Development of an Integrated Statics and Strength of Materials Curriculum with an Emphasis on Design

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Abstract

Traditionally, statics and strength of materials courses have been taught separately with the intent of emphasizing the mechanics of rigid bodies in statics and transitioning to the mechanics of deformable bodies in strength of materials. While this approach has proven to be effective in reinforcing students' understanding of basic principles in mechanics, it has been less than effective in providing students with an understanding of the relationship between the two subjects and their importance in designing structures. At the University of Maryland, the Mechanical and Civil Engineering departments are seamlessly integrating these two courses together, better preparing students to apply mechanics principles in the design of solutions to engineering problems. The new courses are centered around a simple, but well-developed, design project and efforts have been initiated to enhance the instruction with demonstration experiments and computer tools that will be delivered in new interactive, multimedia "Studios". Metrics for success concentrate on comparative evaluation of student performance in the traditional and integrated versions of the curriculum, as well as student feedback on the curriculum's satisfaction of ABET 2000 criteria.

Introduction

Engineering students are facing new challenges in the 21st century that may not be satisfied with existing undergraduate engineering curriculum [1-4]. These challenges require the development of improved skills in a variety of areas, such as engineering design, problem solving, life-long learning, and multidisciplinary teamwork. These skills have been identified in a new set of criteria developed by ABET, known as ABET Engineering Criteria 2000, which is currently being used as a guide for assessing engineering programs reaccreditation [5]. Although these criteria provide a framework for developing 21st century engineering curriculum, implementation of these criteria is being left to the discretion of individual engineering programs.

Five years ago, an effort was undertaken by the University of Maryland (UMD) to establish a philosophical framework for developing new engineering curriculum capable of meeting educational challenges for the 21st century [6]. As part of that effort, a proposal was made to integrate components of the curriculum. The first implementation of this proposal is the integration of statics and strength of materials with an emphasis on design.

While traditional instruction of statics and strength of materials has treated the development of the subjects as mutually exclusive, there appears to be no sound rationale for continued adoption of this approach. In fact, the only real difference between the two subjects is whether or not a body is treated as rigid or deformable. Such a distinction does not in anyway impair the student from understanding both subjects simultaneously. Rather, conventional curriculum has chosen to adopt an approach which appears to better illuminate the differences between the two subjects.

In educating engineers for the 21st century, it is becoming increasingly clear that the seamless integration of curriculum is more important than the delineation of differences in the subject matter. With this in mind, it has become evident that statics and strength of materials are probably two excellent candidates for integration in the undergraduate curriculum. The similarity in their subject matter and their consecutive scheduling in many undergraduate programs substantially reduces the effort involved in integrating them. Furthermore, by integrating the two subjects it becomes possible to add meaningful design projects into the curriculum.

Some textbook authors have attempted to integrate the courses by simply abridging and unifying separate textbooks on the subjects, while still maintaining their current chronological delivery. A prime example of this is Hibbeler's new *Statics and Strength of Materials* text, which is even alluded to in it's preface as being intended, "... for those students who do not need complete coverage of these subjects." [9] While such an approach to integration has some merit in facilitating delivery of the subject matter in the two courses to undergraduate students, it by no means enhances the students' understanding of engineering concepts and their relation to designing solutions to engineering problems. Such an enhancement requires simultaneous discussion of both subjects, as well as their applications to engineering design. Riley, Sturges and Morris have introduced a more integrated approach in *Statics and Mechanics of Materials: An Integrated Approach*, addressing design issues by concluding their chapters, "... with a section on Design Problems ..." [10].

In the new curriculum being developed at the University of Maryland, an approach to integrating statics and strength of materials has been proposed where the presentation of both subjects are centered around a design project. The purpose of this design project is to further develop the inchoate design skills students acquire in their freshman design course. To guide the students through this new approach, a textbook has been initially conceived around the design of bridge structures. Furthermore, computer tools and demonstration experiments are also being developed to enhance the students' physical understanding of mechanics principles, as well as providing them with the tools they will use during the design process. Finally, metrics are being developed to gauge the success of the new curriculum based on satisfaction of ABET 2000 (a) through (k) criteria.

Textbook for the Integration of Statics and Strength of Materials Curriculum

A new textbook entitled, *Design Analysis of Structural Elements,* has been developed which embodies a new educational philosophy for presenting the subject matter traditionally offered in introductory Mechanics courses. The changes in philosophy were based on five premises:

1. Present fundamental mechanics concepts in a more relevant manner.
2. Provide a smooth transition from the introduction to engineering design course to the introductory Mechanics course.

