2006-1669: SEQUENTIAL COURSE OUTCOME LINKAGE: A FRAMEWORK FOR ASSESSING AN ENVIRONMENTAL ENGINEERING CURRICULUM WITHIN A CE PROGRAM

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Abstract

The Department of Civil and Environmental Engineering has recently adopted an expanded set of fifteen program outcomes identified in the American Society of Civil Engineers Body of Knowledge and conducted work leading to development of common course goals with appropriate levels of cognitive achievement based on Bloom's taxonomy. In addition, the department has adopted a holistic process for investigating and analyzing the linkage of individual course goals in various discipline-specific areas of concentration within the curriculum. Sequential course outcome maps or "threads" have been developed, or are under development, for each of the department's major discipline tracts (structural, environmental, site development, and transportation engineering). A major objective in developing this framework for assessment was to evaluate the effectiveness of how well course goals are linked within the undergraduate curriculum and provide a basis for incremental improvement. Creation of course goals, outcomes, and cognitive level linkages yielded additional curriculum assessment benefits including:

- Allowing faculty to check and develop prerequisites which are more consistently linked to a student's actual learning objectives.
- Providing a means for faculty to identify and analyze potential discontinuities in learning goals of core concepts across the curriculum and within a discipline-specific area of concentration.

This paper presents and describes the process being used to develop outcome threads, includes an example outcome thread for the environmental engineering curriculum, and contains a summary of the analysis and potential changes initiated as a result of developing course threads as a framework for assessment. In addition, the paper presents future assessment possibilities utilizing the thread approach to curriculum evaluation.

Introduction/Background

Initiated by the Accreditation Board for Engineering and Technology (ABET) publication "Engineering Criteria 2000", the American Society of Civil Engineers (ASCE) developed and adopted the Policy Statement 465 entitled "Academic Prerequisites for Licensure and Professional Practice." This document establishes a framework for some major changes in the education of civil engineers with the long-term goal that, at some unspecified time in the future, civil engineering candidates for professional registration would be required to obtain a baccalaureate degree plus 30 additional hours of gradate work (B+M/30) prior to obtaining licensure [1]. Due to the considerable impact this implementation of policy statement would have on engineering education, ASCE established the first Body of Knowledge (BOK) committee to help develop and refine the idea presented in the policy statement and to provide guidance for engineering programs regarding what should be taught and learned, how it should be taught and learned, and who should teach and learn it [2].

The ASCE-BOK promulgates a wide variety of academic ideas and philosophies, two of which are most directly addressed within the context of this paper. The committee suggests that in addition to eleven program outcomes identified via ABET Criteria 3 a-k, four additional outcomes should be addressed through the instructional process including: specialized areas of civil engineering; project management, construction, and asset management; business and public policy; and leadership. Table 1 includes a list of all 15 program outcome criteria identifying both ABET and corresponding ASCE-BOK designations. For the purposes of this paper, program outcome criteria will be referenced based on ASCE-BOK designations (1-15). In addition to program outcomes, ASCE-BOK promotes adoption of six levels of Bloom's cognitive taxonomy to establish levels of competency students should attain across specified program outcomes. The six levels of Bloom's taxonomy are summarized as follows [3]:

- Knowledge consists of facts, conventions, definitions, jargon, technical terms, classification, categories, and criteria.
- Comprehension the ability to understand and grasp the meaning of material, but not necessarily to solve problems or relate it to other material.
- Application the use of abstract ideas in particular concrete situations.
- Analysis consists of breaking down complex problems into parts.
- Synthesis involves taking pieces and putting them together to make a new whole.
- Evaluation a judgment about a solution, process, design, report, material and so forth using expertise/experience in the area.

Table 1 ABET/ASCE-BOK Comparison [4]

ABET Criterion 3, a –k	ASCE-BOK Outcomes, 1 – 15
a	1. Technical core
b	2. Experiments/analyze and interpret
c	3. Design
d	4. Multi-disciplinary teams
e	5. Engineering problems
f	6. Professional and ethical standards
g	7. Communication
h	8. Impact of engineering
i	9. Life-long learning
j	10. Contemporary issues
k	11. Engineering tools
	12. Specialized area of civil engineering
	13. Project management, construction, and asset management
	14. Business and public policy
	15. Leadership

The expectation set forth by the ASCE-BOK is that civil engineering graduates with a B+M/30 program demonstrate a level of competency consistent with a prescribed standard for each of the 15 program outcomes. How to implement, document and provide evidence that graduates are meeting these expectations is left up to individual departments, with little more than philosophical guidance provided by ASCE's published reports addressing these topics.

