Curriculum Design of Statics and Dynamics: An Integrated Scaffolding and Hands-on Approach

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ABSTRACT

Statics and Dynamics are necessary fundamental components of the engineering curriculum for Mechanical Engineering (ME), Civil Engineering (CE), and some other engineering disciplines. Students typically take these courses at the beginning of their second (sophomore) year and data suggests that many students drop out of engineering majors around this time. While this may not be directly attributed to Statics and Dynamics, it is widely agreed that these courses are challenging for many students. This paper presents the outline of a recently designed combined course in Statics and Dynamics with many new features that are not observed in the traditional courses in Statics and Dynamics. The need for designing a new combined course has been necessitated by four factors – a need for incorporating hands-on skills that are increasingly demanded by employers, navigating students through a challenging course that is a pre-requisite for other courses, attempting to improve retention of ME and CE students, and balancing the credit hour load of students in a liberal education environment where general education requirements are sizeable. This course has added new learning outcomes to accommodate laboratory experience as well as use of simulation software to enhance student engagement and at the same time provide the students with multiple options that encourage different learning styles. The course has been designed for four credit hours consisting of 180 minutes of lecture time, 120 minutes of laboratory time and 60 minutes of tutoring time every week of the fourteen week semester. The contact time has been distributed so as to promote scaffolding of the learning process. The learning outcomes established for this course include ABET[1] outcomes 'a' and 'e' as well as ABET[1] outcomes 'b' and 'k'. Although it may be argued that the inclusion of more learning outcomes may overburden the students and require them to allocate more time for this course, the feedback from students for the last two semesters has been generally positive. This paper provides the details of the curriculum and explains the rationale behind the changes in a critical course for ME and CE students. It is expected that the curriculum will lead to a broader discussion on the need to revamp critical courses in the engineering curriculum in order to enhance student engagement, and in an attempt to improve student retention in engineering.

Keywords: Curriculum, Statics, Dynamics, Scaffolding.

1. Introduction

The relationship between student engagement and student retention has been widely reported in pedagogical studies on engineering education. The need for student engagement is all the more necessary in sophomore level engineering courses because of a widely reported high drop-out rate of engineering students during this period[2]. While it is difficult to pin-point specific factors that can be held responsible for these high drop-out rates, it is widely recognized that sophomore students find fundamental required courses such as Thermodynamics, Fluid Mechanics, Statics, Dynamics, etc. challenging due to a sudden increase in the requirement of mathematics and physics in these courses. Students often complain that they cannot relate the

content of these subjects to engineering or their perception of engineering, or that they often find the courses to be too theoretical. Furthermore, the classroom lecture format inhibits active interaction between the students and the instructor, as well as among the students that may be crucial in the core classes to retain student interest[2]. Marra et al. conclude that providing opportunities for meaningful faculty interaction may help in retaining students with distinct learning styles[2].

The contribution of laboratory content toward enhancement of student learning is well recognized in existing literature[3]. However Feisel and Rosa emphasize that there seems to be a lack of coherence in the learning objectives for laboratories[3]. Some of the key features of learning through experimentation include encouragement of creativity and teamwork, opportunities for problem solving, analysis and interpretation of data as well as a possibility of learning through failure. These features are very difficult to accommodate in a classroom environment. Learning objectives can be particularly achieved in laboratories when the course content relates directly to the laboratory content through a chain of experiments designed to go hand-in-hand with the lecture content. Furthermore, students are able to see and touch parts in the laboratory, thereby, allowing for alternative cognition and learning styles that many students are known to have. Incorporation of a laboratory component into an important course such as Statics and Dynamics is, therefore, very useful to keep students engaged. Studies have often discussed student frustration with laboratory experiences due to a lack of relevance of laboratory content to lecture content[4]. Establishing a clear link between lecture content and laboratory experiments is expected to enhance student learning.

The role of active and engaged sessions of problem solving has been widely accepted as an important means of enhancing understanding of course content. The method is formally acknowledged as a component of scaffolding in the literature, where students receive guided practice and get prompt feedback to correct mistakes, or where students get help with critical steps in solving problems[5]. As part of the scaffolding approach, students get assistance till they develop critical skills and gain confidence, and till they demonstrate a specific level of problem solving capability[5,6]. This approach is extremely beneficial in topics like Statics and Dynamics where students often make mistakes in drawing free body diagrams, which leads them to the wrong answer resulting in student discouragement. Incorporating a mandatory tutorial session into the course allows for an opportunity to help students in solving problems without going through all the steps with the expectation that they will require lesser help as the semester progresses. Such an approach also gives the students more confidence in tackling numerical problems which may be open ended.