3. Emphasize modeling by stressing the importance of the free body diagram (FBD) throughout the text
4. Integrate the contents of Statics with that contained in Strength of Materials
5. Emphasize the design of structural components for safety.

In short, this educational philosophy espouses developing the principles of engineering mechanics by emphasizing its applications in designing structures. The first edition of the textbook focuses on the design of a bridge structure. Although a civil structure has initially been chosen for the design project, it is envisioned that in future versions, design problems specific to manufacturing, materials, nuclear, aerospace, and mechanical systems could be substituted. The flexibility in choosing the design problem reflects the diverse engineering interests of the students who are currently required to take these courses as part of their core curriculum.

The organization of chapters for the first edition of the book can be seen in Table I. While many of these topics can be found in existing statics and strength of materials texts, they can only appear in this order when the subjects are taught concurrently. In many of the chapters, concepts in both subjects are also presented concurrently. For example, in Chapter 2, the concepts of stress and tensors are introduced at the same time forces and vectors are discussed. Another example can be found in Chapter 5 where the one-dimensional deformation of bodies is introduced through a discussion of cables. Such seamless integration of material from the two courses allows students to better understand the whole of engineering mechanics through the interrelationship of these traditionally disjointed topics. The format differs substantially from the one adopted by Sturges *et al*, choosing to emphasis the introduction of Mechanics of Materials concepts through common structural elements, such as cables and bars, that are applicable to the design problem emphasized in the text.

Chapter	Title
1	Bridges
2	Basic Concepts in Mechanics
3	Forces and Moments
4	Equilibrium
5	Thread, String, Rope, Wire, and Cable
6	Rods and Bars
7	Material Properties
8	Trusses, Space Structures, and Vector Mechanics
9	Stresses in Beams
10	Friction

Table I. Table of contents for current edition of *Design Analysis of Structural Elements*

One chapter of special interest, and probably the most important chapter in the text, is the first one on bridges. It is through this chapter that the connection between engineering mechanics and design of structures is established for the student. The chapter begins with a brief discourse on the history of designing bridges, citing their evolution in terms of materials development and understanding of mechanical principles. This discourse is followed up with more details on the mechanical advantages of different types of bridges and the materials used in their construction, and concludes with the importance of using scale models for verifying design concepts that the students will develop in their project. Thus, chapter one provides students with the foundation they will need in studying mechanics principles as tools for the design process they will use in the remainder of the course.

Currently, the first edition of the book is being use in the first semester of the Mechanics curriculum, the time when Statics is traditionally taught. However, chapters will be included in the next edition of the book to replace the traditional second semester Strength of Materials course material. The tentative organization of these chapters is outlined in Table II. The proposed course material includes introductions to a topic not traditionally covered in the first two semesters of the Mechanics curriculum, the Finite Element Method. Also, concepts that are generally addressed in more detail during advanced Mechanics course, such as pressure vessels and failure criteria, can be given the attention necessary for students to fully understand and apply them in the design process. These chapters will also provide students with the knowledge necessary to analyze more complex design issues in their projects, such as reducing stress concentrations at joints.

Chapter	Title
11	Torsion
12	Pressure Vessels
13	Stress Equations of Transformation
14	Combined Loading
15	Beam Deflections
16	Failure of Columns
17	Stress Concentrations
18	Failure Criteria
19	Finite Element Method

Table II. Chapters to be added to future editions of *Design Analysis of Structural Elements*

Computer Tools and Demonstration Experiments

In the past, professors have been restricted to the use of chalk and chalkboards to illustrate mechanics principles to students. More industrious faculty members were motivated to design physical demonstrations to augment the crude chalkboard illustrations. While the use of these demonstrations has substantially improved the student's visualization of mechanics principles, the computer has become a far more important tool in the design process which enables students to not only visualize mechanics, but to also simulate the performance of mechanical designs. Consequently, a plethora of new computer software has become available for visualizing and solving mechanics problems. Some examples include*: Make Engineering Statics & Dynamics a Moving Experience* [11], *Statics & Dynamics Interactive Simulations using Working Model* [12], and *Visual Mechanics: Beams and Stress States* [13].

