Methods to Improve Student Learning in Statics and Dynamics Courses

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Statics and Dynamics are two very important courses - the building-blocks, which prepare students for many other follow-up courses in the engineering curricula. They utilize the knowledge of mathematics and physics procured by students from the prerequisite courses, and develop the analytical skills necessary for students to identify, formulate, and solve many engineering application problems. One of ABET's (Accreditation Board for Engineering and Technology) criteria- criterion 4, is about Continuous Improvement (CI) which is concerned with the regular assessment and evaluation of the extent to which the ABET student outcomes (SO) are being attained. Student learning, besides providing the background for the follow-up courses, plays a vital role in CI. This paper discusses several methods to improve student learning in Statics and Dynamics courses, with particular emphasis given to the restructuring of the flow of the lecture topics. Some methods have already been implemented in these courses in our institution, and student performance is being closely monitored through direct and indirect assessment measures and evaluation.

Introduction

In the engineering curricula, special emphasis must be given to student learning in the fundamental courses as they provide the foundation or building-blocks for many follow-up courses. Statics and Dynamics are two such courses in the areas of solid and structural mechanics in the mechanical and civil engineering curricula. At our institution, Baker College of Flint, Statics and Dynamics (ME 201 and ME 321) are core courses in the Bachelor of Science in mechanical and civil engineering programs. Additionally, statics is a required course in the Bachelor of Science in industrial engineering and the Associate of Applied Science (AAS) in the Mechanical Technology programs. Students after graduating from the AAS in Mechanical Technology program are given the option of enrolling into the Bachelor of Science in Mechanical Engineering program, which can be completed in three additional years. The follow up courses like Solid Mechanics (ME 211), Mechanical Design (ME 351), Structural Analysis (CE 311), Kinematics (ME 325), and Vibrations (ME421) depend significantly on student learnings in statics and dynamics.

Our institution functions on a 10-week quarter system with final exams held in the 10^{th} week. The institution is a career oriented school with a strong focus on the employment of our graduates which is reflected by an employment rate of 97%. To meet the needs of our two customer groups- students and employers, we are constantly developing new educational programs and innovative delivery methods. Our engineering classes meet once every week in the evenings as most students, classified as non-traditional students, have day-time jobs.

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Continuous Improvement

The mechanical engineering program at our institution is accredited by ABET (Accreditation Board for Engineering and Technology). One of ABET's criteria, criterion 4, is about Continuous Improvement (CI) which pertains to the process of regularly assessing and evaluating the extent to which the ABET's student outcomes are being attained. Many factors contributing to the challenges in attainment of student outcomes in our engineering programs are,

1) A typical 15-week semester course contents compressed into a 10-week quarter system.

2) Student engagement due to lecture classes meeting for long hours- 200 hours of contact time per week with a 20 minute break in between.

3) Students engagement due to attending classes after their day-time jobs.

Students take Statics and Dynamics in the sophomore year and their retention is very important as many students are potentially at risk of attrition around this stage. Both courses require strong analytical skills and problem solving techniques through utilization of students' math and physics backgrounds. These courses are offered once a year, unlike some schools which offer them in subsequent semesters, and sometimes in summer too. Therefore, there is a likelihood of students delaying their graduation should they fail these courses.

Many educators have discussed several methods to enhance student engagement and learning[1, 2, 3]. Kaul[1] and Sitaram used an integrated scaffolding and hands-on approach in their curriculum design of a combined statics and dynamics course. Sitaram[2] integrated the use of the commercial finite element software in both statics and dynamics courses to improve student engagement, better understanding of the theoretical concepts, and develop mastery and confidence in using ANSYS. The present paper discusses several methods to improve student learning in these courses.