Many Academic institutions have started the process of addressing how ASCE-BOK outcomes and assessment criteria can be integrated into the civil engineering curriculum by conducting internal investigations, creating detailed assessment plans and maps, and developing on-line assessment tools. The authors have previously presented a detailed literature review in Bower et al.[4]. References have been included for the readers convienence [5-10]. The Department of Civil and Environmental Engineering (CEE) at The Citadel, which consists of eight full-time faculty and minimal support staff, instructs 140 enrolled students in a four-year undergraduate program. The CEE department recently adopted ASCE-BOK principles as the basis for conducting course assessment, and has made significant changes to the assessment process in an effort to address issues put forth by ABET and ASCE-BOK. Methodological changes have been developed and adopted in a manner so as to minimize administrative time required by faculty and maximize efficiency of required process documentation, with the over-arching goal of establishing a better system for comprehensively tracking improvement items. Systematic tracking of improvements is structured to occur at both the individual class level as well as allowing meaningful aggregation at the curriculum level, reflective of the entire program.

The objective of this paper is to highlight the usefulness of the thread (outcome linkage between specific course goals and sub-areas) as a framework for assessment. This paper describes the process used to develop threads and provides an example course goal and outcome thread for the environmental engineering curriculum within the Department of Civil and Environmental Engineering. In addition, the paper addressees the subsequent changes that have been initiated as a result of the course thread analysis process and outlines the plan for future assessment possibilities utilizing a thread approach to curriculum evaluation.

Thread Development and Analysis

Continuous improvement across the department is based on faculty members completing an end-of-semester course assessment report for each course taught during the term. Use of a standardized format allows information to be readily compiled and analyzed from a variety of academic and administrative perspectives. With the underlying need to aggregate course data on a curriculum-wide level, it was concluded that for this process to be effective course goals needed to be consistent every time a course was offered regardless of the individual instructor or particular semester. As previously mentioned, sub-groups of CEE faculty worked on a course-by-course basis to adopt common course goals, link outcomes, and agree on competency levels that students should attain upon completion. Groups were formed based on classes previously taught and areas of expertise. This process is graphically depicted in Figure 1, along with subsequent tasks described herein, and includes feedback loops for continuous improvement. Once the work of adopting common course goals was completed, uniform BOK program outcomes were aligned with each course goal. Consistent levels of expected student competence were then established, after which two types of useful data aggregations were possible. The highest order of data aggregation was created at the department-wide curriculum level where all courses and course goals were reflected across 1-15 ASCE-BOK outcomes and at assigned 1-6 Bloom's competency levels.

