Teaching Engineering Mechanics in a Problem-Structured Environment

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Introduction

Newtonian mechanics forms the basis for virtually the entire civil engineering undergraduate curriculum. The core courses in mechanics have traditionally been taught as independent entities within a prescribed sequence. The Department of Civil & Environmental Engineering (CEE) at Villanova University is developing a trio of four-credit courses that will present engineering mechanics as a continuum of concepts rather than a series of discrete courses. The key concepts covered in the traditional courses will be retained, but the concepts will be rearranged in a more meaningful manner by grouping them to enable the students to solve common civil engineering problems. One of the major objectives of the integrated courses is to make courses problem-oriented. Concepts from different areas of mechanics will be integrated together into thematic groupings that can be related to "over-arching" problems. The problems help the students visualize how the principles fit together to enable engineers to solve the problem, and serve as a framework to introduce students to engineering mechanics.

In traditional mechanics courses students solve numerous independent problems that tend to highlight a single concept. The integrated courses will illustrate to the student how the concepts complement one another to provide a comprehensive solution. The students will view engineering mechanics as a versatile modeling tool rather than a series of isolated principles. The paper summarizes some of the work to date including learning objectives, assessment protocols and course development.

Background

The BSCE program at Villanova emphasizes five disciplines within civil engineering: environmental, geotechnical, structural, transportation and water resources engineering. All five disciplines rely on engineering mechanics to varying degrees. The core sequence in engineering mechanics consists of six courses as summarized in Table 1.

Table 1 – Current Core Sequence in Engineering Mechanics at Villanova University

Course Number	Course Title	Semester	Format [credits; sessions per week]
PHY 2400	Physics I – Mechanics	Freshman Spring	3 cr. 3 50-minute lecture periods
CEE 2104	Mechanics–Statics & Dynamics	Sophomore Fall	4 cr. 4 50-minute lecture periods
CEE 2103	Mechanics of Solids	Sophomore Spring	3 cr. 3 50-minute lecture periods
CEE 3500	Fluid Mechanics	Junior Fall	3 cr. 3 50-minute lecture periods
CEE 3902	Civil Engineering Materials	Junior Fall	2 cr. 1 50-minute lect. & 1 2-hr lab
CEE 3911	Fluid Mechanics Laboratory	Junior Spring	1 cr. 1 3-hr lab

The current sequence begins in the spring semester of the freshman year and extends to the spring of the junior year. Villanova has a common freshman year that includes PHY 2400 Physics I Mechanics for all engineering students. The remaining five courses are administered by the CEE Department and, with one exception, are taken solely by civil engineering students. The exception, CEE 2103, is also taken by mechanical engineering students.

The five CEE courses are typical of most civil programs and they provide the portal for subsequent courses in structural mechanics, soil mechanics and hydraulics. These core courses have traditionally been taught as independent entities within a prescribed sequence. CEE 2104 is a prerequisite for CEE 2103 and 3500 while CEE 2103 is a prerequisite for CEE 3902 and CEE 3500 is a prerequisite for CEE 3911.

All CEE courses are assessed and evaluated on a regular basis as part of the Department's accreditation process. Recent assessments indicated that educational learning outcomes are being met in the five mechanics courses. However, discussion about continuous curriculum improvement raised the question of whether the material presented in the core mechanics courses can be repackaged to better meet the educational needs of civil engineering students. During the spring 2007 semester the Department formed a committee consisting of the five authors to address this question. The committee is developing a trio of four-credit courses that present engineering mechanics as a continuum of concepts rather than a series of discrete courses. The key concepts covered in the current courses will be retained, but the concepts will be rearranged in a more meaningful manner by grouping them to enable the students to solve common civil engineering problems. Each course will focus on two or more "over-arching" problems. For example, one course will begin by investigating the design and performance of a truss. All the associated design issues are currently addressed as isolated problems in separate courses, but the new sequence would integrate these concepts into a single problem-structured unit within one of the four-credit courses. This approach is expected to better equip students with an ability to formulate, analyze, and solve integrated civil engineering problems, rather than the simplistic mechanics problems that deal with only a single topic.

