

**AC 2009-2286: A METHODOLOGY FOR CURRICULUM MODIFICATION  
APPLIED TO CIVIL ENGINEERING MECHANICS**

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# **A Methodology for Curriculum Modification Applied to Civil Engineering Mechanics**

## **Abstract**

Engineering curricula have traditionally had difficulty keeping pace with the rapid changes that take place in industry. Over the last twenty years, engineering curricula have changed little, especially with regards to core fundamental courses. While many concepts that comprise traditional courses must remain the same, the supplemental topics can evolve and the presentation of the material must be updated to address the ever-changing environment the undergraduate student encounters. The Villanova University Department of Civil and Environmental Engineering, as part of their continuous improvement program, has undertaken the task to rethink its mechanics curriculum. Instead of looking at individual courses as a whole, a methodology that evaluates the individual topics within a curriculum was used and is described herein.

Essentially a Body of Knowledge (BOK) is developed that is targeted towards rethinking a curriculum at the course, discipline, and department levels. The methodology's premise is built around a prioritized list of topics (each linked to an associated student learning outcome) that are utilized in upper level courses or in the practice of civil engineering. The steps involved in developing a BOK are: 1. Development of an all inclusive topic list containing topics traditionally taught as well as those that have been considered supplemental, 2. Development of a mechanism for all faculty to provide input on each topic, 3. Synthesis and evaluation of the data collected, 4. Creation of the prioritized topic list to be included in the curriculum, 5. Parsing of the BOK into logistical modules, and 6. Development of course format, sequence, and content to best fit the BOK. An example of the BOK methodology applied to a mechanics sequence within a civil engineering curriculum is presented. This methodology aided in converting six separate courses and labs into a cohesive three course mechanics sequence.

## **Introduction**

Today's engineering colleges are faced with an increasing quantity of information that is available and demanded by students and industry as necessary for completion of an undergraduate degree. At the same time engineering programs are tasked to increase the depth and breadth of what is presented in a curriculum, there is pressure to reduce the number of credit hours with which this task is completed. Additionally, the demographic now desires information to be interactive and use multimedia. In response, trends show engineering programs overhauling their curriculums to be more innovative, integrated and inclusive of "real world" examples<sup>1-3</sup>. Universities are taking varied approaches in combining courses and presenting material in new formats; the Department of Civil and Environmental Engineering at Villanova University (CEEVU) is no different.

In 2007, the CEEVU began to look at the mechanics courses as the start of the curriculum restructuring. Mechanics is at the root of a civil engineering curriculum. Within mechanics courses, fundamental concepts are introduced and students learn to solve problems. The tools

developed in these courses are used continually throughout the curriculum. The need to most efficiently and effectively present mechanics to civil engineering students drove the authors to develop a methodology to systematically evaluate the current curriculum and design a new curriculum based on the real needs of upper level courses and the students, as opposed to what is traditionally taught in this sequence of courses. In effect, the curriculum was evaluated by topic and learning outcome instead of by course. The topic evaluation created a Body of Knowledge (BOK) of engineering mechanics that every student should exhibit proficiency upon graduation. The methodology presented here allowed the authors to identify and prioritize the topics to be included in the new curriculum. The methodology is presented first for general curriculum evaluation and then the example of the CEEVU mechanics curriculum is presented.

## **Methodology**

There are six steps to develop a BOK for any curriculum and associated learning outcomes:

1. Development of an all inclusive topic list containing topics traditionally taught as well as those that have been considered supplemental,
2. Development of a mechanism for all stakeholders to provide input,
3. Synthesis and evaluation of the data collected,
4. Creation of the prioritized topic list to be included in the curriculum,
5. Parsing of the BOK into logistical modules,
6. Development of course format, sequence, and content to best fit the BOK.

