Use of Structured Overarching Problems in Sophomore-Level Mechanics Courses

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In 2009, the Department of Civil and Environmental Engineering at Villanova University restructured its sophomore mechanics courses to present topics in a more integrated sequence. Courses in the classical areas of Statics, Mechanics of Solids, and Civil Engineering Materials were repackaged into a pair of four-credit mechanics courses which combine content from these areas. The first course (Mechanics I) integrates elements of Statics and Mechanics of Solids along with a few topics from Civil Engineering Materials. The second course (Mechanics II) integrates the remaining elements of Mechanics of Solids with the majority of Civil Engineering Materials.

A key pedagogical component in this curricular restructuring is the use of "overarching problems". The integrated content delivery allows for the full development of commonly encountered problems in civil engineering within mechanics courses at the sophomore year. For example, students are able to use the Statics concepts of equilibrium and truss analysis, along with the Mechanics of Solids concepts of stress, axial deformation, and factor of safety, and the Civil Engineering Materials concepts of steel material behavior, to analyze a decaying steel truss bridge in need of repair and retrofit. Other overarching problems from these courses include the analysis of a concrete gravity dam, the design of a water tower for a Third World country, analysis and material selection for a prestressed concrete highway bridge, the strengthening of wood I-beams using composite materials, and the 3-D analysis of a highway sign structure under combined loading.

This paper describes in detail how overarching problems are used in these courses, from their brief introduction at the beginning of lecture periods to the individual student solutions in a recitation-type period. Lessons learned from the first year of using overarching problems are presented. Pedagogical benefits associated with the use of overarching problems are discussed, and initial assessment results are described.

Introduction: curriculum restructuring

After two years of intense committee work, discussion, and course development, the Department of Civil and Environmental Engineering (CEE) at Villanova University began offering its required mechanics sequence in a new integrated format to sophomores beginning with the Fall 2009 semester. As shown in Table 1, the classical sequence of coursework in subjects of Statics, Dynamics, Mechanics of Solids, Fluid Mechanics, and Civil Engineering Materials was replaced with a series of three four credit courses. An overview of this curriculum restructuring process is provided by Glynn et al.[1] and Wadzuk et al.[2] As described by Wadzuk et al.[3], the departmental mechanics committee used a Body of Knowledge (BOK) approach to identify the key concepts to be included in the new courses. The committee then packaged cohesive concepts into the three new courses. Although the primary intent of the BOK approach was to identify and pair key concepts, the process actually resulted in a net one credit hour reduction as concepts that were historically taught but not used in future courses were identified and eliminated.

The resulting three courses are summarized in Table 2. Mechanics I essentially focuses on concepts of Statics and Mechanics of Solids with emphasis on axial loading. Basic material properties and linear elastic materials such as steels are introduced. Mechanics II consists of remaining concepts from Statics and Mechanics of Solids, and introduces more complex civil engineering materials such as concrete, composites, wood, and asphalt. Mechanics III consists of concepts from Fluid Mechanics, Fluids Mechanics Lab, and particle Dynamics.

Table 1. Villanova CEE old and new mechanics curriculum

Old Mechanics Curriculum			**New Mechanics Curriculum**		
Course	**Credit Hours**	**Semester in Curriculum**	**Course**	**Credit Hours**	**Semester in Curriculum**
Mechanics: Statics & Dynamics	4	Sophomore Fall	Mechanics I	4	Sophomore Fall
Mechanics of Solids	3	Sophomore Fall	Mechanics II	4	Sophomore Spring
Civil Engineering Materials	2	Junior Fall	Mechanics III	4	Junior Fall
Fluid Mechanics	3	Junior Fall			
Fluid Mechanics Lab	1	Junior Spring			

Table 2. Details of new mechanics curriculum (Mechanics I, II, and III)

