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Problem-Based Learning with EFFECTs: Part I – Preparing Future Faculty to Integrate Teaching and Research – SFGE 2016

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SUMMARY: This paper describes an initiative to enhance the preparation of doctoral candidates for the engineering professoriate, with a focus on its implementation in a geotechnical engineering program. The initiative, referred to as Preparing Future Faculty (PFF) PLUS, creates an immersive experience in teaching and learning and fosters connections between research and education. Participating students opt to develop, implement, and assess problem-based learning (PBL) materials in an undergraduate course. This paper focuses on a six-step developmental framework that guides students in the creation of PBL modules. The framework provides support for the process of core concept identification, linking active learning strategies with concepts, selecting a practical application for concepts, and situating the problem within a meaningful context.

KEYWORDS: active learning, critical thinking, engineering education, geotechnical engineering, preparing future faculty, problem-based learning

1 INTRODUCTION

New faculty hires in tenure-track positions in engineering programs are expected to contribute to the core mission of the institution, commonly through the areas of research and scholarship, teaching, and service. Research expectations, in particular, depend largely on the institutional classification. Engineering programs in the U.S. exist in various numbers within a broad range of colleges and universities according to the Carnegie Classification of Institutions of Higher Education™. There are three tiers for Doctoral Universities based on research production: Highest Research Activity, Higher Research Activity, and Moderate Research Activity. There are also three tiers for Master's Colleges & Universities, but these are based on institutional size: Larger Programs, Medium Programs, and Small Programs. Baccalaureate Colleges are categorized on the basis of disciplinary studies, either as Arts & Science Focus or as Diverse Fields. All of the aforementioned classifications contribute to engineering education in the U.S. In some places, the research expectations are high while the service expectations are moderate to low, at least within the first few years. In other places, research expectations are minimal, but teaching and service expectations are high.

Regardless of institutional classification, new tenure-track faculty must support the teaching mission. The requirement to teach at least two courses per academic year is the norm, although some places have much higher teaching loads. Yet, the preparation of future faculty varies from institution to institution. In most doctoral programs, students become experienced in conducting and disseminating research. It is less common for students to gain the same degree of experience in teaching. Furthermore, there are often too few opportunities for students to make experiential connections between teaching and research. This paper describes a program developed at the University of South Carolina that provides doctoral students with a structured plan for the integration of teaching and research within the doctoral dissertation.

2 PREPARING FUTURE FACULTY

Preparing Future Faculty (PFF) is a national programmatic movement to transform how doctoral students are prepared for an academic career. Its roots are in the liberal arts and sciences (Preparing Future Faculty, 2016), which can be found within a broad spectrum of "academic institutions with varying missions, diverse student bodies, and different expectations for faculty." The PFF program at our institution focuses on two of the core features of the national model: (1) observe and experience responsibilities of faculty members through (2) a mentored program (Preparing Future Faculty, 2016). First, it "address[es] the full scope of faculty roles and responsibilities that include teaching, research, and service…" Second, "doctoral students participating in [this program] have multiple mentors and receive reflective feedback not only for their research activities but also for their teaching and service activities."

According to the Center for Teaching Excellence (2016) at the University of South Carolina, the specific program goals are to:

- better prepare participants for all aspects of their faculty careers including teaching, scholarly research, and service;
- provide a mechanism for recognition of initiative and gained experience in the areas of faculty roles and teaching;
- provide participants with credentialing for a diverse and competitive academic job market;
- encourage development of a positive, sustained mentoring relationship with a faculty member, allowing for a more in-depth look at a successful faculty career;
- provide a context to encourage reflective critical thinking to assess personal growth in teaching, professional development skills, and perspectives on the academic community; and
- provide and promote professional development opportunities and resources related to teaching and learning.

In the past five years, students pursuing a doctoral degree in civil engineering, and specifically within the geotechnical program, started to participate in PFF at our institution. To earn the PFF certification, students must earn a minimum number of points for accomplishments and approved activities within the teaching, research, and service categories. Candidates must successfully complete a series of critical self-reflections, and mentors must also provide written reflections on the perceived impacts of their interactions with the candidates. In 2014, the first geotechnical doctoral student with PFF certification was hired as a tenure-track faculty member at an institution with a newly established civil engineering program. Since the program is new, faculty members there are focused on program development, where teaching and service expectations are high, but research expectations are low. This particular institution classifies as Master's Colleges & Universities, Larger Program; in contrast, our former student was educated in a much different environment, since our institution is classified as a Doctoral University with Highest Research Activity.