The committee identified several steps in the development of the integrated mechanics sequence. The tasks included a mechanics survey of other institutions, a cataloging and prioritizing of mechanics topics, an assessment protocol for mechanics courses, the development of the specific courses and an implementation schedule. The first two tasks are essentially complete. The committee is currently addressing the other tasks.

Engineering Mechanics Survey

The committee's first task was to survey civil engineering programs to determine how other institutions present engineering mechanics. The committee examined 50 institutions via their web sites to develop a data base that included total credits in the curriculum and total credits devoted to engineering mechanics. The data on each mechanics topic (statics, dynamics, mechanics of solids, civil engineering materials and fluid mechanics) was further refined to show whether the courses were required or elective, the number of credits, number of lecture hours, number of laboratory hours, and whether or not the course was administered by the civil engineering department. The committee was particularly interested in curricula that combined courses or had other innovative features.

<u>Schools</u> As indicated earlier, 50 schools were included in the survey. Forty-five of the schools either (a) grant a BSCE or BCE degree or (b) grant a BSE degree and are ABET-accredited in civil engineering. The other five schools grant BSE or similar degrees with concentrations in civil engineering or related fields.

Survey Format The survey indicated that schools present mechanics in a variety of courses and formats that include topics in statics, dynamics, mechanics of solids, fluids mechanics, and materials. Many curricula have laboratory sessions or workshops associated with the courses. The committee attempted to standardize the data by computing the total number of 60-minute lecture hours and laboratory hours devoted to statics, dynamics, mechanics of solids, civil engineering materials and fluid mechanics. This standardization attempted to account for differences among programs with respect to quarter vs. semester schedules, length of semesters and hours per session. The committee used its judgment in partitioning the coverage in the case of combined courses or individual courses that included both lecture and laboratory components. Finally, the courses or topics are not considered "required" unless all civil engineering students, regardless of their track, must take them. The preliminary results of the survey are summarized below. The final results will be available in a future publication.[1]

Statics Virtually all the schools required statics as either an independent course or a major portion of a combined course, typically combined with dynamics or mechanics of solids. The course is usually given during the sophomore year. The total number of lecture hours ranged from 9 to 47 with an average value of 32 and 60% of the schools between 33 and 39 hours. The civil engineering department administered the course at approximately 30% of the schools.

Dynamics Seventy % of the schools required dynamics as either an independent course or a major portion of a combined course, typically combined with statics. The course is typically given during the sophomore year. The total number of lecture hours ranged from 12 to 53 with an average value of 34 and 55% of the schools between 33 and 39 hours. The civil engineering department administered the course at approximately 30% of the schools.

Mechanics of Solids Virtually all the schools required mechanics of solids as either an independent course or a major portion of a combined course, typically combined with statics. The course is usually given during the sophomore year. The total number of lecture hours ranged from 11 to 70 with an average value of 37 and 65% of the schools between 33 and 39 hours. The civil engineering department administered the course at approximately 50% of the schools.

Civil Engineering Materials The survey focused on courses that emphasized the properties and behavior of steel, concrete, wood, etc., as opposed to topics in materials science. Sixty-eight % of the schools required a civil engineering materials course, many of which were largely or solely laboratory-oriented. The civil engineering department administered the course at approximately 85% of the schools.

Fluid Mechanics Ninety-two % of the schools required fluid mechanics as either an independent course or a major portion of a combined course, typically combined with thermodynamics or hydraulics. The course is usually given during the junior year. The total number of lecture hours ranged from 12 to 70 with an average value of 34 and 65% of the schools between 33 and 39 hours. The civil engineering department administered the course in approximately 75% of the schools.

Conclusion from Survey The survey indicated that mechanics courses tend to be similar among schools, but there are some significant variations at some institutions. Some schools combine two mechanics areas into one course, but generally the individual mechanics courses are maintained as discrete entities as opposed to treating them a single continuum of concepts.

