Sequential Course Outcome Linkage: A New Look at the Structural Engineering Curriculum of a Civil Engineering Program

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Abstract – In Fall of 2004, the faculty of the Department of Civil and Environmental Engineering at The Citadel adopted an expanded set of fifteen program outcomes identified in the American Society of Civil Engineers Body of Knowledge and completed the 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 now been developed for each of the department's major discipline tracts (structural, environmental, site development, and transportation engineering). Through the process of developing sequenced course threads, a major objective was to identify the effectiveness of how course goals are linked within the undergraduate curriculum. This paper expands the work presented by Bower et al. [1] describing the impact of identifying threads for the environmental engineering tract by presenting both similar conclusions and some new findings that appear to be relevant only to the structural engineering tract. In addition, the process and corresponding tabulations used to quantify the analysis procedure for assessment documentation of the structural engineering tract are provided. This work sets the stage for a department wide analysis of cognitive development assessment along specific subject matter threads.

Keywords: ABET, assessment, course, goal, structural.

INTRODUCTION

The American Society of Civil Engineers (ASCE) has developed and adopted Policy Statement 465 entitled "Academic Prerequisites for Licensure and Professional Practice." This document proposes that at some unspecified time in the future civil engineering candidates for professional registration should be required to obtain a baccalaureate degree plus 30 additional hours of gradate work (B+M/30) prior to obtaining licensure [2]. In addition, ASCE has developed the first Body of Knowledge (BOK) that establishes for civil engineering programs what should be taught and learned, how it should be taught and learned, and who should teach and learn it [3]. Most recently, the National Council of Examiners for Engineering and Surveying (NCEES) voted to increase the amount of education needed for engineering licensure. Specifically, delegates voted to modify the NCEES Model Law language such that an "engineer intern with a bachelor's degree must have an additional 30 credits of acceptable upper-level undergraduate or graduate-level coursework from approved providers in order to be admitted to the Principles and Practice of Engineering (PE) examination." [4]

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Table 1 presents a list of all 15 program outcome criteria currently used at the Citadel and contained in the ASCE-BOK. Corresponding ABET criteria a through k are also listed for comparison. For the purposes of this paper, program outcome criteria will be referenced based on ASCE-BOK designations (1-15). In addition to program outcomes, The Citadel has adopted the ASCE BOK proposed 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 [5]:

- 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 (taken from [1])

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

Academic institutions have begun to address how the ASCE-BOK outcomes and assessment criteria can be integrated into the civil engineering curriculum. Rose-Hulman Institute of Technology [6], the United States Military Academy [7], and the University of Texas at San Antonio [8] have appeared to achieve success relating ASCE-BOK outcomes to courses. Based on input provided by universities attempting to meet the ASCE-BOK, the document has been modified continuously. Ressler [9] summarizes the document's evolution and provides insight on the associated draft ASCE Commentary not yet available to the public. Welch et al. [10] presents the success the United States Military Academy (USMA) has had implementing the ASCE-BOK. The USMA, like The Citadel, has tied outcomes 1 – 15 to course goals and measured these in accordance with Bloom's Taxonomy. Conley et al. [11] concludes that outcomes 1-15 can be met, to some degree, through individual participation in the ASCE Student Chapter. The assessment process used at by the Department of Civil and Environmental Engineering (CEE) at The Citadel is presented in detail by Bower et al. [1] and is not repeated here.