### *Step 1*

Depending on the scope of the curriculum restructuring, all courses within the scope should be broken down into their simplest topics. For examples, in a textbook, a chapter is broken into subsections that present one concept; this one concept is considered a topic. As courses have evolved over time, not all topics within a subject area may be presently included within the course. The topic list should include all topics presently included, not included and considered supplemental. An extensive topic list can be developed using current and old syllabi and textbooks. Additionally, if appropriate, the topic list can include learning outcomes. Every topic has one or more associated student learning outcomes based on Bloom's taxonomy<sup>6</sup>. The outcomes better define the level that a topic is addressed by the instructor and student, which is used in later steps for prioritizing the topic list.

### *Step 2*

Generally, the entire faculty is not involved in the detailed work of developing a curriculum, however their input as a stakeholder is necessary. A survey of the topic list to each faculty member allows each person to have input on which topics are considered fundamental or supplemental. In effect, this survey is the first step in prioritizing and grouping all the topics. The survey can be effective with two questions, although it should be altered for the specific curriculum restructuring:

1. Do you use this topic in subsequent courses in your discipline?  
0 = Never      1 = Used sparingly      2 = Very often

2. Do you think this topic should be part of the curriculum for every Bachelor of Science in Civil Engineering (BSCE) graduate?  
 0 = No      1 = Yes

The questions can be structured to integrate outcomes and the perceived intellectual level, which may be particularly useful when assessing advanced courses. The survey is distributed to each faculty member with the topic list; this question is asked of each topic on the topic list. Question #1 has a narrow focus and refers to the disciplines within a BSCE program (e.g. environmental, geotechnical, structural, transportation and water resources). Each discipline should be represented by at least two faculty members (if possible). Question #2 is broader. A topic may not relate to an upper level course, but could be critical for every civil engineer (e.g. a topic critical to professional practice, graduate courses or a topic that is not directly related to the disciplines covered in depth within a program).

The authors made and distributed the topic list and survey in Microsoft Excel for easy synthesis of data for Step 3 (Figure 1).

**Instructions:**

Enter an acceptable response in each BLUE cell. When an acceptable response is provided, the cell will turn GREEN. When an improper response is provided, the cell will turn RED. When you are finished, please save this file and return it to \_\_\_\_\_ by email. (We will only accept responses electronically, not in written form!)

**Question 1**

Do you use this topic in subsequent (post-mechanics) courses in your discipline?

- 0 = No      1 = Used sparingly      2 = Used often (i.e. this topic is essential for my discipline)

**Question 2**

Do you think this topic should be part of the undergraduate curriculum for every BSCE graduate?

- 0 = No      1 = Yes

		My Discipline (Enter E, G, S, T, or W) ----->	
		W	
Topic	Outcome/Description	Question 1 (Enter 0, 1, or 2)	Question 2 (Enter 0 or 1)
Units of Measurement	Identify base units in English and SI systems; Convert quantities between two units	2	1
Significant Figures	Express answer to correct number of significant figures		
Vector Addition/Vector Resultants	Apply triangle rule to find vector resultant; Resolve a vector into components; Determine the resultant of two or more vectors by addition of components		

Figure 1: Part of survey and topic list in Microsoft Excel

*Step 3*

The survey results are synthesized by scoring each topic. For example, if there are five disciplines, then each discipline gives a score for a topic (average of the faculty members within each discipline score of zero, one or two for the first question) and there is one score for the second question for each topic (average of all faculty). The scores are used as one mechanism to prioritize the topics in the topic list.

In addition to the score each topic received, the authors used objective and subjective analysis to place each topic into one of three categories a) critical to the BSCE program, b) less critical to

the BSCE program (e.g. useful to a single discipline), and c) low priority. An example is given in the “Application” section of this paper.

#### *Step 4*

Once the survey results have been synthesized and analyzed, the topic list is prioritized with topics that must be included in the curriculum, placed in upper level or other courses outside the scope of the portion of the curriculum that is being restructured, or eliminated from the curriculum. An example is given in the “Application” section of this paper.