Course	Course Title	Credit Hours	Semester in Curriculum	Description
CEE 2105	Mechanics I: Fundamental Behavior	4	Sophomore Fall	Forces & moments; equilibrium of particles and rigid bodies; analysis of trusses; stress & strain; axial deformations; distributed force patterns; centroids & moments of inertia; dry friction; column buckling.
CEE 2106	Mechanics II: Material Behavior	4	Sophomore Spring	Shear & moment diagrams; bending & shear stresses; beam deflections; torsion; stress & strain transformations; combined loadings; characteristics of civil engineering materials including Portland cement concrete, masonry, wood, composites, & asphalt; experimental testing using recognized standards.
CEE 3107	Mechanics III: Fluid Behavior	4	Junior Fall	Fluid properties; kinematics of particles & flow; conservation of mass, energy and momentum; fluid resistance, boundary layer theory, flow in conduits; lift and drag; turbomachines.

The three courses are taken sequentially beginning with the first semester (Fall) of the sophomore year. All three courses are team-taught by a pair of faculty members and utilize a four meeting per week format, in which there are three 50-minute periods (Monday, Wednesday, and Friday) used primarily for lectures. The fourth period is a 165-minute "flex" period that meets on Thursdays, and can be used for lectures, laboratory exercises, exams, or for overarching problem solution periods.

Aside from the integration of concepts described above and the use of overarching problems as described below, Mechanics I and II are taught in a fairly traditional manner. Most 50-minute lecture periods involve a set of PowerPoint lecture slides that run on average about 15 minutes, and then the instructor solves two or three example problems for the remainder of the period. Students are assigned simple homework problems that are similar to the in-class examples, and these problems are turned in by the students at the beginning of the next class. Simple demonstrations are used as appropriate to illustrate physical concepts. Quizzes are given weekly to gauge learning and reinforce the most important learning outcomes. Three computation-based examinations are given during the semester in addition to a comprehensive final exam.

Structure: overarching problems in Mechanics I and II

In most classical mechanics courses, students learn a series of basic calculations, such as solving for support reactions in a beam, determining a column buckling load, computing a factor of safety, or locating a centroid. Students are encouraged to master these concepts, but are often not provided the real context of the calculations that they are making. Instead, these basic concepts become more like simple discrete tools that are not interconnected. Students are often given basic homework problems from the back of a chapter in a typical textbook that involve these calculations. As a result, the student may master, for example, determining the moment of inertia of an area, but may not understand why they are making the computation.

The use of overarching problems is a specific structured implementation of Problem Based Learning. Simply defined, an *overarching problem* is a common design or analysis problem encountered in the discipline (in this case Civil Engineering) that involves numerous basic concepts brought together to compose a more complex problem. In this sense, it is a true engineering problem, much more complex than a problem that focuses on a single concept. The complexity of the overarching problem is made simpler for use in a classroom environment, but not in a way that eliminates the interconnectivity of the many steps that make up the problem. Instead, this interconnectivity is emphasized as a teaching tool to provide context for making these simpler calculations.

All three courses in the revised mechanics curriculum utilize overarching problems in some manner to facilitate instruction and learning. However, only the first two courses (Mechanics I and II) utilize the specific format outlined herein. As a result, the use of overarching problems discussed, relates only to experiences in these two sophomore-level courses. As of the writing of this paper, each of those courses has been offered once. The second offering of Mechanics I is currently ongoing.

Three overarching problems are utilized in each course (Mechanics I and II). These problems, and the mechanics concepts that they address, are presented in Table 3. Note that each problem addresses topics from more than one of the classic mechanics areas (Statics, Mechanics of Solids, etc.). A typical overarching problem incorporates concepts from about ten to twenty regular lecture periods.

