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An Ecological Engineering (EcoE) Body of Knowledge to Support Undergraduate EcoE Education

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Abstract

Ecological engineers are increasingly needed to contribute to the design of "nature-based solutions," "engineering with nature," and similar calls for circular, resilient systems. With this demand comes a need to formalize and grow the number of educational programs to train the next generation of ecological engineers. As part of the effort to meet this need, the American Ecological Engineering Society (AEES) formed a Body of Knowledge (BOK) Committee with the specific task of identifying the knowledge, skills, and abilities that academic programs should incorporate into an undergraduate Ecological Engineering (EcoE) program. To establish this knowledge base, the committee first identified 13 example design projects (applications) on which a recent EcoE graduate could be expected to work. Example applications included the design of a stream restoration system and the development of a prairie restoration plan. Next, the specific tasks that the graduate would need to carry out to complete each design application, along with the underlying knowledge or skills needed for each task were outlined. Additionally, the necessary level of learning for each knowledge area was qualified, ranging from simple recollection of facts to integration of knowledge across engineering and ecology to develop designs. Each application area was reviewed by the committee and up to two external EcoE practitioners. Following the development, review, and revision of the application areas, the knowledge, skills, and abilities were condensed by identifying the common knowledge across the applications, with a particular emphasis on key ecological principles new ecological engineering graduates should be able to apply in engineering design. This common knowledge is currently being summarized in the first EcoE BOK report. In addition to supporting ABET program criteria in ecological engineering, this document will provide academic departments guidance in developing EcoE curricula.

Introduction

Ecological engineers apply ecological principles and processes to engineering designs by incorporating considerations of self-organization, uncertainty, sustainability, resilience, the role of humans in ecosystems, and system-scale impacts and benefits to both humans and environment. The theoretical basis of ecological engineering is largely credited to Howard T. Odum, a systems ecologist who, in the early 1960s, began publishing his ideas on applications of ecosystem science to design systems that do useful work for people while at the same time benefiting the environment under the name of "ecological engineering" [1, 2]. The definition and practice of ecological engineering have since expanded to encompass a variety of systems that benefit people and natural systems, including constructed marshes to regulate water quantity and quality while providing habitat functions, biologically diverse and hydraulically functional vegetated systems within agricultural and urban landscapes, and wildlife passage designs that consider animal migration patterns and behavioral ecology alongside engineering design.

The systems design approach and tools employed by ecological engineers are increasingly needed as part of efforts to address society's sustainability goals at local and global scales. For example, the South Florida Water Management District invested \$1 billion to create over 29,000 Ha of treatment marshes to protect The Everglades from phosphorus eutrophication. The engineering design of these systems drew heavily from knowledge areas such as wetland ecology, biogeochemistry, hydrology and hydraulics and employed energy and systems analysis tools commonly utilized by ecological engineers [3]. Calls for ecological engineering skill sets are also evident in the growth of federal funding for "nature based solutions" and "resilient infrastructure" [4, 5]. As another example, the U.S. Army Corps of Engineers has invested heavily in its "Engineering With Nature" program, which funds projects in which natural and engineering processes are integrated to provide societal, environmental and economic benefits [6]. While these initiatives are all interdisciplinary in nature, ecological engineers clearly have a strong role to play.

The growing wealth of opportunities for ecological engineers signals a need for universities to formalize educational programs that will prepare students to employ the tools of ecology in the design of more sustainable systems. Numerous calls to define and adopt a common set of core ecological principles, design thinking approaches, and other skills that should underpin ecological engineering education have been voiced over the past two decades [e.g., 3, 7, 8, 9, 10, 11] but have not been answered in full.

The objective of this work in progress paper is to describe ongoing efforts of the American Ecological Engineering Society (AEES) to develop a Body of Knowledge (BOK) document that defines the core knowledge, skills, and abilities needed by undergraduate ecological engineering students. Anticipated outcomes of this work include (1) a delineation of core knowledge areas across engineering and ecological sciences that are central to undergraduate education in ecological engineering and (2) provision of a guide to university departments pursuing opportunities to create and/or maintain ecological engineering curricula.

As an underlying motivation to this work, the current status of ecological engineering education in the U.S is first summarized. Then, the process through which AEES is developing a BOK for undergraduate ecological engineering education – which begins with examples of design applications on which graduates of EcoE programs may be expected to work and then works backwards to a core set of knowledge, skills and abilities needed to successfully complete designs such as these – is described.

Current Status of undergraduate education in Ecological Engineering

Students wishing to pursue ecological engineering (EcoE) may do so through a variety of degree program pathways at the undergraduate and/or graduate levels. At the undergraduate level, Oregon State University provides the only standalone EcoE program, which has been accredited under ABET's General Criteria since 2010. Other institutions offer EcoE as a concentration or specialty area within degree programs in biological (or biosystems) or environmental engineering (Table 1). The growth of ecological engineering education out of well-established engineering programs is somewhat akin to that of education in environmental engineering, which largely grew out of civil engineering and sanitation engineering programs beginning in the 1960s and accelerating in the 1980s and 1990s [11, 12]. Even today, environmental engineering education programs may still maintain close alliances with civil and/or chemical engineering programs [12]. Similar alliances between EcoE and biological and/or environmental educational programs could also be expected.