The institutional PFF program provides doctoral students with increased awareness and preparedness for academia. However, there are opportunities to expand and tailor PFF to suit the needs of specific disciplines. In civil engineering, there was a desire to enhance the program with a more robust integration of education and research. The outcome was Preparing Future Faculty PLUS, where PLUS is an acronym for Pedagogy and Learning for Undergraduate Students. Throughout this paper, the program will be referred to with a shorthand notation, PFF+.

The core feature of PFF+ is the inclusion of one chapter dedicated to education within the doctoral dissertation. The intent of this novel approach is for doctoral students to: (1) gain meaningful teaching experience; (2) learn and implement innovative pedagogical strategies; and (3) integrate their doctoral research topic with their teaching opportunities.

3 PROBLEM-BASED LEARNING

Problem-based learning, or PBL, is a well-established pedagogical approach for student-centered learning in engineering education

(Smith et al., 2005; de Graaf and Kolmos, 2003; Perrenet et al., 2000). According to de Graaf and Kolmos (2003), the common attributes of PBL include students working in small groups, where the instructor facilitates learning centered about a specific problem. In PBL, the problem functions as the instructional vehicle for acquiring new knowledge. It supports inductive learning, rather than deductive learning that is often associated with a "lecture first, solve second" approach. It is also a common experience for students to work harder in PBL as compared to the traditional lecture format (de Graaf and Kolmos, 2003).

At the University of South Carolina, a PBL framework was created and adopted in a number of undergraduate civil engineering courses. The framework is referred to as EFFECTs, or Environments for Fostering Effective Critical Thinking. In essence, it is a structured approach for problem-based learning that incorporates principles of active learning, collaborative learning, and reflective learning (Pierce et al., 2013; 2012). An EFFECT module is a sequence of consecutive class periods, often three or four, designated for solving one open-ended problem. One of the core outcomes of EFFECTs is that it promotes development of professional skills as well as technical skills (Pierce et al., 2014).

Since the application of EFFECTs has been established within our curriculum, it was deemed an appropriate and efficient mechanism for supporting the PFF+ program. To that end, a training protocol was created for doctoral students who choose to pursue PFF+, as follows: (1) attend an EFFECTs workshop, which are held on an annual basis; (2) observe an EFFECT in an undergraduate course; and (3) work one-on-one with a faculty member, who also serves on the dissertation committee, to develop, implement, and assess a new EFFECT.

A developmental framework, or flowchart, was constructed to guide new adopters in the creation of EFFECT modules, as shown in Figure 1. Each one of the six steps is described in more detail in the following subsections.

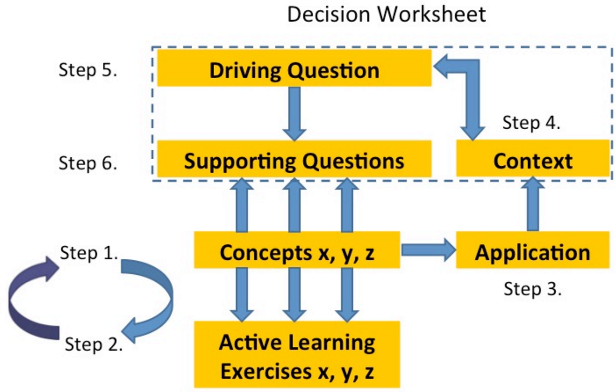

Figure 1. EFFECTs Developmental Framework

Concepts. The first step is to identify the core knowledge that students will learn within the EFFECT module. Core knowledge can include a singular but significant concept or multiple concepts that can be linked together. For instructional efficiency, it is recommended that core knowledge include concepts that are existing, integral elements of the course. In other words, the instructor is delivering the same course content but in a different package. Of course, new concepts can also be added using this approach. Collectively, the identified concepts become the learning outcomes of the EFFECT.