Computer software is not only used for visualizing mechanics principles, but is also employed as a tool for solving mechanical design problems. An excellent example of this is the use of Finite Element Analysis software for analyzing the stress states of structures. Once again, a variety of computer tools are available to the student for solving mechanics problems. In choosing appropriate computer tools for the integrated curriculum, it was decided to utilize tools the students have already been introduced to in their freshman design course. At the University of Maryland, the students are provided with a spreadsheet package, Excel, and a CAD tool, Pro/Engineer, that comes with a finite element package, Pro/Mechanica. In the integrated curriculum, students will be taught to utilize Excel to solve simple mechanics problems, while Pro/Engineer and Pro/Mechanica will be used on more complex ones. They can then employ these tools as they choose to perform initial analysis of their design concepts. Verification of the students design analysis will be provided by experimental measurements on their design models.

In the new integrated curriculum, the aforementioned computer software will be provided to instructors as a resource for their classroom presentations. In addition, simple demonstration experiments are also being designed to illustrate mechanics principles such as trusses, cables, and friction, as well as simple mathematical principles such as three-dimensional vector orientations. In order to deliver these resources, new interactive, multimedia "Studios" originally developed at Rensselaer Polytechnic Institute are being built that will replace the traditional lecture/recitation/lab format [14]. Studios are more cost effective than traditional formats, and provide an environment in which student performance and satisfaction are high. Not only will Studios be used for delivering the newly integrated curriculum, but it will also be utilized as instructional facilities by the freshman design course. The sharing of resources by multiple courses further extends the seamless integration of the undergraduate curriculum into the freshman year, while reducing cost and duplication of educational resources.

Computer tools, demonstration experiments, and Studios provide a basis for building an infrastructure to deliver the integrated curriculum. However, for the infrastructure to be complete, it is necessary that it be centrally organized and administered. The demands on an instructor’s time alone in learning to utilize this infrastructure may prevent consistency in the quality of delivering the new course content when new instructors are used. This dilemma will necessitate the acquisition of additional support for the infrastructure by designating a faculty coordinator for overseeing the administration of the course. The coordinator will also be assigned to organize a team of teaching assistants and teaching fellows to assist students in the application of the computer tools and in completing their design project. New instructors can then focus simply on delivering the textbook material and "canned" demonstration experiments. More instructors will also be employed to reduce class size and provide more individualized attention to students. This infrastructure has already been developed successfully for the freshman design course at the University of Maryland and should greatly enhance the delivery of the integrated curriculum.

Metrics for Evaluating Success of Integrated Curriculum

Many new ideas have been introduced for the integrated statics and strength of materials curriculum at the University of Maryland. However, the success of the new curriculum is not guaranteed. Therefore, metrics have been proposed to provide a quantitative and qualitative measure of success.

To measure success, one must first define it. In many cases, this definition can be found in the philosophy that departments adopt in educating their students. For example, the philosophy of UMD's Mechanical Engineering department is to graduate students "... with the skills and the knowledge base which are necessary for success in today's marketplace and with the education necessary to adapt and succeed in the future as technology continues to change." [15] This philosophy is consistent with ABET's Engineering Criteria 2000, another source for defining success. Consequently, one metric developed by the Mechanical Engineering department for the entire undergraduate curriculum is to provide a student evaluation form where the students would rate the relevance of each course to the (a) through (k) criteria on a scale from 1 to 5. Assessment of the curriculum by instructors is also obtained as a baseline for comparison.

The proposed metric was used for a pilot section taught with the new curriculum during the 1998 Fall semester, along with two sections using the old curriculum. Each section was taught by a different instructor, however instructors collaborated on exam, homework, and even some lecture preparation. In the case of the new curriculum, it was the opinion of the instructor that criteria (a) through (h), and (k) would be appropriate (Figure 1). The consensus for the old curriculum was it addressed only criteria (a), (c), and (e), while touching on criteria (d), (h), (i), and (k) (Figure 1). Student assessment of the (a) though (k) criteria for the new curriculum mimicked the instructor's expectation, and even exceeded those expectations for some of the criteria (Figure 2). Student confirmation of the instructor's assessment provides some validation for the integrated curriculum. However, comparing student assessments of the old and new curriculum indicated that the new curriculum was only clearly better in addressing criteria (c) and (d), which concern development of a student's design and teaming skills (Figure 3). Some of the similarities in the assessments could be attributed to the aforementioned collaboration, which resulted in students taking the old curriculum being exposed to demonstration experiments and some unique applications of mechanics principles, such as in the design of prosthetic devices, which were developed for the new curriculum.

