Session 2268

Statics as a Special Case of Dynamics, An Alternative Way of Teaching Mechanics

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Abstract

For the past 8 years Union College has been teaching a course in the kinematics and kinetics of particles and rigid bodies. This course replaced the traditional statics and dynamics course sequence that use to be taught to mechanical, electrical, and civil engineering students at Union College. More recently this single course has been divided into two courses, one in particle mechanics and one in rigid body mechanics. Using this approach, students are shown that statics is a simplified case of dynamics. Free body and mass/acceleration diagrams, hands on laboratory exercises, and design projects are used to illustrate this relationship. A summary of the success of the course being taught this way is presented.

Introduction

Engineering students are traditionally introduced to topics in engineering mechanics through trimester courses in statics and dynamics. This is true throughout the United States and the World with few exceptions. During the reform of the Union College Engineering Curriculum that took place in the mid 1990s [1], the rational for introducing students to mechanics in this fashion was called into question. Since statics can be considered a subset of dynamics, is there a pedagogical benefit to introducing students to the subject of mechanics from this perspective? Before this question can be answered it is instructive to look back in the history of mechanics, and more importantly engineering mechanics, and see why the statics and dynamics course sequence is so thoroughly entrenched in engineering curricula throughout the world.

Complete histories of mechanics can be found in several references [2-6]. An abridged version is presented here for the purpose of understanding how the teaching of mechanics has evolved in engineering education. The history of mechanics dates back as far as the Egyptian mathematician Euclid (365-300 B.C.). Euclid's contributions to mathematics were essential to the advances in Newtonian mechanics. The Greek scientist Aristotle (384-322 B.C.) is credited with deriving the law of equilibrium of a lever which was later refined by Archimedes (287-212 B.C.). Between Aristotle and Galileo some argue that there were only minor contributions to mechanics. These contributions included the studies of planetary motion by Copernicus (1473-

1543) and Kepler (1571-1630). Stevinus (1548-1620) studied the properties and equilibrium of inclined planes. These studies led to the development of the parallelogram law of forces (parallelogram law of vector addition). Galileo (1564-1642) confirmed Stevinus' result and went on to show that applied force is not necessary to maintain constant velocity motion, Galileo's law of inertia. The next major contribution to the development of mechanics was by Newton (1642-1727). His *Philosophiae Naturalis Principia Mathematica* (1687) described the motion of particles but did not consider rotational motion. Euler (1707-1783) built on Newton's work to describe the motion of systems of particles and rigid bodies. For the sake of this discussion, the next important development in mechanics came from D'Alembert who introduced the concept of the inertial force, which allows dynamic problems to be solved using equilibrium concepts.

From the developmental history of mechanics it appears that statics and dynamics have always been considered closely related. Then why do these two topics continue to be taught separately? The historical pedagogical perspective must be considered in an attempt to understand the contemporary treatise of these topics.

Perronnet in France established the first school of engineering around 1747. In England around this time engineering was treated more like a trade than a topic for discussion at Universities. The educational system in the United States at this time was mostly based on the English system. However, it became clear to many that in order to exploit the natural resources of the United States it needed technically trained people. The first applied science program in the United States was started in 1802 at West Point. The first attempt to teach practical science in the civilian sector was by Gardiner Lyceum in 1822 at Gardiner in Maine. This school could not maintain support and was closed shortly after being opened. In 1823 Stephen Van Rensselaer established the first school of Civil Engineering in the United States. Shortly after this in 1845 Union College became the first liberal arts college to start a program of study in Civil Engineering. It is important to note that the term Civil Engineering at this time was used to differentiate civilian engineering from military engineering.

In searching the Union College archives, the course catalogs of the early Civil Engineering program at Union College show that there was a course taught over two terms called Engineering Statics. This course was concerned with stability of walls, arches, bridges, and other structures. There was also a course called Engineering Statics and Dynamics. This course was taught by a mathematician and used Bartlett's *Analytical Mechanics*. Bartlett's book made extensive use of calculus. It appears that this course was more of an applied science course than an engineering course. It is clear that the courses in statics were developed to give the student depth in a subject that was essential for success in the profession. As engineering evolved into multiple fields, like mechanical and electrical engineering, the need for more depth in the field of dynamics led to the establishment of separate courses in dynamics. Thus, it appears that the only explanations for why these two topics are taught as separate courses is that historically the need for students to have a depth of knowledge in these topics became important at different times.