The integration of engineering curriculum in liberal arts institutions has been discussed in the literature, especially over the last decade[7,8]. This has been particularly challenging since the traditional liberal arts curriculum balances the content of natural sciences, social sciences and humanities. While engineering is an applied science that requires a strong foundation in natural sciences, the requirement of an understanding of social sciences and humanities for engineering students has been questioned in the past. This opinion has been evolving and there is an argument in recent pedagogical research that actually points out the benefits of integrating social sciences into the traditional engineering curriculum[7,8]. However, this poses a significant challenge in terms of balancing the credit hour requirements for engineering students in a liberal arts institution, and still limiting the total number of credits for graduation to 128 or lower. Furthermore, students in a liberal arts institution are not required to declare a major area of study in their first year of university education. This makes student engagement all the more

challenging since the students enrolling in the Statics and Dynamics course in a liberal arts institution can come from very diverse academic backgrounds.

This paper presents the layout of a combined course in Statics and Dynamics that incorporates a laboratory component as well as a mandatory tutorial session to enhance student engagement, and also includes some hands-on learning experience in an important course for ME and CE students. The course has been designed in an attempt to overcome reported concerns in the literature about student retention, as well as to integrate multiple ways of adapting to different learning styles that engineering students at a sophomore level may have. As a result, the combined course incorporates scaffolding and hands-on experience into the curriculum. Furthermore, the designed course also attempts to balance the credit hour requirements without eliminating any essential content. The remaining paper is divided into three parts, Section 2 presents the course content, Section 3 discusses the learning objectives and student outcomes, and Section 4 presents a discussion on findings and observations along with a listing of overall conclusions.

2. Course Outline and Content

The outline of the combined course in Statics and Dynamics (EGE 210) discussed in this paper is presented in this section along with a discussion on the course content as well as the distribution of contact hours. The course is designed for second year students enrolled in Mechanical Engineering (ME) and Civil Engineering (CE) programs. A fundamental course in Physics (PHY 101) and a second course in Calculus (MTH 142) are the two pre-requisites that students need to satisfy in order to be able to register in EGE 210.

The course content for the combined course is outlined in Table 1. As can be seen from Table 1, topics in kinematics and kinetics of three dimensional rigid bodies are not included in the course. Furthermore, some topics such as general plane motion of rigid bodies and constrained plane motion are also not covered in this course. However, it may be noted that all these topics are included in a four credit hour course that the ME students take in their third year, as shown in the curriculum layout in Fig. 1. The follow-up course incorporates six additional weeks of content on Dynamics, and is mandatory for ME students. This is deemed as an acceptable resolution to balance the credit hour requirements. Furthermore, it may be noted that CE students are not required to take a course in Dynamics in many institutions. Therefore, five weeks of introductory Dynamics is deemed to be sufficient in the combined course.

Week 1	Introduction to Vectors; Equilibrium of Particles
Week 2	Rigid Bodies; Equivalent Systems of Forces and Moments
Week 3	Equilibrium of Rigid Bodies
Week 4	Centroids, Center of Gravity, Distributed Forces (Exam 1)
Week 5	Analysis of Trusses and Frames
Week 6	Analysis of Trusses and Frames
Week 7	Forces in Beams; Shear Force Diagrams
Week 8	Shear Force Diagrams; Bending Moment Diagrams (Exam 2)
Week 9	Friction; Applications of Friction
Week 10	Kinematics of Particles
Week 11	Kinetics of Particles
Week 12	Moments of Inertia; Impulse & Momentum (Exam 3)
Week 13	Work & Energy; Kinematics of Planar Rigid Bodies
Week 14	Kinetics of Rigid Bodies: Plane Motion

Table 1. Course content for Statics and Dynamics.

Since the follow-up course is another four credit course, the above mentioned topics are easily integrated without requiring any reduction of content from the course on Kinematics and Dynamics of Machinery. Also, this distribution of topics integrates the content between the two courses allowing the students to see the link between the two courses.

The course content listed in Table 1 is covered through 180 minutes of lecture time and 60 minutes of tutoring time per week. The tutoring session is mandatory and is primarily used for problem solving. The problems solved in the tutoring session are an augmentation of the examples presented during the lecture time, and are solved interactively. Students are given an initial lead after which they are expected to follow through on the problem, and are provided with additional help only when required. Three exams are scheduled during the semester as one of the means of student assessment. It may be noted that all exams are scheduled during the time allocated for the tutorial session to avoid losing any lecture time during the semester.