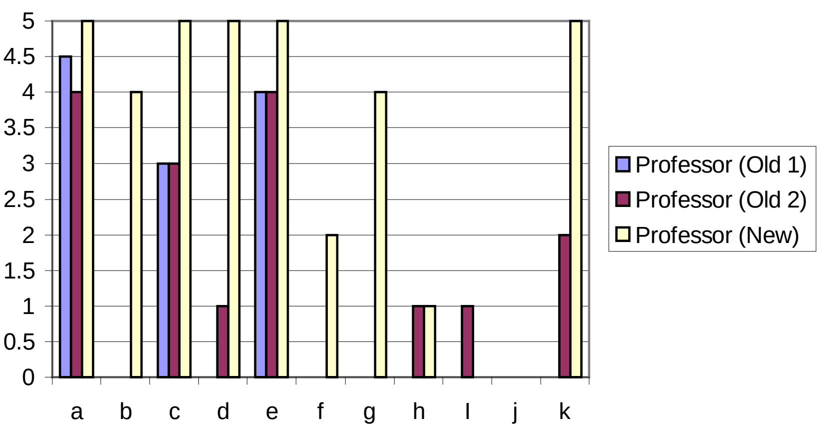

Figure 1. Comparison of evaluations by professors of the old and new curriculum using the ABET 2000 (a) through (k) criteria

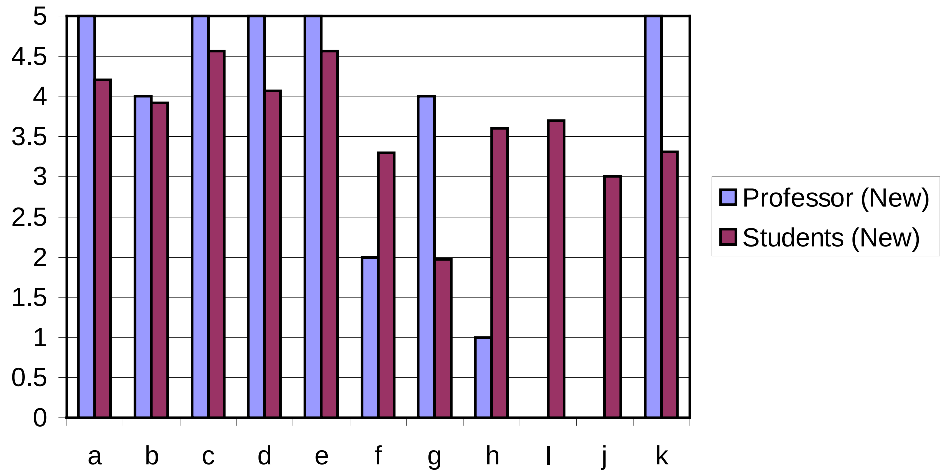

Figure 2. Comparison of professor's and students' evaluation of the new curriculum using ABET 2000 (a) through (k) criteria

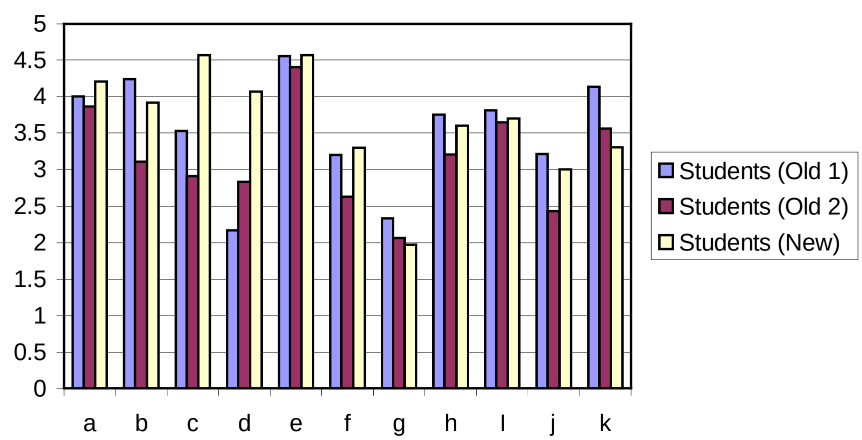

Figure 3. Comparison of evaluation by students of the old and new curriculum using ABET 2000 (a) through (k) criteria

Not only is the success of the integrated curriculum being gauged by qualitative student evaluations, but a more quantitative measure is also being developed. This measure will consist of comparing student performance on identical exams administered to students taking sections of the new and traditional curriculum during the same semester. This process eliminates many variables that may otherwise invalidate the metric's results. However, the variability in instructor efficacy is not accounted for. To eliminate this variable, the same set of instructors will deliver both versions of the curriculum over multiple semesters. This should result in a quantitative measure over a statistically relevant sampling of students. However, initial analysis of student performance on traditional Statics exams administered during the 1998 Fall semester indicates very little difference between the old and new curriculum or between the instructors (Figure 4), mimicking the previous results from student evaluations. Further delineation of the new curriculum's efficacy may be ascertained by including problems on the exams which address specific elements of the ABET 2000 criteria not covered by the old curriculum, such as criteria (c) concerning the design of a system, component, or process to meet desired needs.