#### *Step 5*

The prioritized topic list for the curriculum needs to be grouped so topics that logically relate to each other are together in a module. Special care should be taken in this step to think of the topics themselves, how they relate to other topics, and how they relate to examples. Traditional groupings of topics may become the logical module, but other modules may contain topics that have not traditionally been taught together. These non-traditional modules may help innovation, creativity and linkages across topics and disciplines within civil engineering<sup>7,8</sup>. The modules may also lead to a more efficient curriculum by eliminating unnecessary redundancies.

The authors made an index card for each topic, which included the topic name, associated learning outcomes, traditional course area, and scores (Figure 2). The cards were then treated like trading cards when developing the modules. It was easy to move a topic from one module to the next to see where it fit best.

#### *Step 6*

The modules developed in Step 5 are the ideal way to group topics together. This step addresses how to bring different modules together to fit into the overall semester course structure. The course format is determined; lecture, laboratory, or a combination. The sequence of modules within a semester and from semester to semester must be determined. This step should question whether or not the module content best represents the BOK.

As this step is the most practical part of the methodology to develop a curriculum, many questions about the details of teaching a course like this arise. Some of the modules may not be in accord with the traditional way the topics within the module have been taught. Thus, there are questions about which examples to use, which textbooks or supplemental material should be used, and which professor(s) will teach the modules. Questions may also arise when combining topics in a module that have been taught individually either in a lecture or laboratory setting. This step requires time, patience and communication with those responsible for teaching the material and making the semester schedule.

S-32					
<b>Moments of Inertia of a Composite Area</b>					
Determine moments of inertia of a composite area using standard equations and the Parallel Axis Theorem					
<b>E</b>	<b>G</b>	<b>S</b>	<b>T</b>	<b>W</b>	<b>BSCE</b>
<b>0.00</b>	<b>1.00</b>	<b>2.00</b>	<b>0.50</b>	<b>0.75</b>	<b>1.00</b>
0-0	2-0	2-2-2-2	1-0	0-1-1-1	
Current Lecture Time: 100					
Current Lab Time: 0					
Ver. 2		1/27/09			

Figure 2: Topic card. The topic S-32 refers to this is the 32<sup>nd</sup> topic in the Statics curriculum. The score for each discipline (E - Environmental, G - Geotechnical, S - Structures, T - Transportation, W – Water Resources) for question 1 is given (line under discipline) with individual votes (third line). The BSCE cell is the score for question 2. The colors are conditional based on the scores and are used to facilitate discussion.

### Application

An example of the methodology applied to restructuring the curriculum of the CEEVU mechanics classes will be detailed here. The classic mechanics courses that are included in the scope of restructuring are statics, dynamics, mechanics of solids, materials, fluid mechanics and fluid mechanics laboratory. Statics, dynamics, mechanics of solids and fluid mechanics are currently taught in a lecture style. Fluid mechanics laboratory is taught in a laboratory style. Materials is taught in a combination of lecture and laboratory. These six classes are fundamental to the BSCE program at Villanova University. Several topics are taught in more than one of the classic mechanics courses. These topics, however, were associated exclusively with applications related to one specific discipline within civil engineering, as opposed to demonstrating how the topic could be applied to several areas of civil engineering. Thus, the methodology presented here was used to evaluate the topics and streamline the manner in which these topics are taught. The authors, who applied the methodology, represented the different discipline areas in the CEEVU program.

#### *Step 1*

The topic list included 191 topics in the six courses evaluated. Some of the topics in the list are currently taught (141), and the list was supplemented with topics addressed in the textbooks used, but not currently covered (50).

### *Step 2*

The CEEVU program has five disciplines (environmental – E, geotechnical – G, structural – S, transportation – T, and water resources – W). Fourteen faculty members were surveyed (E – 2, G – 2, S – 4, T – 2, and W – 4). The survey questions were (such as in Figure 1):

1. Do you use this topic in subsequent (post-mechanics) courses in your discipline?  
0 = Never      1 = Used sparingly      2 = Very often
2. Do you think this topic should be part of the curriculum for every BSCE graduate?  
0 = No              1 = Yes

More elaborate survey questions related to the intellectual level of the learning outcomes were deemed unnecessary because there was agreement among the faculty of the learning outcome levels based on the fundamental nature of the content of the mechanics courses.