BOK, A Prioritized Catalog of Engineering Mechanics Topics

One of the committee's most challenging tasks in developing an integrated engineering mechanics sequence was to identify and prioritize the topics to be included in the new courses. The committee addressed this task by creating a “Body of Knowledge” or BOK of engineering mechanics that every student should know upon graduation. The details of this BOK will be presented in a future publication[2]; however, the process is summarized below.

The development of the BOK involved four steps: (1) Prepare an comprehensive inventory of topics relating to engineering mechanics, (2) Develop a mechanism that enables all members of the CEE faculty to assess the importance of each topic, (3) Synthesize and evaluate the data from the faculty, (4) Create a prioritized list of topics that should be included in the curriculum.

The committee began by listing all the topics in the five existing CEE mechanics courses as well as additional topics that are often included in statics, dynamics, mechanics of solids, civil engineering materials and fluid mechanics courses. The topics were actually defined by learning outcomes, e.g., “Calculate the twist angle in solid or hollow circular shafts subjected to tension” and included laboratory exercises, e.g., “Experimental determination of yield stress and modulus in steel sample” as well as laboratory demonstrations, e.g., “Compare laminar and turbulent boundary layers.” The final list included 190 entries. Topics such as shear and moment diagrams that appeared in multiple courses were only listed once.

The committee prepared a survey in the form of a Microsoft Excel Sheet that was sent to each faculty member in the CEE department. The survey listed all the topics and asked two questions:

Do you use this topic in subsequent (post-mechanics) courses in your discipline?
0 = Never 1 = Used sparingly 2 = Very Often

Do you think this topic should be part of the curriculum for every BSCE graduate?
0 = No 1 = Yes

The first question referred to the five disciplines within Villanova’s BSCE program: environmental, geotechnical, structural, transportation and water resources engineering. Each discipline was represented by at least two faculty members.

The first question was designed to identify the topics that were prerequisites for subsequent courses in the undergraduate curriculum. The second question had much broader implications. A topic may not relate to an upper-level course in Villanova’s BSCE program, but could still be a critical component in the BSCE program – a topic with which every civil engineering should be familiar. It could be a topic critical to professional practice, to graduate courses or perhaps a topic that is not directly related to one of the five disciplines.

The committee began the evaluation by preparing a score card for each topic. Each topic had six scores: the first question had five scores, one for each discipline, while the second question had a single score. The scores provided a convenient means to prioritize the 190 topics, but the committee did not rely solely on the numerical values. Each of the 190 topics was examined individually and placed in one of three categories: (a) Critical to the BSCE program, (b) Useful to a single discipline and (c) Low priority.

The “Critical to the BSCE program” category included approximately 120 topics which will be included in the integrated mechanics sequence. The “Useful to a single discipline” category included approximately 30 topics. These topics may, if time permits, be included in the integrated mechanics sequence. They could also become part of the upper-level course in the respective discipline.

Assessment Protocols

The five courses in the current engineering mechanics sequence have prominent roles in the Department's evaluation and assessment process with respect to ABET's General and Program Criteria. The assessment process for the courses includes student surveys, standardized multiple-choice tests, and student work. Student work should provide the clearest indication of the course's effectiveness, but the development of good tools for assessing student work has been elusive. The Department relies on rubrics to assess student work, but the faculty has concerns about the type and the number of problems to sample.

The integrated mechanics sequence will replace the five existing courses in the evaluation process. The committee believed that refining the assessment process is an integral part of improving the engineering mechanics courses. The time spent enhancing assessment tools for evaluation of student work can have significant impacts that extend far beyond the new mechanics courses, since evaluation of student work is a common assessment tool for many courses in the CEE curriculum.