Arguments for the pedagogical benefits of teaching statics and dynamics in a different manner can be made. One advantage to the student is that the connection between the two topics becomes clearer. In the remainder of this paper the evolution of the teaching of mechanics from the perspective that statics is a special case of dynamics will be discussed. This will include the philosophy in the Union College Mechanical Engineering Department that high-level theory introduced during the lecture must be supplemented with experiential learning in the laboratory and design projects. Because our classroom sizes are small, evaluation is difficult; however, assessment of the changes to this course sequence will be discussed.

Union College's Approach to Engineering Mechanics

The Union College curriculum reform of the mid 1990's was fueled by a generous grant from the GE Foundation and the energy of the sitting Dean of Engineering at the time, Dr. Richard Kenyon (now retired). This effort allowed the faculty to step back and rethink the objectives of engineering education and how it was delivered. Part of this effort was to take a close look at the entire sequence of engineering mechanics courses that are offered to engineering students. The situation at Union College is somewhat unique because of the size of the program. Union prides itself in small classes. The total student body is approximately 2000 students of which only about 350 are engineering students. The engineering students currently have the option of studying mechanical, electrical, computer and civil (currently being phased out) engineering. Therefore the early mechanics courses need to take into account the needs of all of these disciplines because it is not practical to have discipline specific courses with this size of a program.

Engineering mechanics education starts with the student's first course in physics. In discussions with the Physics Department at Union College it became apparent that there was significant redundancy between the mechanics in the physics courses and the courses taught in engineering. There is historical precedence for have students first exposed to mechanics as an applied science. It is believed that it is important for engineering students to be introduced to the material from this perspective. More importantly, it is important for engineering students to see how mechanics fits into the bigger picture. As a result of the discussions between the Union College engineering and physics faculty it was decided to have the physics faculty introduce engineering students to physical principles, including mechanics, in an overview format. This overview sequence of physics courses is described as physics: Newton to Einstein. However, detailed problem solving would be left to the engineering faculty. This approach gives the engineering students the broad-brush overview of where everything fits before getting bogged down in the details of the specific topics that are covered in the particle and rigid body mechanics courses.

For the first 150 years of engineering education at Union College, statics was offered as a separate course from dynamics. The wisdom of this was challenged early in the curriculum reform discussions. It seems more logical to talk about kinematics before discussing kinetics of bodies that are absent of acceleration (statics) and those that are accelerating (dynamics). This perspective resulted in Union's first course in mechanics being a course that focused on Newtonian mechanics. First students were introduced to the kinematics and kinetics of particles followed by the kinematics and kinetics of rigid bodies. Energy methods were postponed to a later course. After offering this course for several years it became apparent that there was too much material being covered in too short of a time. Therefore, this first course in mechanics was redeveloped into two courses, one in particle mechanics and a second in rigid body mechanics. In this new sequence of courses students are given more depth and energy methods are discussed in both courses.

Appendix I contains outlines for the particle and rigid body mechanics courses currently taught at Union College. Both courses follow a similar format. First topics in kinematics are developed, followed by topics in kinetics. During the discussion on kinetics, a significant amount of time is spent looking at equilibrium problems. Often problems are first considered with motion and then without. A class of problems that easily illustrates this approach are pulley systems. Problems of this type are first considered as the masses are moving, the mass of the pulleys can be considered significant or insignificant, and finally the system can be considered static. This type of problem also lends itself to experimental verification. Toward the end of both courses work and energy principles are developed from Newton's laws.

The lecture portion of this course is taught with the rigorous use of vectors and calculus. The approach taken is typically applicable to all problems in two and three dimensions. This approach is preferred over planar scalar approaches because it is applicable to a broader range of problems. With these methods students eventually develop their own scalar short cuts; however, they have a complete understanding of the limitations of the methods that they employ.

The first courses in mechanics are the foundation of a students understanding of mechanics. It is essential that engineering students not only come away from these courses with a thorough understanding of the theory, but also with a physical insight into engineering mechanics. For this reason laboratory experiences are integral to these first two mechanics courses. Additionally, these courses include design projects that narrowly focus on the material being covered. Design projects help to reinforce the need for theory and help to motivate students to study the material. The design project is introduced early and lecture examples often involve the project.