a) Restructuring the cascading of course topics

1. *Statics*

Traditionally, both statics and dynamics are taught in the same sequence of course topics in the textbook[4, 5]. Historically, we have adopted this style in our school and the syllabus is shown in Table 1. Our students in statics usually struggle in topics like vectors and their applications, moment of a force, and integration, despite these material being covered in their prerequisite math and physics courses. For example, in the analysis of 3D problems, we have noticed students having difficulties in answering the following questions relevant to Figure 1:

- (i) The determination of unit vector to obtain the cartesian form of force F.
- (ii) The moment of F about A using the vector product.
- (iii) The angle between force F and BC using dot product
- (iv) The moment of F about an axis through AD using mixed triple product (a combination of vector and dot products)

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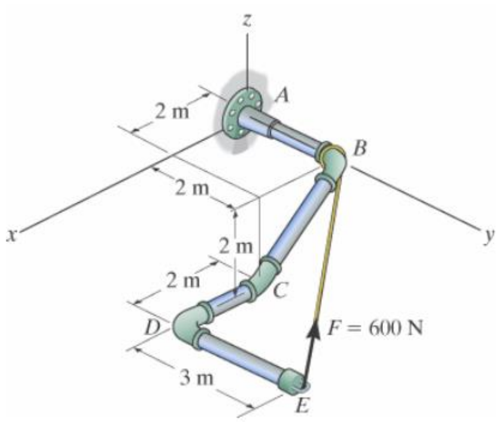
(v) Replacing the Force F by a single resultant force-couple system (equivalent system) at A.



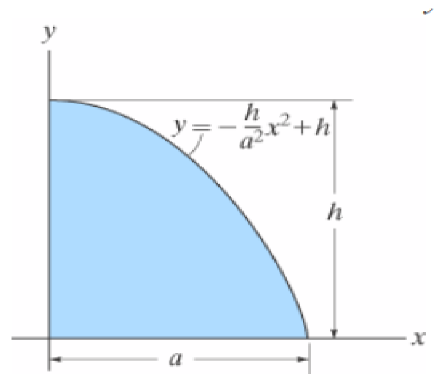


Figure 1: A 3D force

Figure 2: An area

(vi) The determination of centroid and moment of inertia of the area shown in Figure 2 by the method of integration.

Table 1: Syllabus for statics based on the flow of topics of the textbook

Week	Chapter	Topic
1	1 2.1 -2.4	General Principles Vector Addition of Forces
2	2.4 – 2.9	**Addition of Cartesian Vectors, Position Vectors, Force in Cartesian Form, Dot Product**
3	3.1 – 3.4	Equilibrium of a Particle in 2D and **3D**
4	4.1 – 4.4	Moment of a Force, **Vector Product**, Principle of Moments
5	4.5 – 4.9	Moment of a couple in 2D and **3D**, **Equivalent Systems**
6	5.1 – 5.4	Equilibrium of a Rigid Body in 2D, Two and Three Force Members
7	5.5 – 5.7; 6.1 – 6.4	**Equilibrium of a Rigid Body in 3D**; Analysis of Plane Trusses
8	7.1 – 7.2	Internal Loadings in 2D; Shear and Moment
9	9.1 – 9.2; 10.1 – 10.4	Centroid of Areas; Moments of Inertia
10	8.1 – 8.2	Dry Friction

Since 3D analysis of both particles and rigid bodies involves vectors, we plan to postpone its instruction by introducing it after the completion of 2D analysis. This necessitates the restructuring of the cascading of course topics. Consequently, the instruction of the topics pertaining to 3D problems, shown in bold faced letters in table 1, are moved to the later weeks as shown in table 2. We strongly feel that this restructuring of the course topics through the introduction of 3D analysis after 2D analysis would enhance student learning, engagement, motivation, confidence, and consequently their performance. The new syllabus is currently being used and the efficacy of this restructuring would be evaluated.