Active Learning. The second step is to consider active learning exercises (ALEs) that can be associated with the proposed core knowledge. There are a multitude of active learning techniques available; examples of ones that have been embedded in geotechnical modules can be found in Starcher and Pierce (2016) and Pierce et al. (2013). Active learning does not require hands-on components, although their inclusion is often valuable and can help link psychomotor learning and cognitive learning domains. The most significant element of active learning is that it must engage students in minds-on exercises.

Table 1 provides guidance on what factors to consider when choosing activities. It is recommended to identify, at a minimum, one

ALE for each concept. Through the process of considering options, however, it might be determined that multiple ALEs are needed for learning one concept, or that a single ALE works well for covering two or more concepts. The selections must suit the needs of the course.

Table 1. Decision-Making Guide for Development of Active Learning Exercises

Impact Factors	Considerations
1. Instructional Time	• How much time can/should be dedicated to this concept within a class time period? • Is a lecture component needed to supplement active learning of this concept, and if so, how much time will that require?
2. Instructional Environment	• Is the course taught in a classroom, computer lab, experimental lab, or some other space? • What is the arrangement of seats, desks, and other furniture or equipment within that space? • Can a specific class period be moved outside or to another space to accommodate active learning, if desired?
3. Class Size and Structure	• How many students are in the course? • Are there established student teams within this course? • Will students engage in active learning exercises as individuals, pairs, teams, or some combination thereof?
4. Resources	• Human resources: Are other persons (e.g., guest instructors, teaching assistants) available to support active learning, if desired? • Technological resources: Will students need access to computers or other electronic devices? • Material resources: Are materials, supplies, and/or equipment needed, and if so, are these resources accessible? • Financial resources: Are funds available for acquisition of resources, if needed?

Application. The third step is to consider the practical applications of the core knowledge identified in step one. The application is intended to represent a singular but generic use of core knowledge in practice. Geotechnical practitioners, for example, are involved with earthen structures such as dams, levees, embankments, cut slopes, and retaining walls. Each one of these can represent an application for a specific set of core knowledge.

Context. The fourth step is to provide a meaningful context for the selected application. The context helps to connect students with the problem, and as such, its importance should not be understated (Pierce et al., 2013). Context refers to the characteristics and purpose of a specific, often real, example of the application. In other words, if the application is an earthen dam, then a context could be the failure of the Teton Dam in northwestern U.S. in 1976. Or, an alternative context could be the more recent collapse of the Fundao and Santarem dams in southeastern Brazil in 2015. It should be noted that it does not need to be a real example, but the context should at least represent a realistic scenario. There are often a multitude of options for assigning context to a particular EFFECT.

Spatial and temporal factors impact the choice of context. In other words, the time and place associated with the EFFECT should be aligned with its intended audience. For example, the use of a current event in context can be effective, especially when student awareness of the event is expected to be high. The likelihood that students will be engaged in the problem-solving process should increase when students are more interested in the problem. Thus, the context functions as a bridge between the domains of affective learning and cognitive learning.

Once the context is chosen, a problem statement is written for the decision worksheet, as shown in Figure 2. The decision worksheet initiates the EFFECT module; in other words, it serves as the starting point for students to navigate through the PBL sequence. It is common to distribute this worksheet for students to complete as individuals without the use of informational resources. Upon completion, students discuss in groups.

Decision Worksheet: EFFECT Name

Problem Statement:

Context-Supporting Image(s)

Driving Question:

Answer Box:

Supporting Question 1:

Supporting Question 2:

Supporting Question 3:

Supporting Question 4:

Figure 2. Decision Worksheet Template

Driving Question. The fifth step is to develop a driving question, which serves as the student prompt to solve a specific problem set within the context. A driving question can be likened to a Fermi problem, which requires students to estimate an answer with little to no assigned information. While there are no established rules for solving Fermi problems, a three-step process can be utilized for estimation: (1) make reasonable qualitative assumptions; (2) make appropriate quantitative approximations; and (3) solve using dimensional analysis. The integration of Fermi problems in engineering education is not unique (Thomas et al., 2013; Shakerin, 2006; Lunt and Helps, 2001), although research on their use and effectiveness for developing estimation skills appears to be limited (Pierce et al., 2013).