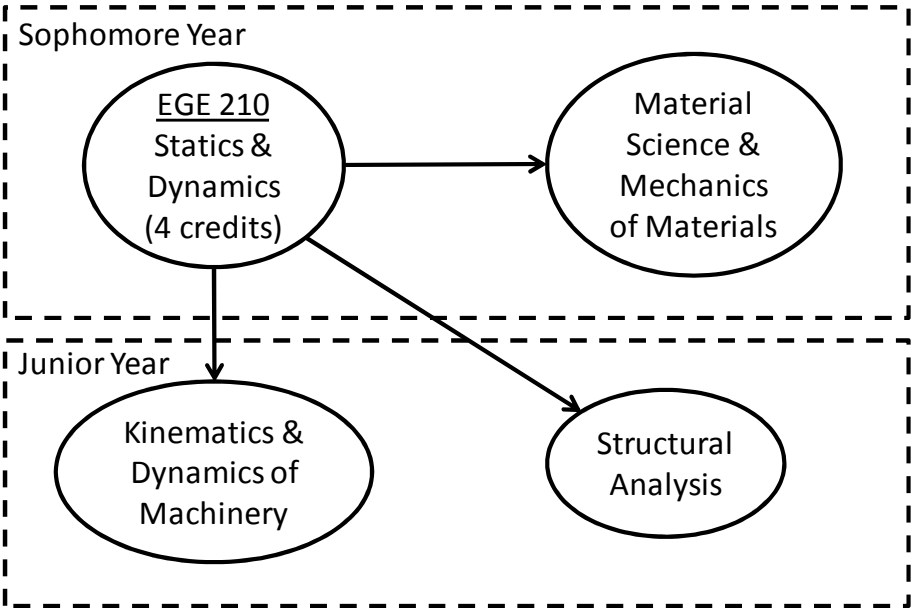

Fig. 1. Curriculum Layout – Statics, Dynamics and other Mechanics Courses.

The list of experiments conducted as part of the laboratory content for the course is provided in Table 2. The content of the laboratory is designed so as to introduce the students to the use of instruments such as load cells, accelerometers, displacement transducers, strain gages, etc., as well as basic principles of data collection. Also, students use MATLAB® for post processing data collected from the oscilloscope or data acquisition units for dynamic systems. Students also get introduced to ANSYS (commercial finite element analysis software) for performing finite element analysis on structural elements such as trusses, frames and beams. The use of finite element modeling and analysis allows the students to appreciate the value of an analytical tool that can be used to substitute hand calculations. It may be noted that students use MATLAB® and ANSYS repeatedly for subsequent courses enabling them to have a thorough familiarity with these computational and analysis tools.

Lab 1	Experimentation with cable tension, cable loading and cable rating
Lab 2	Experimentation with pulley systems using multiple pulley configurations
Lab 3	Experimentation with resistor circuits to build Wheatstone bridge, as well as introduction to power supply unit, oscilloscope and signal generator
Lab 4	Experimentation with strain gauges to measure strain on coupons under tension
Lab 5	Experimentation with a truss structure and measurement of strain on several members of the truss
Lab 6	Experimentation with beams with multiple boundary conditions, measuring load, strain and deflection
Lab 7	Experimentation with dry friction using multiple surfaces
Lab 8	Introduction to finite element analysis with ANSYS using trusses and beams for static analysis
Lab 9	Introduction to finite element analysis with ANSYS using frames and trusses for static analysis, and beams for dynamic analysis
Lab 10	Experimentation with spring-mass-damper systems and demonstration of principles of data collection
Lab 11	Experimentation with beams under dynamic loading as well as data collection using string potentiometers and accelerometers
Lab 12	Experimentation to demonstrate the principles of modal analysis using a modal impact hammer on a beam

Table 2. Laboratory content for Statics and Dynamics.

This repeated use of the analysis tools prepares students very well for junior and senior level classes, where they learn about the theoretical aspects of the analysis. Having an early exposure to analysis software allows students to have a thorough familiarity with tools that can be used for Senior Design projects, and are also extensively used in the industry.

The content listed in Table 2 is covered through 120 minutes of laboratory time per week. Most of the experiments are designed so as to enhance student understanding of the content covered in the class. Students are provided with handouts explaining the purpose and methodology of each experiment, as well as the relevance of the experiment to the theoretical content covered in class. Students work in groups of two and submit an individual laboratory report for each laboratory session.