Table 2: Syllabus for statics based on restructured flow of topics

Week	Chapter	Topic
1	1 2.1 -2.4	General Principles. Vector Addition of Forces.
2	3.1 - 3.3; 4.1, 4.4, 4.6	Equilibrium of a Particle in 2D. Moment of a Force in 2D, Principle of Moments, Moment of a couple in 2D.
3	9.1 – 9.2; 4.9 5.1 - 5.3	Centroid of Areas; Reduction of Simple Distributed Loadings. Equilibrium of a Rigid Body in 2D
4	5.4 – 5.5	Two and Three Force Members; Free Body Diagrams
5	6.1 – 6.4, 6.6	Analysis of Plane Trusses; Frames and Machines.
6	7.1 – 7.2; 8.1 – 8.2	Internal Loadings in 2D; Shear and Moment. Dry Friction.
7	2.5 – 2.9	**Addition of Cartesian Vectors, Position Vectors, Force in Cartesian Form, Dot Product**
8	3.4 4.2, 4.5, 4.6	**Equilibrium of a Particle in 3D.** **Vector Product**, **Moment of a couple in 3D.**
9	5.5 – 5.6; 5.7 10.1 – 10.4	**Equilibrium of a Rigid Body in 3D**; Constraints and Statical Determinacy Moments of Inertia
10	4.5, 4.7	**Equivalent Systems**

2. Dynamics

Currently, the cascading of topics in ME321 Dynamics follows the order as in the textbook, and the syllabus is shown in Table 3. The sequence involves kinematics (Chapter 12 of text) and kinetics of particles (Chapters 13, 14, and 15), followed by kinematics (Chapter 16) and kinetics of rigid body (Chapters 17, 18, and 19). We plan to restructure the flow of topics by first completing kinematics of particles and rigid bodies sequentially, and then discussing the chapters on kinetics of particles and rigid bodies, thus segregating the topics of kinematics and kinetics.

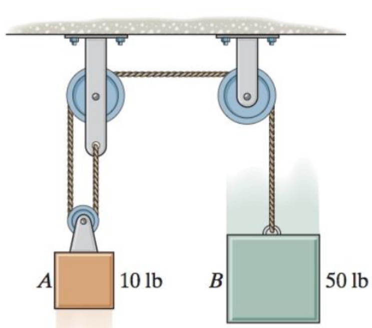


Figure 3: Rope-pulley system

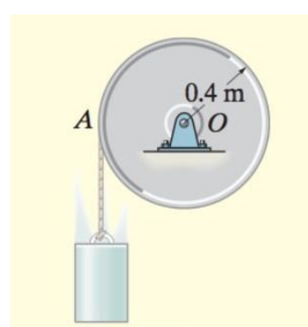


Figure 4: Rope around a drum

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Additionally, in the analysis of kinetics of particles and rigid bodies three methods are used – Newton's II law (Chapters 13 and 17), principle of work and energy (Chapters 14 and 18), and the principle of impulse and momentum (Chapters 15 and 19). Figure 3 refers to the problem on kinetics of particles where in the velocity of each block is to be determined 2 seconds after the blocks are released from rest. Figure 4 refers to the kinetics of rigid bodies where in the drum's acceleration has to be determined given its mass and radius of gyration, and the mass of the block. Both problems can be analyzed by all the three methods. Because these methods are taught in sequence (Chapters 13 through 15 for particles; and 17 through 19 for rigid bodies), students are exposed to all the three methods simultaneously. We have observed over several years that this causes confusion in students as well as a lack of appreciation of the advantages of one method over the other. We therefore plan to restructure this as well, by considering one method at a time for both kinetics of particles and rigid bodies. With this restructuring, the sequence of topics on kinetics would be Newton's II law for kinetics of particles and rigid bodies (Chapters 13 and 17), principle of work and energy for kinetics of particles and rigid bodies (Chapters 14 and 18), and principle of impulse and momentum for kinetics of particles and rigid bodies (Chapters 15 and 19). Thus, the overall restructuring is shown in table 4 which involves moving around the bold faced course topics in table 3. This results in the following sequence for kinematics and kinetics - Chapters 12, 16, 13, 17, 14, 18, 15, and 19.