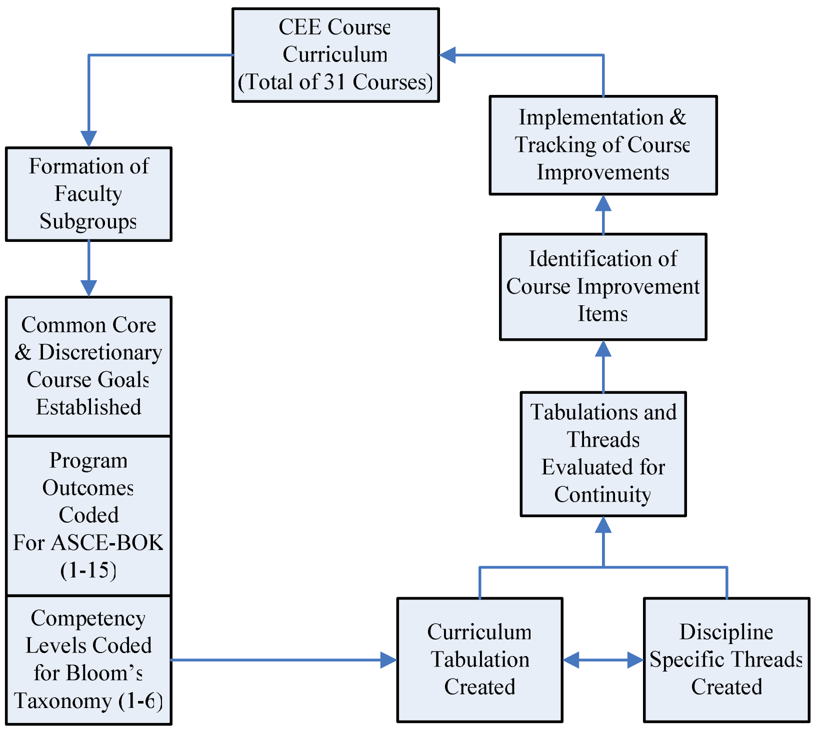

Figure 1 Course Goal Evaluation Process

Course curriculum outcomes are combined with other student development activities such as ASCE Student Chapter activities, Corps of Cadet barracks life, and student employment/internships to create a comprehensive view of the overall student experience. As this approach combines a large amount of information in a single tabulation, extracting meaningful information for specific improvement purposes can prove to be difficult. Even though a comprehensive view is useful, an additional step was created in which course goal data is aggregated along specific discipline tracts. These tracks are coined Sequenced Course Threads. The goal is to generate a number of threads specifically for structural, environmental, site development, geotechnical, and transportation areas of technical concentration. This level of aggregation creates a more workable economy of scale for identifying continuity between related courses and targeting improvements to enhance student learning.

Definition of Environmental Engineering at the Citadel

The process of compiling and analyzing data, outlined in Figure 1, necessitates the formation of a definition of what comprises the environmental educational background for a civil engineer graduating from The Citadel. The Association of Environmental Engineering and Science Professors (AEESP) defines environmental engineering as follows:

> "Environmental Engineering is the application of scientific and engineering principles to assess, manage and design sustainable environmental systems for the protection of human and ecological health.
>
> Environmental Engineering encompasses a range of specialties including:
>
> - Air Pollution and Air Quality Control Processes
> - Drinking Water, Surface Water, and Groundwater Quality
> - Chemical, Physical, and Biological Water and Wastewater Treatment Processes
> - Environmental Chemistry, Microbiology, Geology, and Ecology
> - Hydrology and Water Resources
> - Hazardous, Radioactive, and Solid Waste Management and Remediation
> - Solid Waste, Sludge and Disposal, and Wastewater Management
> - Environmental Toxicology and Risk Assessment
> - Public Health, Management and Policy
> - Global- and Regional-Scale Environmental Impacts
> - Mathematical Modeling of Environmental Processes
> - Sustainable Engineering Systems
> - Environmental Sampling, Sensors, Analytical Methods, and Nanotechnologies" [11]

Based on the AEESP definition and on individual course objectives related to forenvironmental engineering in the curriculum, the environmental curriculum a civil engineer student at The Citadel is defined as follows:

> Environmental Engineering at the Citadel is the application of scientific and engineering principles to assess, manage and design sustainable environmental systems for the protection of human and ecological health.
>
> Environmental Engineering at the Citadel encompasses a range of introductory, fundamental, and design topics:
>
> - Introduction to Air Pollution and Air Quality Control Processes
> - Introduction to Hazardous and Solid Waste
> - Introduction to Risk Assessment
> - Introduction to Data Analysis and Presentation
> - Introduction to GPS Data Gathering and Analysis
> - Introduction to GIS as a tool for data presentation
> - Introduction to Mathematical Modeling of Environmental Processes
> - Introduction to Environmental Sampling Analytical Methods
> - Fundamentals of Fluid Mechanics Hydraulics

- Fundamentals of Hydrology and Water Resources
- Water and Wastewater Treatment Plant Design
- Environmental Engineering Capstone Design with Multidisciplinary Teams

With this broad definition of environmental engineering at The Citadel, the authors have established a generalized context for presenting, discussing and improving a sequenced course thread within the detailed discipline track of environmental engineering.

Sequenced Course Thread for Environmental

Through creation of sequenced course threads along major discipline tracts and central learning activities within the Civil and Environmental Engineering program, faculty are able to describes how course goals are successively linked through the four-year undergraduate curriculum. Table 2 is a sequenced list of course goals and associated ASCE-BOK outcomes for the environmental engineering thread. It provides an illustration of each course containing an objective related to environmental engineering, the number of course goals related to environmental engineering, and the BOK program outcomes to which these goals are mapped. Table 2 provides a useful stepping-stone for further analysis along the thread. Another useful means of tabulating course goal data for this discipline tract was accomplished by cross tabulating ASCE-BOK program outcomes with Bloom's levels of competency across all course goals contained within the sequenced course thread for environmental engineering. This provides an useful manner to visualize how well course goals are distributed through a particular discipline tract. Program outcomes and levels of competency for courses in the environmental course thread are shown in Figure 2. For example, Figure 2 identifies that there are