Supporting Questions. The sixth step is to add supporting questions to the decision worksheet. The purpose of these questions is to guide students through the process of estimating an answer to the driving question, based on their current state of knowledge. At the same time, student responses to these questions can be used for assessment of student knowledge. In particular, student responses can be used for identification of knowledge gaps, misconceptions, and misunderstandings.

Normally, four supporting questions are included on a decision worksheet. Each question, designated as SQ1 through SQ4, is designed with a specific purpose, as described below:

- SQ1: Visualization of Problem – This question asks students to provide a specific illustration associated with the problem and a written description of it. Examples include a plan view, cross-section, chart or plot, flowchart, and diagram, among others. The type of illustration should be selected such that it reveals information about student understanding of core knowledge identified in step one and/or the application identified in step three.
- SQ2: Factor Identification – This question asks students to list the factors that impact the solution. In other words, what information is needed to solve the problem? If desired, a list of prioritized factors can be requested. For example, one might ask students to consider and identify the three most important pieces of information that must be known for this particular problem.
- SQ3: Assumptions and Approximations – This question asks students to make an appropriate assumption or approximation for each factor identified in SQ2. With these, students can perform a dimensional analysis to estimate an answer to the driving question.
- SQ4: Failure Implications – This question asks students to consider what constitutes failure of the given problem.

4 IMPLEMENTATION PLAN

The long-term goal is to create a sustainable model for the development of future faculty and, through that process, generate a published collection of PBL modules within the EFFECTs framework, with a focus on geotechnical engineering. Three geotechnical modules have been developed and implemented at two institutions (Pierce et al., 2013); a geoenvironmental module is also available, but it has not been published yet. A faculty member within the EFFECTs community of practice led the development of each one of these four modules. Moving forward with the PFF+ program, the expansion plan will also include doctoral student-led development of instructional materials.

The first PFF+ module, on soil-cement stabilization, is described in a companion paper (Starcher and Pierce, 2016). This module was developed for an undergraduate geotechnical engineering lab course. It was implemented during the spring 2016 semester at our institution. Within the geotechnical program, there are a sufficient number of undergraduate courses to support future PFF+ students, as shown in Table 2. Since the current research efforts of doctoral students in our program are concentrated on experimental studies, the corresponding five-year strategic plan for PFF+ focuses on two lab courses, Introduction to Geotechnical Engineering Lab and Experimental Methods in Geotechnical Engineering. Presently, a second PFF+ student has initial plans to incorporate a module on dam seepage and centrifuge modeling into the latter course. As part of his training, this student served as a teaching assistant this semester for the soil-cement stabilization module.

5 SUMMARY

In closing, the vision for this PFF+ program is that it creates the foundation for a universal model of a more comprehensive and integrative experience for doctoral students in engineering. The goal is to enhance the preparation of future faculty to be effective and engaged teachers who are knowledgeable in student-centered learning practices.

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Table 2. Geotechnical Courses and EFFECTs at University of South Carolina

Course [academic requirements]	EFFECT
Introduction to Civil Engineering [first-year and transfer student requirement]	• Levee Reconstruction (Pierce et al., 2013)
Introduction to Geotechnical Engineering [junior requirement]	• Tower Settlement (Pierce et al., 2013) • Flood Control (Pierce et al., 2013)[1]
Introduction to Geotechnical Engineering Lab [junior distribution]	• Unpaved Road Stabilization (Starcher and Pierce, 2016) • Flood Control (Pierce et al., 2013)[1]
Foundation Analysis and Design [senior distribution][2]	• N/A
Earth Structures [senior distribution][2]	• N/A
Geosynthetics and Geotechnical Design of Landfills [senior elective]	• Geomembrane Liner Durability
Geotechnical Engineering in Transportation [senior elective]	• N/A
Experimental Methods in Geotechnical Engineering [senior elective]	• Dam Seepage, anticipated release in 2017-18

[1]developed at Marshall University for course that integrates lecture and lab
[2]distribution courses are program area requirements, meaning that most students will complete one of these two courses

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