Table 3: Syllabus for dynamics based on the flow of topics of the textbook

Week	Chapter	Topic
1	12.1 - 12.7	Kinematics of a Particle Rectilinear Kinematics; Curvilinear Motion: Rectangular Components, Normal and Tangential Components
2	12.8, 12.9; 13.1 – 13.5	Curvilinear Motion: Cylindrical Components; Absolute Dependent Motion; Relative-Motion of Two Particles; Kinetics of a Particle: Force and Acceleration Newton's Second Law of Motion: Rectangular Components, Normal and Tangential Components
3	13.6 14.1 – 14.6	Equations of Motion: Cylindrical Coordinates; **Kinetics of a Particle: Work and Energy**
4	15.1 – 15.7	**Kinetics of a Particle: Impulse and Momentum**
5	16.1 – 16.7	**Planar Kinematics of a Rigid Body**
6	17.1 – 17.5	**Planar Kinetics of a Rigid Body: Force and Acceleration**
7	18.1 – 18.5	**Planar Kinetics of a Rigid Body: Work and Energy**
8	19.1 – 19.2	**Planar Kinetics of a Rigid Body: Impulse and Momentum**
9	19.3	**Planar Kinetics of a Rigid Body: Conservation of Momentum** ANSYS Exercises
10	12 - 19	Course Review and Final Exam

We strongly feel that this restructuring of the course is very much necessary given that the dynamics course is one of the intense courses as well as a foundation course to the follow up courses like vibrations and kinematics in the curriculum.

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Table 4: Syllabus for dynamics based on the restructured flow of topics

Week	Chapter	Topic
1	12.1 - 12.7	Kinematics of a Particle Rectilinear Kinematics; Curvilinear Motion: Rectangular Components, Normal and Tangential Components
2	12.8, 12.9; 16.1 – 16.7	Curvilinear Motion: Cylindrical Components; Absolute Dependent Motion; Relative-Motion of Two Particles; **Planar Kinematics of a Rigid Body**
3	13.1 – 13.6	Kinetics of a Particle: Force and Acceleration Newton's Second Law of Motion: Rectangular Components, Normal and Tangential Components, Cylindrical Coordinates.
4	17.1 – 17.5	**Planar Kinetics of a Rigid Body: Force and Acceleration**
5	14.1 – 14.6	**Kinetics of a Particle: Work and Energy**
6	18.1 – 18.5	**Planar Kinetics of a Rigid Body: Work and Energy**
7	15.1 – 15.7	**Kinetics of a Particle: Impulse and Momentum**
8	19.1 – 19.2	**Planar Kinetics of a Rigid Body: Impulse and Momentum**
9	19.3	**Planar Kinetics of a Rigid Body: Conservation of Momentum** ANSYS Exercises
10	12 - 19	Course Review and Final Exam

b) Assessment:

The achievement of the Student Outcomes (SO) of the Mechanical and Civil Engineering programs is mostly based on data from Direct Assessment measures administered in the major core engineering courses. The descriptions of the assessment processes are:

(i) Multiple choice questions modeled after questions in the Fundamentals of Engineering Exam (FE).
(ii) Questions involving Step-by-Step solutions.
(iii) Laboratory Report in courses with experimental laboratories.
(iv) Project in courses with projects, including the Senior Design Project
(v) Senior Design Project presentation.

The assessment processes (i) and (ii) are applicable to the statics and dynamics courses, and the assessment questions are incorporated in the final exam. It is very important to choose proper assessment questions to evaluate student learning. The multiple choice questions chosen are modeled after the FE exam that most students take during their senior year, and form one component of the comprehensive final exam. They are aimed at testing the students understanding of the basics concepts. The scoring of these questions is either correct/ incorrect. The target for percentage of students answering the questions correctly has been established by the engineering department at 60%. The questions involving Step-by-Step solutions are chosen to assess students' preparation for the follow up courses, in addition to testing their conceptual understanding and analytical capability. For instance, the assessment questions in statics involves the background needed for dynamics, solid mechanics, and structural analysis courses.