Table 2 Sequence Course Thread – Courses within Curriculum which contain Course Goals Related to Environmental Engineering

Semester	Course No.	Course Title	Course Goals	BOK Outcomes
Fresh. 1st	Civl 100	Introduction to CEE	4	1,3,4,5,6,7,11
Fresh. 2nd	Civl 101	Engineering Graphics	3	5,7,11
Soph. 1st	Civl 209	Computer Applications for CEE	6	1,5,7,11
Soph. 2nd	Civl 207	Geomatics	3	1,2,7,8,11
	Civl 237	Geomatics Lab	3	1,2,3,4,5,7,8
Jr. 1st	Civl 305	Transportation Engineering	1	6,10,14
	Civl 312	Intro. to Environmental Engineering	5	1,2,4,5,6,7,8,9,10,11
	Civl 314	Engineering Administration	5	1,5,6
	Civl 330	Measurements, Analysis & Modeling	7	1,2,3,4,5,10
Jr. 2nd	Civl 313	Hydrology & Water Resources	9	1,3,5,8
	Civl 315	Fluid Mechanics	7	1,3,5
Sr. 1st	Civl 418	Fluid Mechanics Laboratory	4	1,2,3,5,6,7,8,11
	Civl 408	Water and Wastewater Systems	7	1,3,5,10,11,12
Sr. 2nd	Civl 419	Environmental Engineering Laboratory	7	1,2,7,11,12
	Civl 422	Environmental Engineering Capstone	9	1,2,3,4,5,6,7,8,9,10, 11,12,13
Optional	Civl 450	Civil & Environmental Eng. Internship	3	7,14,15

	1	2	5	11	12	3	4	7	9	6	8	10	13	14	15
Evaluation							Experience					Post-Licensure			
Synthesis	408 422		408 422	408 422	408 422	408 422									
Analysis	312 313 315 408 419	419	312 313 315 408	419	312 408 419	313 408		419			313				
Application	209 207 237 313 314 315 408 418 419	207 237 418 419 422	209 237 313 314 315 408 418	209 207 418 419	408 419	237 408 418 422	237	209 237 418 419 422		314 418	237	Experience			
Comprehension	209 312 315 330 418 419	330	209 312 315	209 207 419	312 419	315 330	330 422	207	422	422	207 312 418 422	312	422	422	
Knowledge	100 313 330		100 101 312 313 330	100 101	312 408	100 408	100 330	100 101		100 305	312	305 312 408	422	305	

Figure 2 ASCE-BOK Outcomes versus Bloom's Levels of Competency for Courses in the Environmental Engineering Sequenced Thread

course goals for CIVL 408 address ASCE-BOK Outcome 1 at the Application, Analysis, and Synthesis levels of competency. Furthermore, a similar but more simplified tabulation merely showing the number of course goals for each outcome at specific competency levels is provided in Figure 3.

The organization of Table 2, Figure 2, and Figure 3 was developed to establish a functional data structure that collectively describes the instructional progression of students advancing through the curriculum within the defined discipline tract of environmental engineering. Tabulations are structured to allow evaluation of meaningful relationships between educational subject matter, program outcomes, and competency levels. Due to the linked nature of course, outcome, and competency data presented in Table 2, Figure 2, and Figure 3, analysis and evaluation of this information is presented collectively. From a review of these tabulations, a number of interesting and useful quantifiable observations regarding the environmental engineering curriculum were noted:

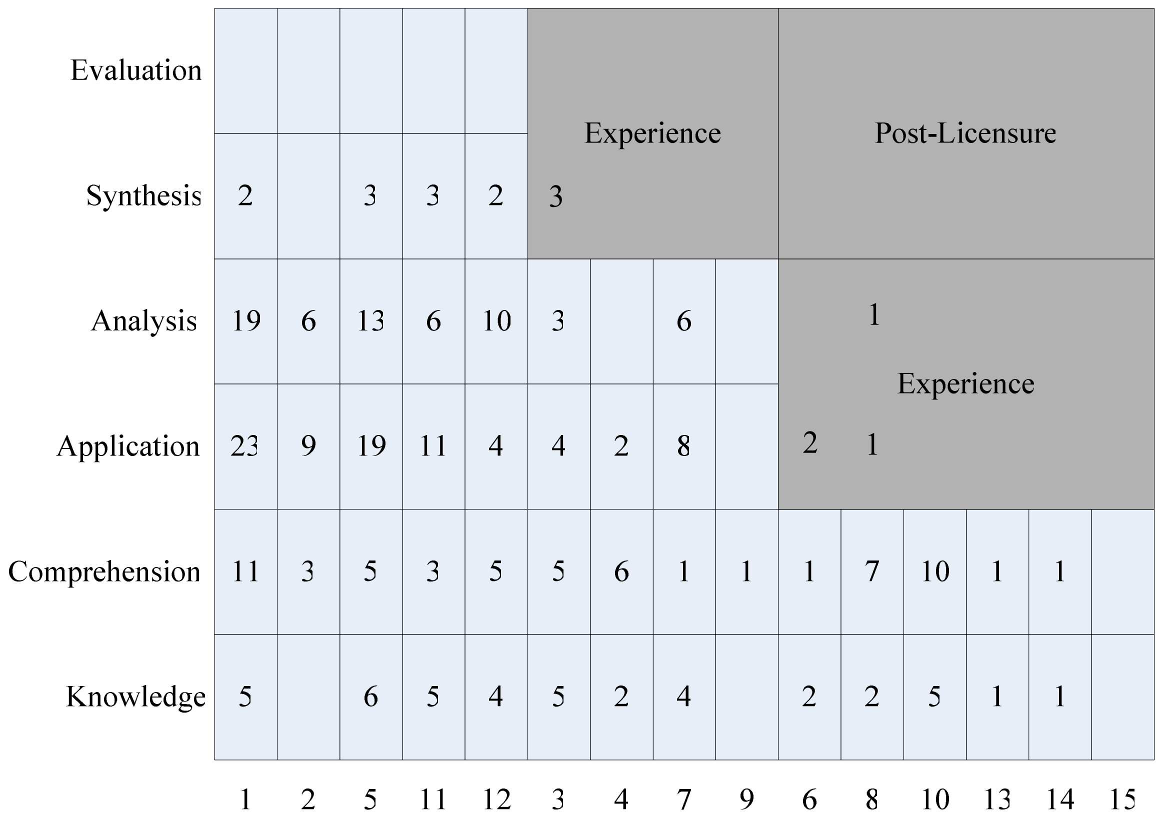

Figure 3 ASCE-BOK Outcomes versus Bloom's Levels of Competency for the number of course goals in the Environmental Engineering Sequenced Thread

- Of the 31 courses offered within the departmental curriculum, 16 courses contain elements of environmental engineering and are represented in the sequenced course thread for this discipline tract, as shown in Table 2. The number of course goals varies considerably from courses such as transportation engineering, Civl 305, which contains only one course goal related to environmental engineering, while in fundamental courses such as Introduction to Environmental Engineering, Civl 312, all ten course goals contribute to the instructional thread of this area of concentration.
- In total, students are exposed to 83 individual course goals contained in the sequenced course thread for environmental engineering, as delineated in Table 2. Of additional interest is the observation that environmental engineering subject matter is presented to students during every semester of the four-year undergraduate curriculum.
- Through aggregation of goals and outcomes for this discipline tract as presented in Figure 2, 14 of the 15 ASCE-BOK outcomes are being addressed through courses linked within the environmental engineering thread.
- As depicted in Figure 2, 100 and 200 level courses taken during the freshman and sophomore years appear more towards the lower range of the Bloom's taxonomy scale, which is consistent with a sound sequential educational process.
- Figures 2 and 3 visually confirm that heavy concentrations of course goals are distributed across Bloom's Taxonomy levels for ASCE-BOK Outcomes 1, 3 and 5, which are related to Technical Core, Design and Engineering Problems. These are

key focal points for instructing students in environmental engineering and provide evidence that a considerable amount of instruction is concentrated on these essential skills over a large number of courses in the curriculum.

