"Catastrophic Failures", *"Designed for Failure"*, and *"Adventures in Mechanics"* One Credit Freshman "Mechanics" Seminars

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As part of its mission to provide, through service courses, the fundamentals of mechanics and materials, the Penn State Engineering Science and Mechanics Department created the following one-credit freshman seminars: ***Catastrophic Failures***, ***Designed for Failure***, and ***Adventures in Mechanics***. The objectives of these three one-credit mechanics/materials-related seminar courses include:

- initiate meaningful dialog between students and faculty,
- inform students as to ethical expectations,
- orient students as to particular options of study,
- demonstrate via case studies what engineers 'do', and
- provide laboratory awareness and experiences.

Catastrophic Failures

Engineered systems sometimes fail in catastrophic ways.... bridges collapse, buildings burn, airplanes explode, ships break in two, spontaneous combustion occurs, autos crash, etcetera. Virtually all such failures occur because the designers, builders, and/or users have overlooked some unexpected combination of inputs; they seldom fail due to simple overload. For example, a bridge designer may have overlooked the potential danger of aerodynamic loading and mechanical resonance, or having a bridge mooring struck by a tugboat; the building designer may not have considered an earthquake; the ship designer may not have expected a combination of very cold weather and large waves, nor 'bad material' etc. This seminar explores such design deficiencies through the study of case histories of a number of infamous failures, such as the explosion of the Challenger (modern era) and the sinking of the Titanic, which caused catastrophic loss of life. A primary objective of reliving such failures is to alert students to the various factors that must be considered for a safe and effective engineering system, and to encourage them to broaden their education so that they will not repeat the mistakes of the past in their own careers. An example of a bad result is summarized below.

> *Broken Engine Mount Recall*
> Engine designed prior to pressurization for re-burning vapors, pressurization led to oil leaks, oil leaks onto rubber engine mount, mount degraded to point it could not restrain upward motion, on hard cornering (centrifugal acceleration) and acceleration (engine torque), engine lifted out of support cradle, and in some cases jammed accelerator as well as gear selection. Result; auto goes out of control.

Designed for Failure

Engineering mechanics and materials behavior are the foundation of many engineering devices that are intended to fail under controlled conditions in a predetermined manner. Thus, shear pins, fuses, tabbed pull tops on soda cans, tear-lines on paper towels, water-sprinkler valves, air bags, crumple zones on automobiles, sacrificial ceramic tiles on the space shuttle, break-away signs, are examples of items that are designed by engineers to fail in a predictable way. The appropriate mechanics, such as fracture mechanics, behind such failures, and the material response, such as ductile/brittle transitions are considered and illustrated via classroom demonstrations, movies, and current articles. Proposed legislation regarding *Mandated Buyback, Disassembly, and Disposition of Manufactured Products* and the significant engineering challenges this will entail is discussed. For example, the disposal of rubber tires that have been engineered 'not to fail under severe loading', continues to be a national problem, particularly as environmental impact is considered

Course Format, Student Participation, and Evaluation: The course is shared with various faculty members speaking on their interests and expertise. Students participate via a 100-word, or less, critique of each class (50 minutes each week), a brief report (one to two pages) on an appropriate item from at least 50 years ago (due at mid-term), and a concise report (two to three pages) on an item of contemporary interest. Class discussion is encouraged.

Adventures in Mechanics

Adventures in Mechanics is a 1-credit freshman seminar that seeks to have students explore the field of mechanics of common products in a 'hands-on' way. All three branches of mechanics are considered: experimentation, theory, and computation. Student teams are formed to make measurements, do calculations, and discuss issues. Topics include:

- Error analysis – a formula for the volume of a block with a circular hole is derived, measurements are taken to determine the most probable value of the volume, the formula is differentiated with respect to the measured quantities to estimate the error in the calculation.
- Bungee cord – weights are applied to bungee cords having different lengths and diameters, elongation is measured, force-deformation and stress-stress curves are plotted to demonstrate why stress and strain variables are used in mechanics rather than force and deformation.
- Soda can – is strain gaged in order to determine the pressure release upon popping the top. The theory of the strain gage and strain gage circuitry is briefly discussed. The effect of temperature on internal pressure is also illustrated.
- Bicycle – student groups discuss how various components of a bicycle carry load and could possibly fail (e.g., handlebars, frame, crankarms, spokes, brake cable, brake pads, chain), bending of the handlebars and pedal spindle are discussed and strain gage measurements taken, combined bending and torsion of the crankshaft is discussed and analyzed.
- Meter stick – Deflection measurements of a meter stick as a cantilever beam are used to determine its Young's modulus. An error analysis is performed. Later in the semester the same meter stick is used to validate Euler's buckling formula.
- Dynamics – Newton's 2^{nd} law is experimentally validated via vibration of a cantilever beam.
- Computer aided engineering – Finite element analysis software is discussed and commercial codes are demonstrated from company websites.

- Interactive materials – shape memory alloys, magneto-rheological fluids, and piezoelectrics are demonstrated.

Student Feedback

All ESM courses are evaluated each semester via the SRTEs (student ratings of teaching effectiveness), which are distributed and collected by staff (in the absence of the faculty) during class near the end of the semester. In addition to numerically rating the course and the instructor, students are encouraged to provide written comments. Nearly all the freshmen did so and nearly all the freshmen attended all class sections. Several themes were prevalent; i) students did not want to "see equations", they wanted to "see demonstrations", ii) they commented negatively on both "overheads" and "Power-point" type presentations although they responded positively to professional level videos, and they were disappointed that they were not exposed to more laboratories (they have 3-4 such visits). For all three seminars a strong sentiment for "more hands-on" experiences was noted. One of the expected outcomes of successfully meeting our objectives is an improved retention of students. To this end one student wrote "...now that I know what engineers do, I am going to switch into Business," yet most students wrote positive comments about their experience with several noting on the forms or to their instructors that they intended to choose Engineering Science (the departmental BS curriculum) as their major. At Penn State such choices are generally made at the end of the sophomore year. As this is only the second year for the courses, we have no hard longitudinal data, only our impressions. Perhaps the best measure of the value that we believe these courses have is that we are more-or-less offering them via a faculty overload with minimal compensation. To date the faculty has enthusiastically supported this activity.

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Richard P. McNitt has been a Professor and Head of the Engineering Science and Mechanics Department at Penn State University since 1981. He is a Fellow of the Society of Engineering Science, and a member of: ASEE, the American Academy of Mechanics, the Association of Chairmen of Departments of Mechanics, the Society of Experimental Mechanics, Sigma Xi, and the Order of the Engineer. Dr. McNitt advanced from an Assistant Professor to a full Professor in the Engineering Science and Mechanics Department at the Virginia Polytechnic Institute and State University between 1965 and 1981. He received a B.S. in Engineering Science from Penn State University in 1957, a M.S. in Engineering Mechanics from Penn State University in 1959, and a Ph.D. in Engineering Science from Purdue University in 1965.