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Similarly, the assessment questions in dynamics involves the background needed for kinematics and vibrations courses. The scoring of these questions is based on a rubric that has 5 categories- Excellent, Good, Average, Fair, and Poor. The target for percentage of students performing at the levels of Excellent or Good has been established by the department at 60%. The assessment results over several years will be monitored to get a more complete and meaningful picture, and will form one of the main components of continuous improvement.

A similar assessment process is necessary in the prerequisite Math and Physics courses to evaluate student's preparation leading to statics and dynamics course. The department of engineering is currently working with the Math and Science departments to implement the assessment process in MTH 244 and SCI 251 courses. The assessment questions proposed involves vectors, vector products (dot and cross products), determinants, integration, moment of a force, Newton's laws of motion, and energy methods.

c) Discussion Board Forum

Discussion board is one of the key components to enhance student learning. It is an excellent medium for students to exchange ideas and better understand different perspectives. It also gives instructors an additional method of assessing student understanding of the course material. Discussion board forum in blackboard (a course management tool used by most schools) was set up in both statics and dynamics courses. Questions centered on the conceptual understanding of the lecture topics and homework are posted each week to this forum. In an effort to encourage student participation, the discussion board forum was included in the overall grading process.

d) In-class group activities

In-class group activities form one of the methods of active learning, and many educators have recognized the advantages of cooperative learning. For classes that meet for long hours, the in-class group activities are vital for increasing student engagement and learning. Students were grouped in pairs, and two in-class group activities, each 30 minutes in duration, were given during the lecture classes every week. If student work was incomplete, an opportunity to complete the problem at home was given. The work was collected the following week and graded.

e) Help study sessions/lab hours

It is extremely important to have help study sessions in the fundamental courses. Study sessions were conducted an hour prior to the lecture class in both statics and dynamics courses in order to give students the opportunity to ask any questions related to lecture material and homework,. It is extremely difficult to find tutors in our institution as most students have day-time jobs. Therefore, the study sessions were conducted by the instructor of the course. Although this demands instructor's time, yet it provides the instructor a good measure of students' understanding of the course material. The department is proposing to add more contact hours as lab hours to the static and dynamic courses. These lab hours would mainly involve problem solving sessions and will replace the study sessions. Since all students have to attend the lab

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hours, the problem solving sessions are bound to reach a larger student population in these courses.

Conclusion

Several methods to improve student learning in Statics and Dynamics courses are discussed in this paper. Particular emphasis is given to the restructuring of the flow of the lecture topics. To the best of author's knowledge, the restructuring of the flow of course topics as described in the current paper is not mentioned in any textbook or literature. This novel approach is the outcome of the author's experience based on student performance and comfort level, as well as his experience teaching these courses several times at Baker College and many universities across the country. Given the pace of a quarter system curriculum, this restructuring is very much necessary for our engineering program at Baker College. Proper selection of assessment questions are important to measure student understanding, comprehension, and preparedness for follow up courses. The discussion board forum in blackboard must be used as it encourages the exchange of thoughts and ideas, and increased student participation can be effected by including it in the grading scheme. Incorporating in-class group activities in lecture classes and assigning additional contact hours as lab hours for problem solving sessions are necessary for enhancing student learning.

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Biography

Dr. Pattabhi Sitaram is Associate Professor and Chair of the Department of Engineering at Baker College in Flint, Michigan. He worked in the automotive industry, primarily at General Motors, for fifteen years as crashworthiness simulation and methods development engineer, and a Subject Matter Expert for plastics, composites and foam materials. He hast taught extensively at both undergraduate and graduate levels in Civil and Mechanical Engineering disciplines. His research interests include Finite Element Analysis & Design, Crashworthiness, Vibration, Structural Stability, and Plates & Shells.

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