### *Step 3*

The survey results, combined with the authors assessment placed 123 of the 191 topics in the “critical to the BSCE program” category, 30 topics in the “less critical to the BSCE program” category and 40 topics in the “low priority” category. The authors reviewed the data and used the scores as a guide, but each topic was discussed before placed in one of the three categories. Generally, a BSCE score less than 0.5 and no discipline critically relying on a topic categorized that topic as “low priority.” Topics critically important to multiple disciplines and with a BSCE score greater than 0.9 categorized that topic as “critical to the BSCE program.” Topics categorized as “critical to the BSCE program” were included in the BOK and topics categorized as “low priority” were eliminated from the BOK. Several topics fell into the “less critical to the BSCE program,” and there was extended discussion on each of these topics. The discussion of each topic tended to follow the following sequence of questioning:

- Was the topic important to one discipline area?
- a. If yes, should the topic be included in the mechanics sequence or taught in the upper level course?
  - b. If no, is the BSCE score high?
    - i. If yes, why is the BSCE score high?
    - ii. If no, this topic was placed in the “low priority” category

The question (b.i.), why is the BSCE score high, was the most subjective part of the decision to categorize each topic. Several points of discussion from this question were a) do the faculty perceive the topic as important, b) does industry perceive the topic as important, 3) is the topic perceived as important because it has always been traditionally taught, and 4) is it on the Fundamentals of Engineering Examination. The discussions on the topics that fell in the “to be further evaluated” pile took several days to conclude if the topic should be placed in the mechanics BOK or if it should be placed as a low priority or taught in a non-mechanics course. There were a few topics that the authors could not come to consensus on and the other faculty members were asked their opinion.

#### *Step 4*

Once the survey results were synthesized and analyzed, the topic list was ranked. While there were 123 topics on the mechanics BOK, some of the topics were given high priority, in that they are fundamental to other mechanics topics, as well as other courses within the CEEVU curriculum (e.g. units of measurement and significant figures). These high priority topics needed to be presented early in the new mechanics sequence. Most of the topics that were critical to one discipline were shifted to upper level courses outside the mechanics sequence, although a few were retained because they naturally fit into a module with other topics in the mechanics sequence.

#### *Step 5*

Module development took several days. The process the authors went through involved multiple steps. First, each author went through the BOK and developed what they thought were natural groupings. Then, the authors met and discussed the different groupings each author had developed. Modules were then arranged based on the groupings of each author, brainstorming ideas of pertinent example and real world problems. For example, moments of inertia is taught in statics, mechanics of solids and materials, but is combined into one module, held together by an overarching problem (Table 1). The overarching problem is determined by the course teachers; it should be a typical engineering problem that embodies several topics within the module. Once modules were established, other faculty members were asked their opinion on the modules, other examples and permutations of the modules. Once the individual modules were established, the authors then sorted the modules into logical courses, where each course contained several modules. Sorting the modules into courses considered how the modules interacted, how the topics within the modules interacted with non-mechanics courses that the students may be simultaneously taking and the time expected for each module to ensure that a practical amount of material was in each course.

#### *Step 6*

The outcome of using the mechanics BOK to develop modules into a course format was instead of six courses to cover the mechanics topics, a series of three courses was proposed:

1. Mechanics I: Fundamental Concepts – engineering calculations, equilibrium, stress, properties of steel, axial deformations, friction, distributed loads, centroids, moments of inertia, properties of wood, buckling of columns
2. Mechanics II: Material Behavior – properties of concrete, internal forces, shear and moment diagrams, bending stresses, shear stresses, beam deflection, Euler buckling, combined loadings, torsion
3. Mechanics III: Fluid Behavior – Newton’s laws, equations of motion, flow fields, conservation of mass and energy, Bernoulli equation, pipe losses, impulse and momentum, drag, pumps, similitude.