In addition to accreditation concerns, there is a task-related concern with respect to the assessment go student work. Will the new mechanics sequence improve student learning? There is a time-critical need to assess the current mechanics courses using techniques that allow for baseline comparisons between the current and new formats. These comparisons will determine whether the desired improvements in student learning is occurring. There are two issues to be studied in such comparisons. The first is whether students are able to better solve basic mechanics problems. The second is whether students are better able to identify, break down, and solve more advanced problems that rely on several integrated mechanics principles. The first issue will require evaluation of student work while students are enrolled in these mechanics courses, while the second issue will require evaluation of students' abilities in upper-level courses.

The committee has addressed the first issue regarding the basic mechanics problems. It has identified 25 particularly critical learning outcomes which will be evaluated. Each of three new courses will have between 7 and 10 of these learning outcomes. The committee considered a number of assessment tools including a Concept Inventory and various types of proficiency tests. The committee decided to use standardized quizzes. The evaluation for each outcome will consist of an announced 10 to 15 minute quiz which will remain essentially the same year-to-year. All quizzes will be graded on the basis of 10 points and the class results will be summarized on a single sheet that includes the distribution of grades and a listing of the common mistakes. The faculty will try to be consistent in grading, particularly with respect to point deductions. The system is currently operational for the CEE 2104 and CEE 3500 courses and will be implemented in CEE 2103 during the spring 2008 semester. This evaluation process is designed to establish a data base for comparing the current mechanics courses to the new mechanics sequence and is far more extensive than the Department's accreditation protocols.

The second issue regarding the student's ability to solve problems that rely on several integrated mechanics principles will be addressed in a similar fashion at a later date.

Course Development

The committee is now in the process of developing the three courses. It has separated the 120 "Critical to the BSCE Program" topics into thematic groupings and identified "over-arching" problems that relate to the topics within each grouping. The three 4-credit courses will be given in successive semesters; however, the second course will not be a prerequisite for the third course. All three courses will meet four times per week. Three of the four sessions will consist of 50-minutes lectures while the fourth session will be listed as a 3-hour laboratory. In reality, the fourth session provides a measure of flexibility. Some weeks it will serve as an additional 50-minute lecture period or test period. Other weeks it will be used as a laboratory session where each half of the class has a 90-minute laboratory exercise or demonstration.

Tentative outlines for the three courses are presented below. The lists of topics are not comprehensive. They have been condensed to a few descriptive titles.

Mechanics I Structural Behavior (Fall, Sophomore Year)

Topics: engineering calculations, equilibrium, stress, properties of steel, axial deformations, friction, distributed loads, centroids, moments of inertia, properties of wood, buckling of columns

Over-Arching Problems: design of a truss, equilibrium of a retaining structure, bucking of a wood column

Mechanics II Material Behavior (Spring, Sophomore Year)

Topics: properties of concrete, internal forces, shear and moment diagrams, bending stresses, shear stresses, beam deflection, Euler buckling, combined loadings, torsion

Over-Arching Problems: design and performance of wood beams, strains in beams, cracking in beams, torsion in drill rods

Mechanics III Fluid Behavior (Fall, Junior Year)

Topics: Newton's laws, equations of motion, flow fields, conservation of mass and energy, Bernoulli equation, pipe losses, impulse and momentum, drag, pumps, similitude

Over-Arching problems: piping system, flow around a bridge pier, hydroelectric dam design, water treatment plant design

Project Status

The committee has essentially completed two of the major tasks including the Engineering Mechanics Survey and the BOK for Engineering Mechanics. Some of the Assessment Protocols have been established and implemented. The committee is currently working on course development and a number of related issues such as the selection of text books. The initial offerings of the three courses should occur during the 2009-2010 academic year.

Conclusion

The CEE Department at Villanova University is developing a trio of four-credit CEE courses that present engineering mechanics as a continuum of concepts rather than a series of discrete courses. The new courses will be taught in a problem-structured environment wherein topics in engineering mechanics will be clustered into thematic groups that focus on a single problem. The problems help the students visualize how specific principles fit together to enable engineers to solve the problem, and serve as a framework to introduce students to engineering mechanics.

Bibliography

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