Table 1. Current listing of undergraduate ecological engineering programs or concentration/emphasis areas under other engineering programs in the U.S..

Institution	Program or Concentration Name	Degree Program Affiliation
Oregon State University	Ecological Engineering	Ecological Engineering
Auburn University	Ecological Engineering	Biosystems Engineering
Clemson University	Ecological Engineering	Biosystems Engineering
University of Illinois	Ecological Engineering	Agricultural & Biological Eng.
Michigan State University	Ecosystems Engineering	Biosystems & Agricultural Eng.
North Carolina State University	Ecological Engineering	Biological & Agricultural Eng.
The Ohio State University	Ecological Engineering	Food, Agricultural & Biological Eng.
University of Minnesota	Environmental & Ecological Eng.	Bioproducts and Biosystems Engineering
University of Nebraska	Environmental & Ecological Eng.	Biological Systems Engineering
Purdue	Environmental & Ecological Eng.	Environmental & Ecological Engineering
St. Francis University	Ecological Engineering	Environmental Engineering
State University of New York	Ecological Engineering	Environmental Resources Engineering
University of Colorado Boulder	Applied Ecology	Environmental Engineering
University of Maryland	Ecotechnology Design	Environmental Science & Technology

For ecological engineering education to keep pace with growing opportunities in the workforce, the need to establish a standardized set of core curricular topics to serve as the foundation for curriculum development is paramount [3]. For example, while nearly all curricula from the EcoE program and concentration areas in Table 1 require students to take one or more courses in ecology, it is not clear in all cases which concepts and tools from the ecological sciences are then incorporated in engineering coursework and eventually employed as part of student design experiences. As stated by [13], the goal of EcoE programs is not just to teach engineers a little ecology, but rather to support an engineering discipline in which the base science (ecology) is integrated throughout students' engineering science and design experiences. A potential lack of consistency from one educational program to another along these lines is a disservice to students wishing to pursue careers in ecological engineering and may impede mainstreaming of EcoE education. Thus, there is a need to clarify a set of core competencies that EcoE programs and concentration areas should incorporate to guide curriculum design.

Current work to develop an ecological engineering body of knowledge

In recognition of this need, the American Ecological Engineering Society (AEES) formed a committee to define the EcoE Body of Knowledge (BOK). A BOK represents the full set of concepts, skills, knowledge, and abilities needed by professionals working in a particular domain. The process for developing the EcoE BOK presented herein was focused at the undergraduate level, though defining an expanded set of core competencies at the post-baccalaureate and later professional stages is planned for the future. This effort to develop an undergraduate EcoE BOK is parallel to, but distinct from, AEES' ongoing collaboration with professional societies representing biological (ASABE), civil (ASCE) and environmental engineering (AAEES) to develop ABET accreditation criteria for ecological engineering programs.

A conceptual framework of the process adopted to develop the EcoE BOK is illustrated in Figure 1 and described as follows. This process was somewhat akin to outcome-based or "backward" curriculum design approaches described, for example, [14]. To establish the undergraduate EcoE knowledge base, the committee first identified 13 example design projects (applications) on which a recent EcoE graduate could be expected to work (Figure 2). These application areas drew from recent work by an international group of ecological engineers [3] and were selected to represent a diversity of design applications that could be appropriate to undergraduate EcoE programs. After identifying this diverse set of representative design application areas, the steps of the design process an undergraduate could be expected to complete and then the knowledge, skills and/or abilities needed to complete each step were defined. Here, the frame of reference was a design project that engineering students commonly complete as a culminating major design experience required in ABET-accredited engineering programs [15]. Bloom's Taxonomy was then used to describe the cognitive level of learning needed to apply identified knowledge areas to the corresponding step of the design process at the undergraduate level. This process was first completed by a committee composed of AEES members from academia and industry with expertise in one or more of the application areas. After an application area was completed, it was shared with at least two external reviewers with expertise in the application for feedback. Whenever possible, external reviewers with industry experience were targeted to ensure that the knowledge, skills, and abilities as well as expected cognitive levels reflected what potential employers of EcoE graduates expected of new hires. Comments from external reviewers were then incorporated by the committee of AEES members. After completing this process for each of the design application areas, the knowledge areas, skills and abilities held in common across multiple, if not all, EcoE design application areas will be identified. At present, the AEES committee has identified a preliminary set of core competencies and ecological principles. The final set of common competencies resulting from this process will serve as the foundation of the undergraduate EcoE BOK.