DEFINITION OF STRUCTURAL ENGINEERING AT THE CITADEL

The process of compiling and analyzing data outlined in Bower et al. [1], allows the Department of Civil & Environmental Engineering at The Citadel to identify what the educational background is of a structural engineer graduating from the Citadel. According to the Structural Engineers Association of Northern California (SEANC) [12]:

> "A structural engineer analyzes and designs the gravity support and lateral force resistance of buildings, bridges, and other structures.
>
> **A Structural Engineer** - This is the person whose responsibilities we are defining. Structural engineering is a specialty within Civil Engineering. Structural engineers create drawings and specifications, perform calculations, review the work of other engineers, write reports and evaluations, and observe construction sites. A Professional Engineer's license is required in order to practice structural engineering.
>
> **Analyzes and Designs** - These verbs describe the basic tasks of structural engineering, that is, relating numerical quantities of physical forces to physical configurations of force-resisting elements. Analysis is the process of determining forces in each element (such as a beam) when the configuration of elements is already defined. Design is the process of configuring elements to resist forces whose values are already known. Analysis and Design are complementary procedures in the overall process of designing new structures. After performing a preliminary design, the designer estimates the final configuration of elements of a structure, but only until an analysis is performed can the forces in those elements be known. After performing an analysis, the element forces are known, and the elements can be designed (their configuration can be chosen) more precisely. The process iterates between analysis and design until convergence is achieved.
>
> **Gravity Support and Lateral Force Resistance** - Structures are subject to vertical, or "Gravity" Loads and horizontal, or "Lateral" Forces. Gravity loads include "dead," or permanent, load, which is the weight of the structure, including its walls, floor finishes, and mechanical systems, and "live," or temporary load, which is the weight of a structure's contents and occupants, including the weight of snow. Lateral forces include those generated by the wind, earthquakes, or explosions. Structural elements must be designed so that, as a system, the structure can resist all loads and forces to which it's subjected.
>
> **Buildings, Bridges, and Other Structures** - Structures are any system that resists vertical or horizontal loads. Structures include large items such as skyscrapers, bridges, and dams, as well as small items such as bookshelves, chairs, and windows. Most everyday "structures" are "designed" by testing, or trial-and-error, while large, unique, or expensive structures that are not easily tested are generally designed by a qualified structural engineer using mathematical calculations. Most practicing structural engineers design and analyze buildings, bridges, power plants, electrical towers, dams, and other large structures that are essential to life as we know it." [12]

Based on the SEANC definition and on individual course objectives related to structural engineering in the curriculum, structural engineering at the Citadel is defined as follows:

Structural engineering at the Citadel is the application of scientific and engineering principles to assess, analyze, and design sustainable structural systems for both serviceability and life safety.

Structural engineering at the Citadel encompasses a range of introductory, fundamental, and design topics:

- Introduction to Structural Engineering Systems
- Introduction to Load Paths
- Introduction to Structural Materials

- Introduction to Finite Element Analysis of Structural Systems
- Mechanics of Materials
- Structural Analysis
- Reinforced Concrete Design
- Steel Design
- Structural Engineering Capstone Design with Multidisciplinary Teams

With this broad definition of structural engineering at the Citadel, the authors have established a generalized context for presenting, discussing and improving the sequenced course thread.

SEQUENCED COURSE THREAD FOR STRUCTURAL ENGINEERING

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 show 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 structural engineering thread. It illustrates, in order, each course that contains an objective related to structural engineering, the number of course goals related to structural engineering, and the BOK program outcomes to which these goals are mapped by the instructors. Table 2 is 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 structural engineering. This provides an easy way to visualize how well course goals are distributed through a particular discipline tract. Program outcomes and levels of competency for courses in the structural course thread are shown in Figure 1. For example, it may be seen in Figure 1 that there are course goals for Civl 423 that address ASCE-BOK Outcome 2 at the Application 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 shown in Figure 2.

Table 2. Sequence Course Thread – Courses within Curriculum Containing Structural Engineering Related Course Goals.