It is acknowledged that covering the content of Statics and Dynamics within four credit hours becomes challenging, especially with the introduction of the laboratory content. However, moving some of the topics to the junior level course in Kinematics and Dynamics of Machinery helps in balancing the work load for students. This distribution also allows for making connections between courses that many students often fail to recognize. For CE students, some of the content such as topics related to statically indeterminate systems has been moved to the junior level course in Structural Analysis, as can be seen in the curriculum layout in Fig. 1. The distribution of the content and the addition of laboratory and tutorial content allow an incorporation of new learning objectives and outcomes, and at the same time accommodates multiple cognitive styles that the students with diverse academic backgrounds may have.

3. Learning Objectives and Outcomes

This section presents a discussion on the learning objectives and outcomes of the combined course on Statics and Dynamics discussed in the previous section. Some preliminary feedback received from the students is also included in this section.

The learning objectives established for the course result from a combination of lecture and laboratory content discussed in the previous section. The learning objectives established for the course are listed below.

Students finishing the combined course in Statics and Dynamics should be able to:

i. Demonstrate the application of vectors for the analysis of static equilibrium.
ii. Analyze different structural elements like trusses, frames and beams.
iii. Demonstrate an understanding of the principles of kinematics and kinetics of particles and planar rigid bodies.
iv. Demonstrate strong technical report writing skills.
v. Identify techniques for measurement using instrumentation with recognition of the principles of data collection.

Out of all the learning objectives listed above, the objectives pertaining to report writing and measurement techniques are not commonly observed in Statics and Dynamics. The incorporation of the laboratory component in the course makes the inclusion of these two objectives possible. The curriculum for ME and CE students has been designed such that there is a constant stream of courses with a laboratory component, thereby constantly improving student skills in report writing and experimentation. Both these skills are extremely important learning outcomes that have been recognized by ABET[1]. Both these skills are also extremely crucial for the successful completion of the Senior Design project. Therefore, inclusion of these objectives is important for laying a foundation that will help students in building necessary skills.

The learning outcomes identified for the combined course in Statics and Dynamics are as follows:

i. Students learn to apply the principles of static equilibrium to particles and rigid bodies.
ii. Students learn to analyze truss and frame structures.
iii. Students apply the principles of equilibrium for analyzing beams.
iv. Students analyze problems involving frictional forces.
v. Students learn to draw shear force and bending moment diagrams.
vi. Students apply the principles of kinematics and kinetics of particles.
vii. Students learn to apply the principles of work and energy as well as impulse and momentum to particles.
viii. Students analyze planar rigid body kinematics and kinetics.
ix. Students learn to write technical laboratory reports.
x. Students apply measurement techniques and formulate experiments based on laboratory handouts.

The above listed learning outcomes correspond to the following student outcomes identified by ABET[1] for accreditation of engineering programs:

i. Ability to apply knowledge of mathematics, science and engineering (ABET student outcome ‘a’).
ii. Ability to design and conduct experiments, as well as to analyze and interpret data (ABET student outcome ‘b’).
iii. Ability to identify, formulate, and solve engineering problems (ABET student outcome ‘e’).
iv. Ability to use the techniques, skills, and modern engineering tools necessary for engineering practice (ABET student outcome ‘k’).

The course discussed in this paper was taught for the first time during Fall 2011 and eighteen students (14 male, 4 female) were enrolled in the course. It may be noted that the university wide guideline is to limit the student to faculty ratio to a maximum of 20:1. All the students enrolled in the class met the required pre-requisites and had declared ME or CE as their major. The laboratory for the course was divided into two sections with one section consisting of

eight students and the other section consisting of the remaining ten students. Students were divided into groups of two for the laboratory component and each student was required to submit an individual laboratory report. A weekly tutorial session was conducted for which attendance was mandatory. The tutorial session was mostly focused on solving example problems and problems related to weekly assignments. Students were encouraged to work in groups during the tutorial sessions. Student assessment consisted of three exams during the semester and a final cumulative exam. A weekly assignment and a weekly quiz were also a part of the assessment. The weekly quiz was based on the content of the weekly assignment in order to directly assess student understanding of the course content on a week by week basis.

Feedback received from the first group of students who have taken this course has generally been positive. Some of the student comments about the laboratory component and the tutorial sessions are as follows:

‘the lab structure was good’
‘overall very good lab component’
‘labs were interesting and helped me to get exposure to new equipment’
‘the lab helped me gain skills I can use in my career’
‘the labs helped me better understand what I was learning in the class’
‘the tutorials helped me to understand lecture content’
‘labs were directly related to what we did in class. That made it a lot easier to understand the material’
‘the lab helped me become more comfortable with MATLAB’
‘lab helped to give meaning to what was taught in lecture’
‘lab was interactive, fun and useful for the learning process’

The student comments were collected through a survey at the end of the semester. The student comments listed above clearly illustrate that the integration of laboratory content into the combined course was successful. However, the survey could not be used to quantitatively assess the achievement of learning outcomes.