- Tabulations shown in Figures 2 and 3 are useful in identifying gaps or holes in the distributions of course goals represented within a particular sequenced course thread. This is evident for Outcome 2, experiments/analyze and interpret data, where only three of the six levels of Bloom's taxonomy are covered. The department is in the process of developing a plan to address this discontinuity.
- A number of prerequisites are required for the main courses within the environmental engineering tract, which are primarily taken by students during their junior year. As shown in Figures 2 and 3, it stands to reason that a large number of course objectives appear for ASCE-BOK outcomes at Bloom's levels 4 and 5, which correspond to application and analysis.
- The semester-by-semester sequence in Table 2 and distribution of course goals in Figure 2 are useful in evaluating how linked course material is presented to students who are progressing through the curriculum on a course-by-course continuum. These tabulations are helpful in identifying discontinuities within the curriculum such as courses which should be scheduled concurrently. For example an improved sequence of course goals may result from scheduling Civl 315, Fluids Mechanics, to occur concurrently with Civl 418, Fluid Mechanics Laboratory. Similarly, student instruction may be enhanced by offering Civl 408, Water and Wastewater Systems during the same semester as Civl 419, Environmental Engineering Laboratory.
- Course goals from several courses are shown in areas of the matrix representative where graduate engineers would acquire exposure to these levels of outcomes during their pre-licensure work experience. As shown in Figures 2 and 3, this occurs for ASCE-BOK Outcome 3, Design, at Bloom's level 5, Synthesis, with course goals from Civl 408 and Civl 422. It is important to note that typically a specific goal pertains to two or more outcomes, due to the content-driven nature of technical course goals. This is the case where these two courses are listed for BOK Outcomes 1, 5, 11 and 12 at the Bloom's synthesis level. This can complicate the analysis of a thread. However, it may be possible to address this issue by splitting the course goals and generally attempting to have fewer outcomes listed for each individual course goal.
- Based on an evaluation of Figure 3, it becomes evident that course goals within the environmental engineering thread for ASCE-BOK outcomes 2, 9 and 15 are not associated with as many course goals as other outcomes. A plan is currently being developed to address this for Outcome 2, experiments/analyze and interpret data, since subject matter related to this outcome is an important component of the environmental engineering thread. However, Outcome 9, life long learning, and Outcome 15, leadership, are instructional components with a more broad-based application across all discipline concentrations. These type outcomes and levels need to be evaluated at the curriculum level, independent of discipline specific tracts.

Conclusions

Development of sequenced course threads for specified areas of concentration within the civil and environmental engineering curriculum, and subsequent analysis of course goals using ASCE-BOK outcomes and Bloom's levels of competency constitute an effective framework and foundation for establishing a process of continuous improvement and curriculum assessment. Through these efforts a functional data structure describing the instructional progression of students within defined discipline tracts is founded upon the creation of meaningful linkages between educational subject matter, program outcomes, and competency levels. As faculty periodically review, regulate, and refine the course curriculum within this organizational framework of analysis, process documentation, appropriately reflective of continuous improvement, is readily produced in a succinct and efficient manner.

Use of this framework allows the extensive work invested by the department in assessment efforts to be more disciplined and systematically focused upon specific improvement needs, predicated on better organization of course goals and outcomes, with the tracking of results for this method demonstrating a better manner of department-wide aggregation of data reflective of a comprehensive approach to program and curriculum assessment. In the absence of a solid organizational structure, improvements have had the appearance of being identified and addressed randomly verses systematically. The underlying objective of these evaluation procedures and future expansion to address comprehensive curriculum assessment is to maintain a comprehensive, well-integrated, and up-to-date curriculum that prepares students for professional practice and/or graduate work. Furthermore, development and execution of these organizational approaches for curriculum analysis and course improvement are intended to create an engaging means for faculty to address program assessment requirements and to seamlessly create recorded evidence needed to support ABET documentation for self study report preparation and accreditation reviews.

Future Steps:

- Expansion of the environmental sequenced course thread analysis to include linkage of course goals and outcomes with detailed leaning objectives for each course. This will allow creation of a highly functional map of the students' experience at a level of detail that delineates practically every technical topic covered for all courses in the curriculum connecting to this thread.
- Development and adoption of uniform means for measuring and assessing ASCE-BOK outcomes with respect to individual course goals and detailed learning objectives in a manner that better quantifies and documents continuous improvement.
- Sequenced course realignment and/or redefinition of course offerings to create an ever improving flow of instructional learning and course materials as presented to, and experienced by, students matriculating through the environmental engineering tract.
- Creation of a course and outcome electronic database allowing program-level aggregation along all major discipline tracts (environmental, structural, site

development, geotechnical, and transportation) that provides an overall picture of the curriculum and facilitates rigorous analytically driven assessment methods needed to plot a pre-defined strategy for long-range continuous improvement.

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