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	4	5,7,11
Soph. 1st	Civl 209	Computer Applications for CEE	6	1,5,7,11
Soph. 2nd	Civl 202	Statics	6	1,5
Jr. 1st	Civl 301	Dynamics	1	1,5
	Civl 304	Mechanics of Materials	9	1,5
	Civl 307	Mechanics of Materials Laboratory	7	1,2,5,7,11
	Civl 314	Engineering Administration	5	1,5,6
	Civl 330	Measurements, Analysis & Modeling	1	1
Jr. 2nd	Civl 327	Asphalt and Concrete Laboratory	1	1,3
	Civl 302	Highway Engineering	1	8,10
	Civl 315	Fluid Mechanics	1	1,5
	Civl 309	Structural Analysis	9	1,5
Sr. 1st	Civl 404	Reinforced Concrete Design	9	1,3,5,10,11,12
Sr. 2nd	Civl 410	Foundation Design	4	1,3,5,11
	Civl 406	Steel Design	9	1,3,5,10,11,12
	Civl 423	Structural Engineering Capstone	9	1,3,4,5,6,7,9,10, 11,12,13
Optional	Civl 450	Civil & Environmental Eng. Internship	3	7,14,15

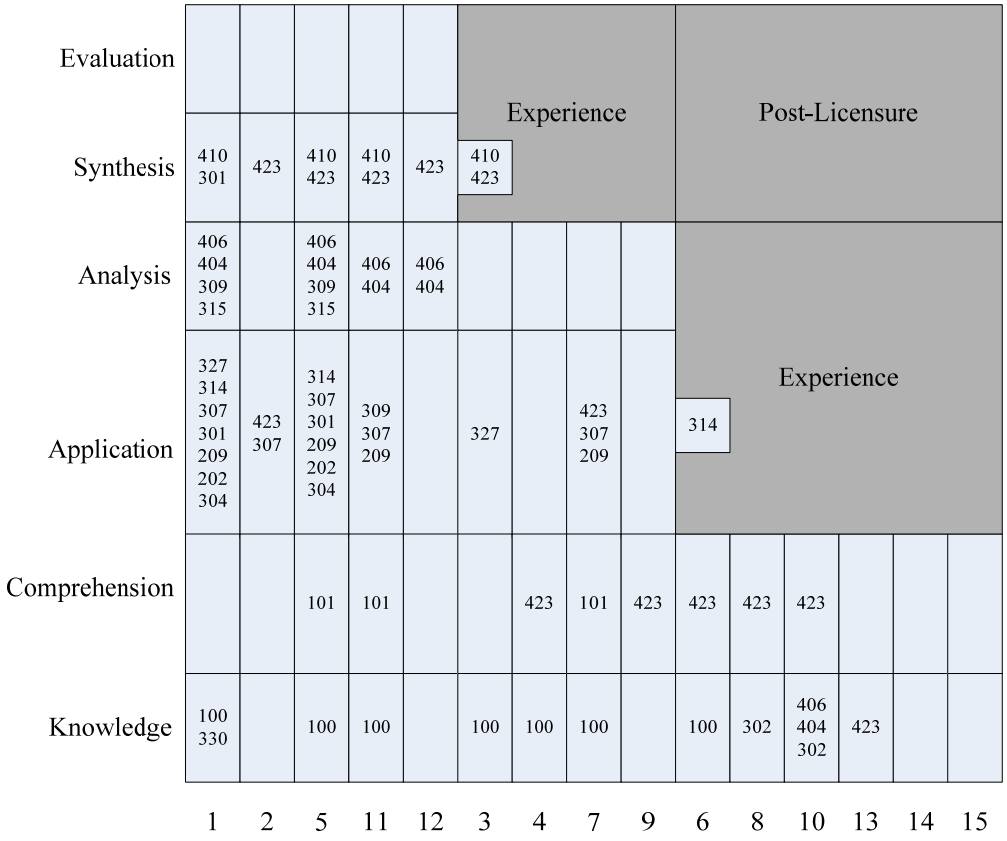

Figure 1. ASCE-BOK Outcomes versus Bloom's Levels of Competency for Courses in the Structural Engineering Sequenced Thread.