Table 3. Description of overarching problems in Mechanics I and II

Course	Overarching Problem		Concepts Addressed
Mechanics I	I-1	Steel Truss Retrofit Analysis & Design	Rigid body equilibrium, truss analysis, steel material properties, elastic axial deformations, normal & shear stress, allowable stress, factor of safety, design of simple connections
	I-2	Gravity Wall (Dam) Analysis	Centroid/center of gravity, distributed loading, hydrostatic pressure, friction, rigid body equilibrium, impending motion analysis
	I-3	Design of a Water Tower for a Third World Country	Centroid, moment of inertia of an area, parallel axis theorem, Euler column buckling (including end effects), basic cost analysis and choice of alternatives
Mechanics II	II-1	Prestressed Concrete Bridge Design	Concrete material properties, concrete mix proportioning, shear and bending moment diagrams, flexural stresses, beam deflection, combined stresses (axial load + bending), centroid, moment of inertia, composite beams
	II-2	Strengthening of Wood I-Joists Using Composites	Centroid, moment of inertia, allowable stresses, flexural stresses, shear stress, shear flow, superposition, wood & composite material properties, composite beams, stress transformations, Mohr's circle
	II-3	Analysis of a 3-D Highway Sign Structure	Centroid, moment of inertia, 3-D rigid body equilibrium, flexural stresses, shear stress, torsional (shear) stress, biaxial bending, superposition, beam deflection, angle of twist

Implementation: use of overarching problems in the classroom

Overarching problems are used in the classroom in two primary ways. First, overarching problems are used in a PowerPoint slide at the beginning of most lectures, immediately after a title slide and a slide of the lecture's learning outcomes. The overarching problem is used to provide context for the lecture's topics and learning outcomes. The instructor spends no more than one or two minutes using the problem to tie back to previous lectures and set up the upcoming lecture. An example of an overarching problem slide used in this manner is presented in Fig. 1.

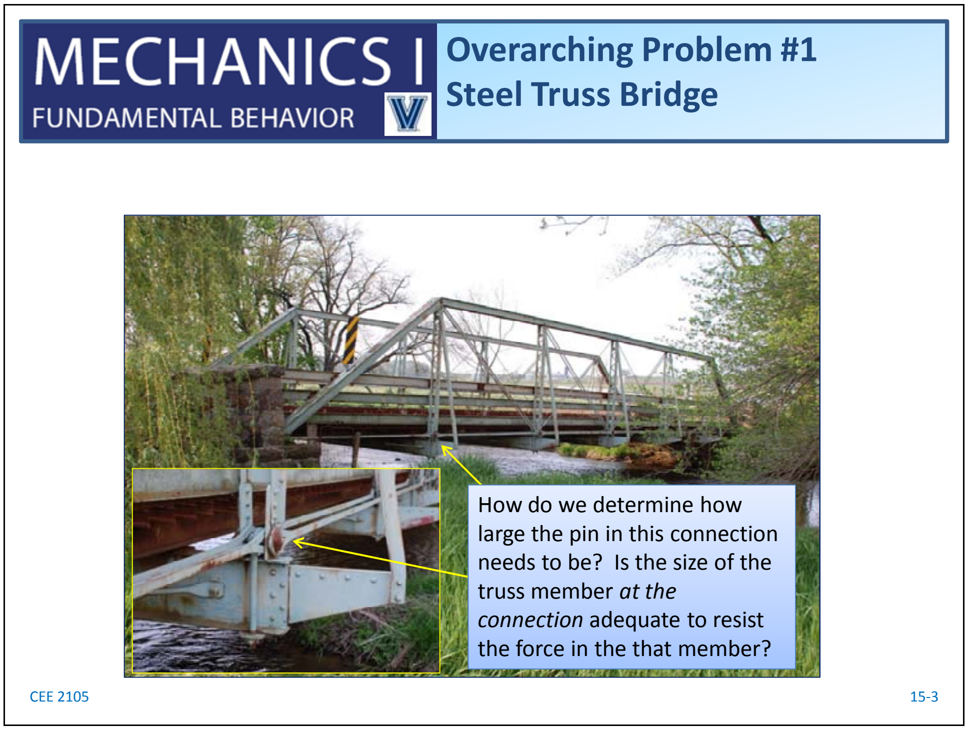

Figure 1. Example of slide used at the beginning of a lecture (Overarching Problem I-1)

After all primary concepts that make up an overarching problem are presented in a regular lecture format, a Thursday flex period class meeting is then used for the overarching problem solution. Students are first given a brief PowerPoint overview of the problem with pertinent background information. Recall that students have already been introduced to the problem at the beginning of several previous lectures, so these overviews are kept quite brief. Students then begin solving the overarching problem either individually or in pairs, in a recitation-type format.