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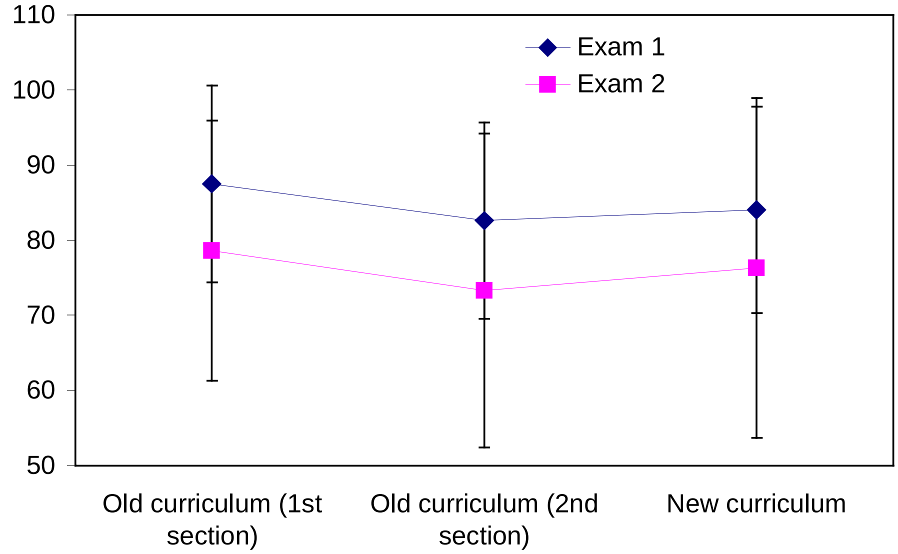

Figure 4. Comparison of student performance in sections of the old and new curriculum

Conclusions

Statics and strength of materials curriculum are being seamlessly integrated by the Departments of Mechanical and Civil Engineering at the University of Maryland. The new integrated curriculum is centered around a simple, but well-developed, design project and enhanced with demonstration experiments and computer tools delivered in new interactive, multimedia "Studios". Metrics for success concentrate on comparative evaluation of student performance in the traditional and integrated versions of the curriculum, as well as student feedback on the applicability of the curriculum to ABET 2000 criteria. Initial indications are that the new curriculum is more successful at addressing ABET 2000 criteria concerned with the student's development of design and teaming skills without adversely affecting the student's ability to solve traditional Statics exam problems.

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Curriculum development â€“ an introduction. The word curriculum derives from the Latin currere meaning â€˜to runâ€™. This implies that one of the functions of a curriculum is to provide a template or design which enables learning to take place.Â The emphasis on different aspects varies with the participantsâ€™ and teachersâ€™ perceived needs. The dynamic curriculum requires change and resource managementâ€. Needs assessment.Â should be designed with a variety of learning (and teaching) methods â€¢ Learners need to be treated as people and there should be opportunities. for them to make contributions which are valued by teachers â€¢ Effective learning is active â€“ people learn best when they are engaged in. Many curricula and instructional materials, however, are not designed to help students conditionalize their knowledge. For example, textbooks are more likely to tell students how to do something than to help them understand the conditions under which doing it will be useful (Simon, 1980, p. 92).Â The emphases of a curriculum for supporting learning with understanding are presented in Table 7-1. INSTRUCTION.Â To promote understanding, explicit instruction in metacognition should be integrated into the curriculum. Thus, instruction should create tasks and conditions under which student thinking can be revealed so that students, with their teachers, can review, assess, and reflect upon what they have learned and how. Curriculum develop-ers themselves must design a content scope and sequence for any interdisciplinary unit or course. 2. Thq Polarity Problem. Traditionally, interdisciplinarity and the discinline fields ha' I been seen as an either/or polarity, which has promoted a range of conflicts. Not only does the curriculum design offer from a luck of clarity, but real tensions can emerge among teach-ers.Â TRANSOISCIPLINARY: Beyond the scope of the disciplines; that is, to start with a problem and bring to bear knowledge from the disciplines (Meeth 1978). With the exception of the definition for interdisciplinary, experience in the field has made me reticent to use these definitions, They repre-. The growing need for interdisciplinary curriculum content.