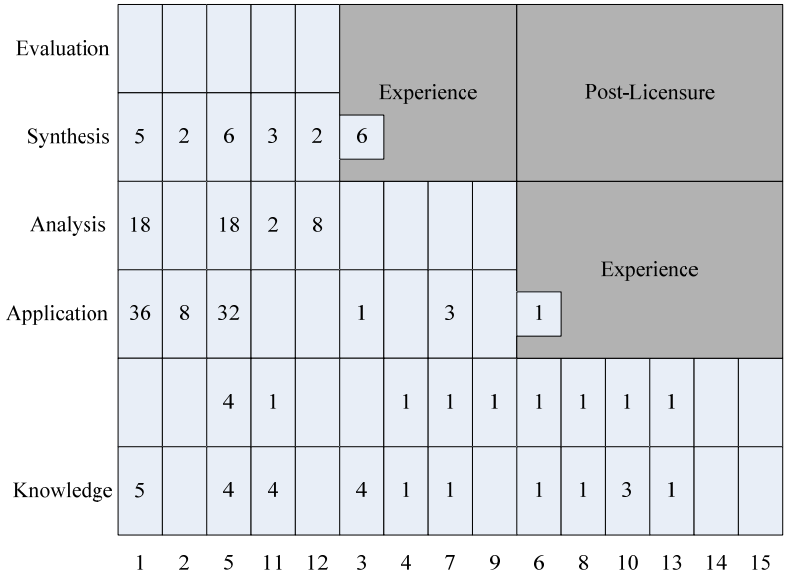

Figure 2. ASCE-BOK Outcomes versus Bloom's Levels of Competency for the number of course goals in the Structural Engineering Sequenced Thread.

The organization of Table 2, Figure 1, and Figure 2 was developed to establish a functional data structure that collectively describes the instructional progression of students within the defined discipline tract of structural 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 1, and Figure 2, analysis and evaluation of this information is presented collectively. From a review of these tabulations, a number of useful observations regarding the structural engineering curriculum were noted and similar to those made by Bower et al. [1] for the Citadel's environmental engineering discipline:

- Of the 31 courses offered within the departmental curriculum, 18 courses contain elements of structural 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 highway engineering, Civl 302, which contains only one course goal related to structural engineering, while in fundamental courses such as Structural Analysis, Civl 309, all nine course goals contribute to the instructional thread of this area of concentration.

- In total, students are exposed to 89 individual course goals contained in the sequenced course thread for structural engineering, as delineated in Table 2. Of additional interest is the observation that the structural 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 1, 13 of the 15 ASCE-BOK outcomes are being addressed through courses linked within the structural engineering thread.

- As depicted in Figure 1, 100 and 300 level (introduction type) courses taken during the freshman and junior years appear towards the lower range of the Bloom's taxonomy scale, which is consistent with a sound educational process.

- Figures 1 and 2 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 structural 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 1 and 2 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 two 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 structural engineering tract, which are primarily taken by students during their junior year. As shown in Figures 1 and 2, 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.

- Course goals associated with several courses are shown in areas of the matrix where it is indicated that graduate engineers would acquire exposure to these levels of outcomes during their pre-licensure work experience. As shown in Figures 1 and 2, this occurs for ASCE-BOK Outcome 3, Design, at Bloom's level 5, Synthesis, with course goals from Civl 423, Civl 410, and Civl 301.

- Based on an evaluation of Figure 1, it becomes evident that course goals within the structural engineering thread for ASCE-BOK outcomes 2, 9, 14, and 15 are not associated with as many course goals as the 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 structural engineering thread. However, the other outcomes 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.

- No overlap between environmental engineering and structural engineering currently exists at the course goal level. However, tanks are sized and designed based on information provided by multidisciplinary teams working together in these areas. An overlapping course goal at the knowledge level can be recommended.

CONCLUSIONS

The Citadel's Department of Civil & Environmental Engineering is in the process of completing discipline thread analysis for all disciplines of civil engineering. Similar conclusions have been reached for each discipline. The final step will be to adopt a uniform means for of 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.

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