The problem is broken down into a series of several "steps", and students solve one step at a time. To avoid confusion, each step of the overarching problem is printed on a different color sheet. Examples of overarching problem solution sheets are provided in Fig. 2. Students must solve the question presented in each step correctly, and get their answer checked by the instructors before they are given the next step of the overarching problem to solve. Students assemble the problem as they progress through the steps, often using the results from a previous step as the input for a future calculation.

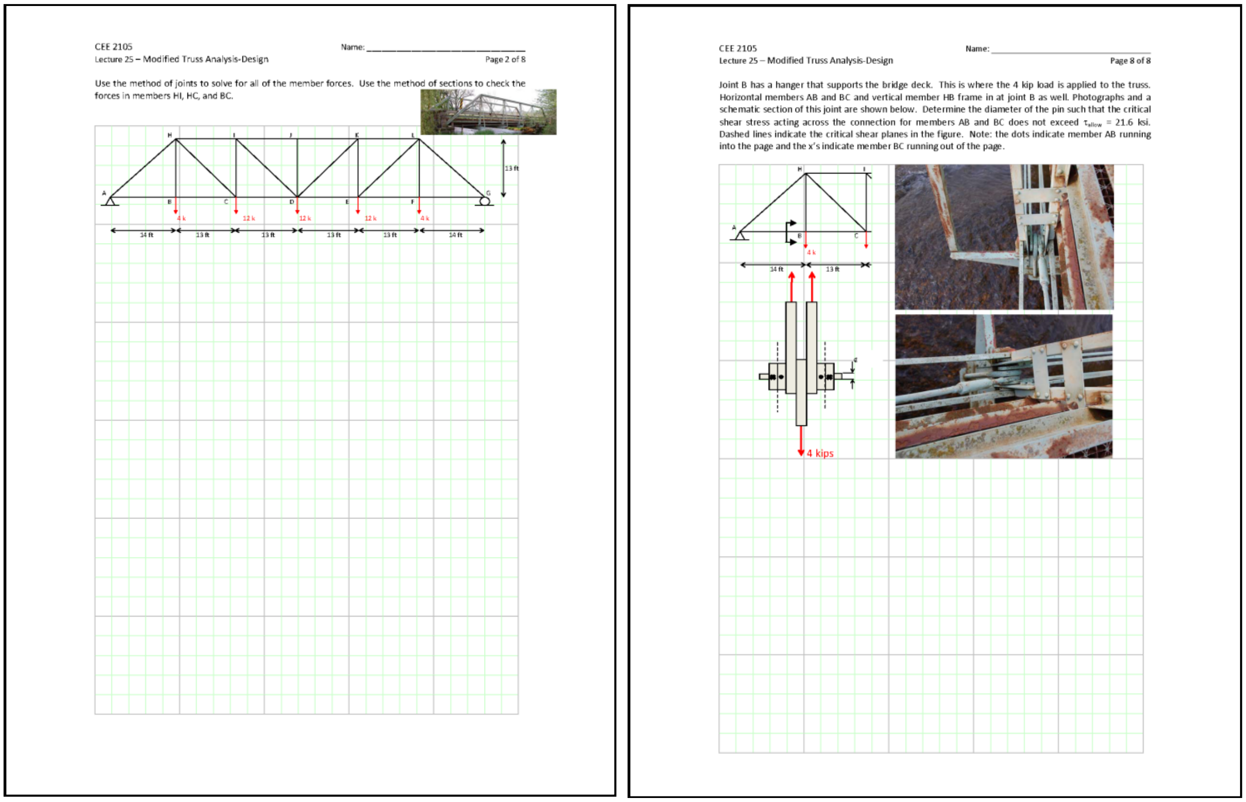

Figure 2. Example overarching problem solution sheets (from Overarching Problem I-1)

Each overarching problem period typically uses up most of the 165-minute class period and consists of about six to eight steps. During this time, both instructors circulate around the room answering students' questions and checking answers. The overarching problem is collected and students are given credit, and solutions are posted as with any typical smaller problem. A detailed list of steps in a single (typical) overarching problem is given in Table 4.

