliminary results indicate that majority of the students found the amount of information covered to be adequate, without being too technical and overwhelming. Students appreciated the informative slides on career options. Feedback on the visuals, especially the images that had real-world connections was highly positive. This included visuals such as the earthquake in Japan, geotechnical engineers at work, and past students interning at local companies. About 68% out of total 40 students, who participated in the field trials have shown interest in taking additional classes in biogeotechnics.

The module was also reviewed by the curriculum committee of the Center. The feedback was highly encouraging as noted by one of the reviewers, “My broad comment on the module is that I found it informative, well-organized, nicely tailored for freshmen, and flexible enough to accommodate for different audiences and durations.”

Next steps

Future work involves the dissemination of the module to the remaining three partner universities of the Center where further data on effectiveness of the instructional materials will be collected. Afterward, the module will be made available on the CBBG website for nationwide dissemination.

Discussion and implications

While using a traditional lecture method for delivering the module, we incorporated a few cognitivist and constructivist strategies drawing from the Merrill’s first five principles of instruction and the 4C/ID model.^{5,6} Merrill’s five principles⁵ include real-world problems, activation of existing knowledge, demonstration, application, and integration. 4C/ID model has four components: learning tasks, supportive information, procedural information and part-task practice for teaching complex tasks by mimicking real-life situations.

To provide a broad overview of the geotechnical engineering tasks, we introduced different examples from real life situations, what Merrill termed as “real-world problems”.⁵ These included collapsing buildings, fugitive dust problem, tunnel excavation, trees surviving hurricanes, building foundations for skyscrapers inspired by tree-root systems, and directional drilling for oil and gas pipelines. We used real-life images in the instructional slides and included real world news stories in instructor notes as supportive information. This strategy seemed to make connections with the students’ prior knowledge and experiences. Various examples and activities included throughout the module provided the application understanding and task-practice in order to reinforce the technical concepts and create engagement. As noted earlier, a small biogeotechnics demonstration was suggested to help freshman students realize what a biogeotechnical engineer can do.

Although this work is specific to biogeotechnics, we believe a few elements from this work were valuable in achieving the desired goals of increasing student interest and motivation. These

aspects include a) building a team of engineers and educators to create the module b) following a systematic process of instructional design, c) spending ample time on graphics to strike the balance between what the SMEs wanted to convey and what the students will be able to understand, d) making connection with the natural world of students through real images and news stories, and e) conducting multiple formative evaluations to engage in an iterative design process.

In summary, instructional design is a goal-oriented, learner-centered, empirical process. While it is a well-accepted practice in business and industry, military and government, its use is becoming increasingly common in academia.⁴ The systematic procedures used in the design makes the instruction more effective, efficient and relevant compared to other less stringent approaches of instructional planning.²⁰ Collaborative design teams of engineers and educators working to develop engineering education materials are uncommon.¹⁹ The promising instructional design strategies outlined here could be generalized and applied to other engineering domains to help engage freshman students and achieve expected learning objectives. This work has implications toward longitudinal research in understanding principled practices of interdisciplinary approaches when it comes to developing engineering education.

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Appendix
An Introduction to Biogeotechnical Engineering
Instructor Handout

Background

This instructional module is developed to motivate and educate freshman civil engineering students to learn about, become interested in, and to consider careers in, biogeotechnical engineering. The module is meant to be a teacher-led, in class, customizable lecture for a 60 to 90 minutes session for introductory engineering courses.

Organization and timeline:

- | | |
|--|------------------|
| 1. Pre-survey assessment | 6 to 8 minutes |
| 2. Instructional time with in-class student activities | 50 to 75 minutes |
| 3. Post-survey assessment | 8 to 10 minutes |

Assessments

Links to the online assessment instruments are provided within the presentation. Participants may use their laptops, tablets, or smartphones to take the surveys; however, it is suggested to keep some paper copies of the assessments for backup.

Supplies needed for the instructional delivery of the module

- Classroom equipped with computer and speakers, projector, and screen
- PowerPoint slides, pre-loaded onto a USB or shared drive
- Paper copies of pre and post assessments as backup
- Students should come prepared with paper and pencil
- Pictures of implemented applications, samples of bio-cemented sand, or other visual aid

Suggestions for effective delivery

- Review instructional slides (along with notes provided below each slide) ahead of time
- To view notes during instructional delivery, either start PowerPoint in presentation mode
→ presenter view, or print out the notes before class
- Modify slide 35 to include elective course numbers specific to your institution
- If short on time, skip slides 29 to 34
- If there is extra time in the class period, show the following video created by Geoengineer.org: **Fascinating Geotechnical Engineering News that Happened in 2016** -<https://www.youtube.com/watch?v=eOBwkdB4rU0>