Laboratory Experiences in Mechanics

The laboratory portion of this course is used to reinforce the theory being taught in the lecture portion of the course and to build the students physical intuition. Physical intuition, or a feel for the physical world, is critical to the synthesis portion of the design cycle. Students initially find engineering mechanics counterintuitive; it is imperative that their engineering education expands their physical understanding of phenomenon. The most appropriate place for students to gain this insight into the physical world is in the laboratory. In the laboratory students can play with the phenomenon they are studying. They can explore the

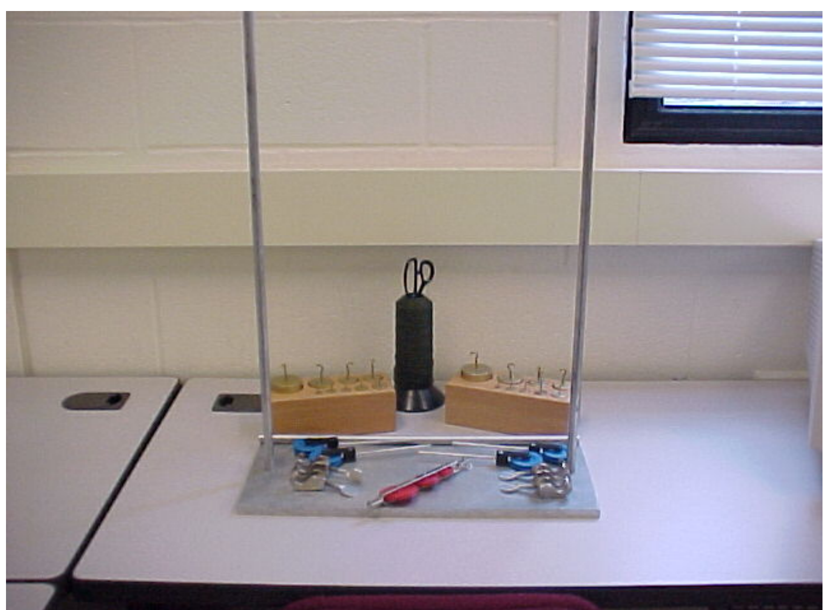

Figure 1: Vertical force table used in teaching Engineering Mechanics.

bounds of the theory and gain a deeper understanding of its significance. Students are repeatedly warned that physical intuition is only used to check problems, never to solve them. When your physical intuition does not coincide with reality it either means that you have made a mistake or that there are phenomena involved that you are unaware of. In other words, this is the point of discovery.

The courses in mechanics have laboratory activities almost every week, typically seven to eight laboratory experiences per ten week term. These experiences involve students looking at an engineering situation, modeling it mathematically, and then physically. Many of the laboratories make use of the vertical force tables seen in Figure 1. Using these tables students study both equilibrium and kinematics situations. The topics for the laboratories include transmissibility of forces, particle equilibrium, resultant moments/moments as a free vector, projectile motion, friction, equilibrium and motion of pulleys, and many more. As part of this laboratory sequence, students reproduce Simon Stevinus' 16th century experiment demonstrating the parallelogram law of vector addition. Figure 2 shows this experiment using model trains.

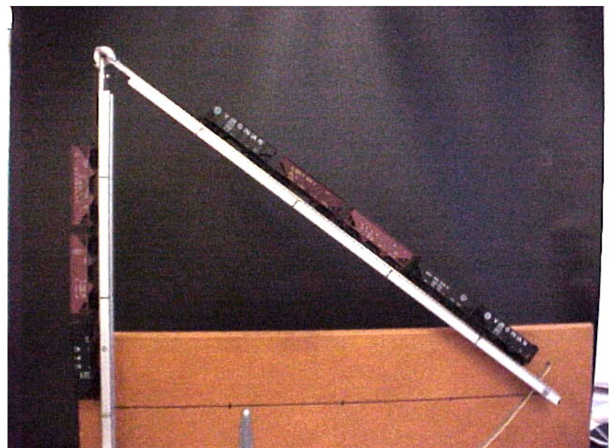

Figure 2: Set-up used to reproduce Simon Stevinus' 16th century experiment demonstrating the parallelogram law of vector addition.

An additional benefit of the laboratory experience is that students are introduced to technical writing. Students are required to write formal lab reports, summary reports, memos and to maintain a laboratory notebook. Similar report writing is required in all mechanics courses in the curriculum.