The student survey responses for the course have been positive with the overall student satisfaction averaging to 3.24 (out of a maximum of 4). Student responses generally range in the category of ‘Satisfied’ or ‘Very Satisfied’. One example of student responses from the survey is shown in Fig. 2.

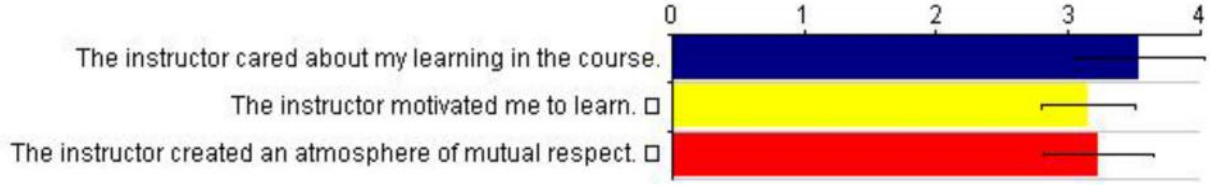

Fig. 2. Student Survey Response – Example.

Although student comments on the laboratory component of the course have been generally positive, a quantitative analysis is not done at this stage because of a lack of significant amount of data, and also because of a lack of a control group that can be used for analysis. This will be done as part of future work in order to quantitatively understand the results, and also comprehend areas of improvement which can be incorporated into the course in the future. Some recent studies using web-based course presentation or the inverted classroom strategy will also

be investigated to thoroughly analyze the achievement of student outcomes[9]. Future work will also focus on comparing cognitive abilities of students for problem solving and compare it with results from other similar studies[10,11] in the existing literature. Findings from other universities that have integrated similar features into a combined course in Statics and Dynamics will also be studied in detail in order to seek improvements that can be made to the curriculum discussed in this paper. It may be noted that one similar combined course in the existing literature points out a positive response, although the course has lesser contact time and does not have tutorial or laboratory components[11].

4. Discussion and Conclusions

The curriculum for a combined course in Statics and Dynamics is an attempt to customize learning as much as possible within the framework of classroom teaching. The intent of the curriculum discussed in this paper is to enhance student engagement through the introduction of laboratory content that supplements the theory introduced in the classroom. The laboratory component is expected to allow students to be creative and try out solutions without being too concerned about getting a wrong answer, and is also expected to help students who may have a different cognitive style. The larger aim of the laboratory component is to engage students and relate the theoretical classroom content with components and systems that students can see and feel. Many undergraduate engineering curricula have one or two specific courses that are used for introducing students to experimental methods, instrumentation, data collection, etc. The perceived shortcoming of this approach is that it does not allow any room for connecting the specific theoretical content of courses from sophomore and junior level with the experimental methods. The combined course discussed in this paper integrates the use of instrumentation and experimentation with theoretical content in order to enhance student learning, and allow students an opportunity to relate the lecture content with physical systems. The laboratory content also provides hands-on experiences that improve student engagement.

The use of scaffolding to enhance student learning has been well recognized in the existing literature[5]. Mandatory tutoring sessions are used as an effective means of scaffolding student learning in the curriculum discussed in this paper. This is particularly important in topics like Statics and Dynamics which are a pre-requisite for multiple courses. The intent of the tutorial sessions is to provide students with a guided practice to gain confidence in the subject matter, with the expectation that students will be able to complete more and more of the work unassisted as the semester progresses. This is seen as a much better alternative to the commonly used walk-in sessions, where students may require a high amount of motivation to make use of the voluntary tutorial sessions.

The overall aim of the curriculum is to balance the total number of credit hour requirements without removing any necessary content, and at the same time introducing hands-on skills. Student engagement and student retention are two additional aims that have been incorporated through the use of scaffolding. It is believed that the curriculum for the combined course in Statics and Dynamics adds multiple critical features that will enhance the achievement of student outcomes in a very important course for ME and CE students. This has been corroborated by other studies that have attempted a similar combined course with generally positive student feedback[11].

The combined course discussed in this paper will be analyzed in a future study to quantitatively assess whether the established learning objectives are being achieved. Also, student response and student learning outcomes will be compared to other studies in order to

comprehend possible ways of improving the course content. Future studies will also attempt to review possible cognitive overload due to the combined curriculum and due to the additional learning outcomes introduced in the curriculum, and explore ways to mitigate the cognitive overload by using ideas such as concept maps[12].

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