Figure 4 is an example of one course. Within the one course there are five modules. Two of the modules (classes 1-6 and classes 25, 27-30) are function modules introducing the course and some fundamental concepts common to all modules. The other three modules use a common problem encountered in engineering to serve as an overarching theme for the module. For



example, classes 7-24, 26 cover topics that are needed to solve a truss problem. The classes within this module are in lecture and laboratory format, so that students are provided with theory and then given the opportunity with a laboratory to observe how the theory works in practice.

Table 1: Example of a module, including the course the topic has traditionally been taught in, topic, and associated learning outcomes.

<b>Mechanics I: Module C</b>			
Overarching Problem: Design, analysis, and testing of a wood compression member.			
<b>Area</b>	<b>Topic ID</b>	<b>Topic</b>	<b>Outcome</b>
Statics	S-31	Moments of Inertia by Integration	Determine moments of inertia of an area by integration and use of the Parallel Axis Theorem (as necessary)
Statics	S-32	Moments of Inertia of a Composite Area	Determine moments of inertia of a composite area using standard equations and the Parallel Axis Theorem
Materials	M-26	Anisotropic Material Behavior	Define longitudinal and tangential directions of a fiber-reinforced material
Materials	M-27	Wood	Define anisotropic behavior specific for wood
Materials	M-28	Wood Testing	Define tension and compression parallel/perpendicular to grain, shear, and flexural testing; relations between various strengths
Mech Solids	MS-36	Buckling of Columns	Analyze/design compression members with pinned ends via the Euler buckling equation
Mech Solids	MS-37	Slenderness Ratio	Use the Euler buckling equation to develop plot of stress vs. slenderness ratio
Mech Solids	MS-38	End Effects	Use the modified Euler buckling equation to analyze compression members with free or fixed ends.

Currently, statics and dynamics are taught first semester sophomore year, mechanics of solids is second semester sophomore year, fluid mechanics and materials is first semester junior year, and fluid mechanics laboratory is second semester junior year. The new sequence has Mechanics I in the first semester sophomore year, Mechanics II is the second semester sophomore year and Mechanics III is the first semester junior year. Originally, the authors thought that Mechanics II and III would be taught in parallel, but it was ultimately determined to be taught serially because of external scheduling issues.

Another scheduling hurdle that needed to be overcome was that the courses are proposed as a combination of lecture and laboratory, for a total of six hours a week. Additionally, as the CEEVU is a smaller department, we need to be wise with our teaching resources. The proposed curriculum is planned to be team taught. This is not practical for a make-up class for students who are off sequence, as class size is very small in these sections. In our instance, it was decided that we would offer traditional trailer sections or accept similar courses from the mechanical

engineering department to replace the mechanics sequence. As we have only a few students per year in this position, we have the flexibility to answer this question on a case-by-case basis.

The authors believe that the new arrangement and presentation of mechanics topics will enhance students' understanding of the material. However, there is no textbook that follows this presentation. Thus, we have decided to use parts of traditional textbooks as we concluded it was imperative to have an external source for the student to use. We are also looking into working with a publisher to combine textbooks in digital format.

The authors have gone through the methodology to develop the three courses and the first offering of the course sequence will start fall 2009. To measure the effectiveness of the course, the authors use common quizzes as the main metric. Short quizzes on the key topics have been given to students in the traditional classes for the past two years. The quizzes have been graded systematically, identifying common errors and tallying how many students make each of the common errors. The same quizzes will be given in the new courses and the results of the quizzes before and after the new course has been introduced can be used to compare the effectiveness of the new course.

## **Conclusions**

The core civil engineering curricula, such as the mechanics courses, have not changed much in both concepts and delivery<sup>9</sup>. One possible reason for not changing mechanics curriculum in the past could be that the information is presented to faculty, as well as students, in ways that do not instill creativity (e.g. textbooks tend to be basically the same and have changed little over time). By using the methodology presented here, creativity in curriculum development can be achieved. The methodology gives a systematic way to evaluate a curriculum and break it down into small, movable pieces. With the small pieces, the topics of the BOK, clearly identified, a curriculum can be restructured without the limits imposed by the traditional textbook approach. This new curriculum can be tailored to meet the needs of the stakeholders. Additionally, by creating a BOK in this manner, the BOK can be modified to meet a specific goal, updated for future curricular changes and shared with other departments and universities.