Design Experiences in Mechanics

Design projects have been incorporated into this course sequence to help students make the connection between the theory being taught and its application to engineering design. Design projects are carefully chosen to make sure that the phenomena involved in the design are within the context of the course. The design projects are introduced early in the course so that the

Figure 3: Mechanics course trebuchet design competition.

Figure 4: Mechanics course kicking machine design competition

project can be integrated into examples during the lecture portion of the course. Because the design project requires construction, it is important to make sure that the project can be reasonably constructed in two or three weeks. It is very important that students successfully complete the project. The design project also requires the students to prepare oral presentations of their final designs. Union's engineering programs prefer to integrate oral and written communication skills into the courses as opposed to offering separate courses in communication.

Some of the successful projects performed in this course include the construction of Trebuchet (Figure 3), kicking machine (Figure 4), rollercoasters, simplified walking machines, and tug-a-war vehicles. Students find these projects very stimulating.

Summary

Teaching mechanics from the perspective that statics is a simplified case of dynamics has been very successful at Union College. Static and dynamics grades on the FE exam have improved since the material has been taught in this fashion. It needs to be noted here that FE exam results are confounded by a trend in a higher quality of student attending Union College during the same time frame and the fact that not all mechanical engineering students take the exam. The number of students that did take the exam hardly forms a statistically significant pool. Anecdotally, students coming out of this course sequence appear to have a better grasp of the material and are performing better in the follow on courses. One of the difficulties with approaching the instruction of mechanics in this way is that there are no books on the market that use this approach.

Appendix I

OUTLINE FOR ESC019 – PARTICLE MECHANICS

PARTICLE KINEMATICS (4 WEEKS)

Review of Scalars and Vector, Reference Frames, Vector Derivatives, x, V, a
Rectilinear Motion, Relative Motion, Constrained Motion

LAB EXERCISE - Cam Motion Analysis

Curvilinear Motion – Rectangular Motion
Curvilinear Motion – Cylindrical Motion

LAB EXERCISE - Introduction to Videopoint

Curvilinear Motion – Tangential Motion

PARTICLE KINETICS (3 WEEKS)

FORCES, Free Body Diagrams and Systems of Particles
Particle Kinetics – Rectangular Coordinates

LAB EXERCISE - Particle Kinetics/Kinematics Lab – Pulley system

Particle Kinetics – Cylindrical Motion
Particle Kinetics – Tangential Motion
Equilibrium Concepts

LAB EXERCISE - Equilibrium – Stop Light Lab

Friction

LAB EXERCISE – Friction Lab

WORK AND KINETIC ENERGY OF PARTICLES (1 WEEK)

IMPULSE AND MOMENTUM TECHNIQUES FOR PARTICLES (0.5 WEEKS)

INTRODUCTION TO RIGID BODIES (1.5 WEEKS)
- The Moment Vector
- Equipollent Systems

LAB EXERCISE – Couples and Moments
- Equipollent Systems
- Centroids and Mass Centers

OUTLINE FOR ESC020 – RIGID BODY MECHANICS

RIGID BODY KINEMATICS (3 WEEKS)
- Introduction to the Loop Closure Equation
- Introduction to the Omega Theorem
- Translation/Rotation
- Planar Motion
- Angular Velocity
- Angular Acceleration
- Instantaneous Center of Zero Velocity
- **LAB EXERCISE-Kinematics of Linkages**

KINETICS OF A RIGID BODY (3 WEEKS)
- Equations of Motion
- Euler's Equation
- **LAB EXERCISE-Cylinders Rolling Down Inclined Plane**
- Conditions of Rigid Body Equilibrium
- Support Reactions
- Equipollent System Reactions
- Friction
- Tipping
- **LAB EXERCISE-Friction and Tipping**

TRUSSES and FRAMES (2 WEEKS)

- Plane Trusses
  - method of joints
  - zero-force members
  - method of sections
  - forces in straight and curved two-forced members
- Space trusses
- Frames

WORK AND ENERGY METHODS (2 WEEKS)

- Work of Forces and Couples Acting on Rigid Bodies
- Kinetic Energy of Rigid Bodies in Plane Motion

Principle of Work and Energy for the Plane Motion of Rigid Bodies
Power
LAB EXERCISE-Analysis of Design Project

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