Table 4. Steps in solution of Overarching Problem I-1

Step	
1	Determine support reactions for truss
2	Determine forces in truss members using method of joints/method of sections
3	Determine material properties (elastic modulus, yield stress, ultimate stress) from given tension test data for sample taken from bridge member
4	Determine actual axial stresses in truss members and determine factor of safety against yielding
5	Determine elongations of all diagonal truss members
6	Determine normal (net section) and bearing stresses on diagonal truss member with eyebar type end connection and check against allowable stresses
7	Design (size) pin in connection at joint between main truss and deck hangers, given allowable shear stress in pin

Outcomes and initial assessment

Overarching problems in sophomore-level mechanics courses provide many advantageous pedagogical outcomes, including the following:

- Presenting "real" engineering problems early in the curriculum
- Providing context for the use of simple "tool-like" concepts
- Illustrating the interconnectivity of smaller calculations (output becomes input)
- Keeping students more interested and engaged in lectures
- Providing students an opportunity to reinforce their understanding of basic concepts (during overarching problem solution periods)

Informal feedback from students based on a single year was extremely positive. In order to obtain student feedback on the value of overarching problems, students were asked at the end of the semester to rate the value of several course instruments. As noted in Table 5, students gave overarching problems a high rating, indicating that they contributed significantly to students' own perceptions of their learning.

Table 5. Student ratings of course instruments in Mechanics I and II (2009-10 Academic Year)

Course Instrument	**Mean Rating**	
	Mechanics I Fall 2009	**Mechanics II Spring 2010**
Textbook	3.4	3.1
Lecture Notes	4.2	4.3
Example Problems Solved in Class	4.9	4.9
Homework Problems	4.7	4.5
Quizzes	4.3	4.0
Practice Exams	4.6	4.8
Exams	4.7	4.4
In-class Demonstrations	4.7	4.4
Having the Course Co-Taught by Multiple Faculty	4.6	3.7
Overarching Problems	4.6	4.0
Rating scale: 1 = No contribution … 5 = Significant contribution Sample size: 57 (Mechanics I), 45 (Mechanics II)		

It is interesting to note that overarching problems rated higher than some other instruments such as the textbook and lecture notes. Students' perception that example problems in class (other than overarching problems) contribute most significantly to their learning is likely due to the fact that most exam problems are similar to these examples. It is also noteworthy that the mean rating for overarching problems was significantly lower for Mechanics II than Mechanics I. A potential reason for these lower ratings is identified in the section of this paper entitled Challenges.

More comprehensive assessment plans based on evaluation of student work (especially in-class quizzes) and short student surveys given immediately after overarching problem solution periods are in the process of being developed.

Challenges

The use of overarching problems worked well in the first year of the restructured mechanics courses. The primary challenges are, as with any example problem, in developing the appropriate depth of examples to foster student learning without it becoming too laborious to solve in the class time provided. In general, the overarching problems in Mechanics I seemed to be of appropriate length and depth. Students appeared to leave these overarching problem sessions feeling confident and showing a sense of accomplishment. In two of the overarching problems in Mechanics II, however, some students ran out of time to solve the problem in class as the level of computation was higher given the more advanced concepts in the course. It is anticipated that these problems will be adjusted accordingly for the second offering of the course next year.

Summary

Overarching problems provide a structured opportunity for improved student learning in the Villanova University Department of Civil and Environmental Engineering's new sophomore-level mechanics curriculum. Problems are used to provide context for the basic computations and concepts that form the backbone of traditional sophomore-level mechanics courses, and to illustrate how these smaller calculations interrelate in a larger design or analysis problem. Initial feedback on the value of the overarching problems, based on the first year offering of the new courses, has been extremely positive.

Bibliography

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