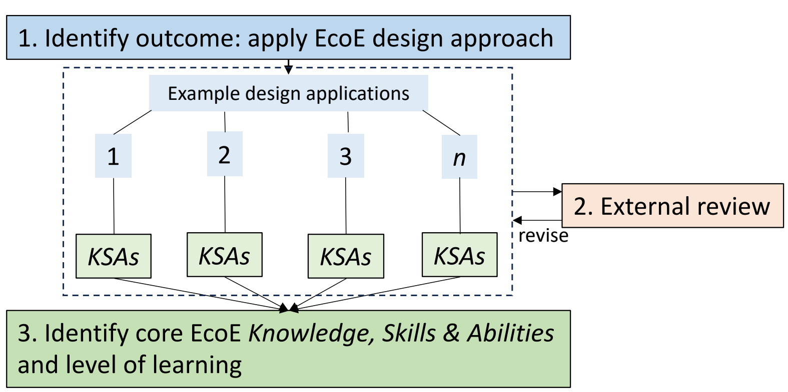

Figure 1. Conceptual diagram of process adopted to identify core knowledge, skills and abilities (KSAs) needed to successfully apply ecological engineering design at the undergraduate level and which form the basis of the BOK. Example EcoE design applications are presented in Figure 2.

It should be emphasized that the set of application areas identified as part of the BOK development process were intended to serve as a tool for distilling the core knowledge, skills and abilities to EcoE education programs. It follows that there is not a particular set of design application areas that an undergraduate EcoE program must include in its curriculum; rather, it is the core curricular competencies that underpin the EcoE design approach that are essential. While the set of core competencies that emerge from this BOK process should be considered essential to all EcoE curricula, EcoE programs and emphasis areas are free to incorporate design application areas to which they apply core EcoE competencies as appropriate to faculty expertise, regional industry or other constituent needs, and other program-specific considerations.

It is also recognized that other engineering programs, for example biological and environmental engineering, may identify overlaps with the application areas used to formulate the EcoE BOK. Again, the role of these application areas for distilling the core knowledge, skills and abilities needed to apply an ecological engineering design approach in any of these application areas is emphasized. For example, an ecological engineering approach to the mitigation wetland design would be expected to include ecosystem principles such as plant community succession and linkages between design wetland hydroperiod, key wetland ecosystem functions, and resulting ecosystem services. The grounding of the engineering design process in ecosystem science is a central tenant and distinguishing feature of ecological engineering practice.

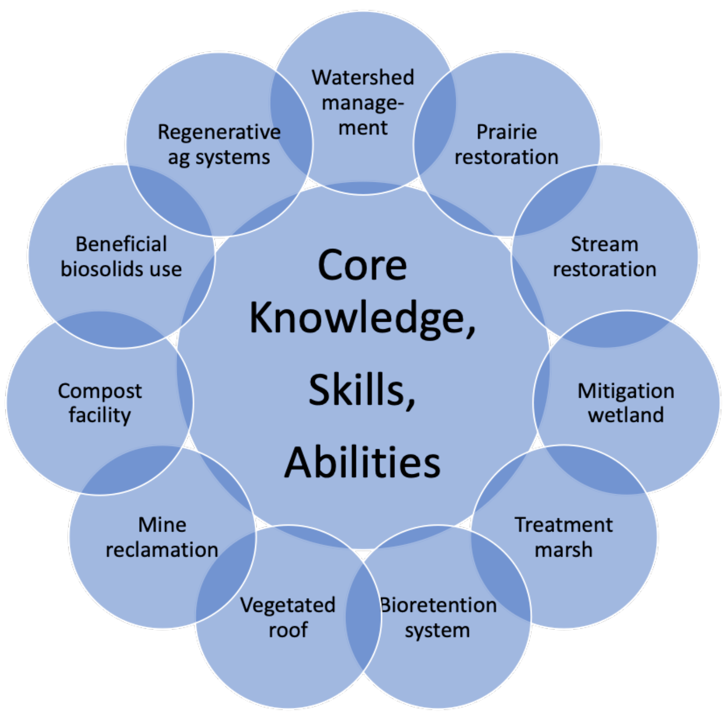

Figure 2. Overview of ecological engineering design applications used to derive a set of core knowledge, skills, and abilities at the undergraduate level for inclusion in the BOK. Phytoremediation and stormwater wetland (not pictured) design processes were also considered.

Future Work and Conclusions

The AEES BOK committee is currently finalizing the external review processes and subsequent revisions to each of the application areas in Figure 2. A complete report of the EcoE BOK and a descriptive listing of core ecological principles and knowledge areas is expected by the end of this year. Once complete, the EcoE BOK is intended to serve as a useful guide to educators in the ecological engineering domain. For example, the BOK can be used as a benchmark against which EcoE programs or concentration areas can compare their curriculum and other degree requirements to determine if graduates of their program are prepared to contribute to the ecological engineering workforce. While the application areas were a tool in developing the EcoE BOK rather than the primary focus, they can still be used by educators to assist in designing the content and depth of coverage within introductory through more advanced ecological engineering design courses. Ultimately, establishing the EcoE BOK is an important step in formalizing the training of future engineers to develop solutions that benefit humans and the environment.

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