# MECHANICS I: FUNDAMENTAL CONCEPTS

## FALL SEMESTER

1 10:30 - 11:20 2 11:30 - 12:20			1 10:30 - 11:20 2 11:30 - 12:20			1 11:30 - 2:15 2 2:30 - 5:15			1 10:30 - 11:20 2 11:30 - 12:20	
Monday		Tuesday	Wednesday		Thursday	Friday		Saturday	Sunday	
1 Lecture Course Introduction/ Significant Figures			2 Lecture Units/ Dimensional Analysis		3 Lecture Vector Components & Resultants (2-D)		4 Lecture Moment of a Force (Scalar Formulation)			
			5 Lecture Moment of a Couple (Scalar Formulation)		6 Lecture/Lab Design & Factor of Safety		7 Lecture 2-D Particle Equilibrium			
8 Lecture 2-D Particle Equilibrium			9 Lecture Rigid Body Supports & Free Body Diagrams		10 Lecture/Lab Rigid Body Equilibrium		11 Lecture Rigid Body Equilibrium / Static Determinacy			
12 Lecture Analysis of Trusses (Method of Joints)			13 Lecture Analysis of Trusses (Method of Sections)		14 Lecture/Lab Truss (Open-Web Steel Joist) Analysis & Testing		15 Lecture Normal and Shear Stress			
16 Lecture Simple Connections (Axial, Shear, and Bearing Stresses)			17 Lecture Strain		18 Exam		19 Lecture Stress-Strain Diagrams; Ductile vs. Brittle Materials			
20 Lecture Steel Types, Applications, Chemistry, Corrosion			21 Lecture Generalized Hooke's Law; Poisson's Ratio		22 Lab Steel Tension Testing		23 Lecture Axial Deformation			
24 Lecture Elastoplastic Behavior (Axial Deformation); Residual Stress			25 Lecture 2-D Vector Operations/Position Vector		26 Problem Overarching Problem Solution (Truss)		27 Lecture 2-D Particle Equilibrium (Space Truss Analysis)			
28 Lecture Statically Indeterminate Problems			29 Lecture Virtual Displacement Method; Indeterminate Problems (Force Method)		30 Lecture/Lab Statically Indeterminate Problems (Force Method)		31 Lecture Equivalent Force Systems (Coplanar Forces)			
32 Lecture Equivalent Force Systems (Parallel Forces)			33 Lecture Distributed Force Patterns		34 Exam		35 Lecture Hydrostatic Pressure; Hydrostatic Pressure on a Submerged Plane Surface			
36 Lecture Generalized Distributed Loading over an Area			37 Lecture Centroid/CQ by Integration		38 Lecture Centroid/CQ by Integration		39 Lecture Centroid/CQ of a Composite Area			
40 Lecture Centroid/CQ of a Composite Area			41 Lecture Particle Dynamics (Laws of Motion)		42 Lecture/Lab Dry Friction		43 Lecture Dry Friction - Rigid Body Problems			
44 Lecture Overarching Problem Solution (Retaining Wall)										
46 Lecture Moment of Inertia by Integration			46 Lecture Parallel Axis Theorem		47 Exam		48 Lecture Moment of Inertia of Composite Areas			
49 Lecture Moment of Inertia of Composite Areas			50 Lecture Wood/Anisotropic Material Behavior		51 Lab Buckling Demonstrations - Steel and Wood		52 Lecture Buckling of Columns			
53 Lecture Slenderness Ratio	54 Lecture End Effects		55 Problem Overarching Problem Solution (Wood Compression Member)		56 Lecture Review of Key Concepts					

Figure 4: Example of one new course with several modules. Each module is in a different color.

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