AC 2007-1341: INTEGRATING A MACHINE SHOP CLASS INTO THE MECHANICAL ENGINEERING CURRICULUM: EXPERIENTIAL AND INDUCTIVE LEARNING

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Integrating a Machine Shop Class into the Mechanical Engineering Curriculum: Experiential and Inductive Learning

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Introduction

Inductive learning begins with concrete experience, observations, or a question, and then develops knowledge, skills, and theory from that basis[1]. Research has demonstrated it is superior to the more traditional deductive learning methods in that inductive learning promotes deep knowledge structures, critical thinking, and intellectual development[1]. Further, industrial employers have often called for mechanical engineers who have hands-on skills and integrated knowledge[2-3]. This paper examines how a Machine Shop Practices and Solid Modeling course (MENG 351) is integrated with other concurrent or future courses, utilizing an inductive and active learning model[1,4]. We expect that the integration of hands-on machining/fabrication, experimentation, analysis, design, and theory results in less compartmentalization of knowledge, greater student enthusiasm, and deeper learning of concepts. Integration of MENG 351 occurs across a number of courses, including Systems Laboratory, Mechanics of Materials, Machine Design, Thermodynamics, and others.

Projects were carefully chosen to achieve the learning objectives of MENG 351 and to interface with future courses in the inductive learning process. The shop portion of MENG 351 is aimed at developing skills in woodworking, manual machining, and sheetmetal fabrication. In a later course (Manufacturing Processes), students develop CNC and welding skills. Students worked in teams of 2 for almost all projects. In the shop, this buddy-system arrangement helped ensure students were attentive to each other's safety; no significant injuries occurred throughout the course.

Woodworking Projects: Fast-Return Actuator and Acoustic Guitar

As their introductory project to woodworking equipment, students constructed a simple mechanism (Figure 1). This fast-return actuator (an inversion of the slider-crank mechanism) is then analyzed in the concurrent Dynamics class. This project taught skills on the miter saw, table saw, drill press, sander, and band-saw. The basic design was adapted and modified from Levy[5]. Mechanical engineering students sometimes have pre-existing skills in woodworking; this project was designed to allow both basic and advanced versions, to provide challenge to all levels. This project typically took 1 lab period.

For their second woodworking project, students designed and built simple acoustic guitars (Figure 2). This project interfaces well with a Vibrations course, incorporating vibrating strings, resonance, and acoustic coupling[6]. A schematic-only neck and box design was provided, and most students enjoyed modifying the basic design towards styling or greater size. A through-body neck was specified to ensure strength and linear alignment of neck and body. The soundboard is reinforced on its backside and uncoupled from the neck. Instrument-quality guitars are made from expensive tonewoods such as spruce, cedar, mahogany, and maple. But, adequate resonance properties can be obtained from less expensive materials: 1/8" Baltic-Birch plywood was specified for the soundboard and back of the body, ¼" poplar for the body sides, and ¾" poplar for the neck. Strings were made from nylon fishing line (30 – 80 lb test) and 10-24 eyebolts worked as tuners. The guitar project developed similar skills as the fast-return actuator, but at greater precision. This project took 2 lab periods, and generated high student enthusiasm and creativity.

Figure 1: Sample fast-return actuator -- the students' first woodworking project. Pulley at rear is for optional drive system by DC motor and pulley.

Figure 2: Students from one lab section showing guitars and term projects.

Sheetmetal Project: Reinforced Hollow Beam

To practice sheetmetal forming methods, and to provide an experiential basis for beam theory in Mechanics of Materials, pairs of students designed and fabricated hollow aluminum beams with various cross-sections and bulkhead designs[7]. The students learned to use the following machines for this project: 52" Stomp Shear (Pexto), 6" Corner Notcher (Enco), 40" Box/Pan Brake (Grizzly G0578), Hand drill, and Pop-rivet gun. The students were constrained to making the main beam cross-section from an 11"x16" sheet of .032" thick 5052-H32 aluminum. Bulkheads were made from additional material. Students were encouraged to try different cross-sections (rectangular, U, I, and triangle sections) as shown in Figure 3. Most teams choose a 2"x3" rectangular or I-section. To prevent collapse of the cross-sections, bulkheads were specified at each of the 3 load application points, though the detail design of each bulkhead was up to the students. Beam construction generally took 1 lab period. All beams were tested in a 3-point bending test fixture of 15" span, recording the maximum load and mode of failure, and the test specimens are being saved for later analysis in Mechanics of Materials.

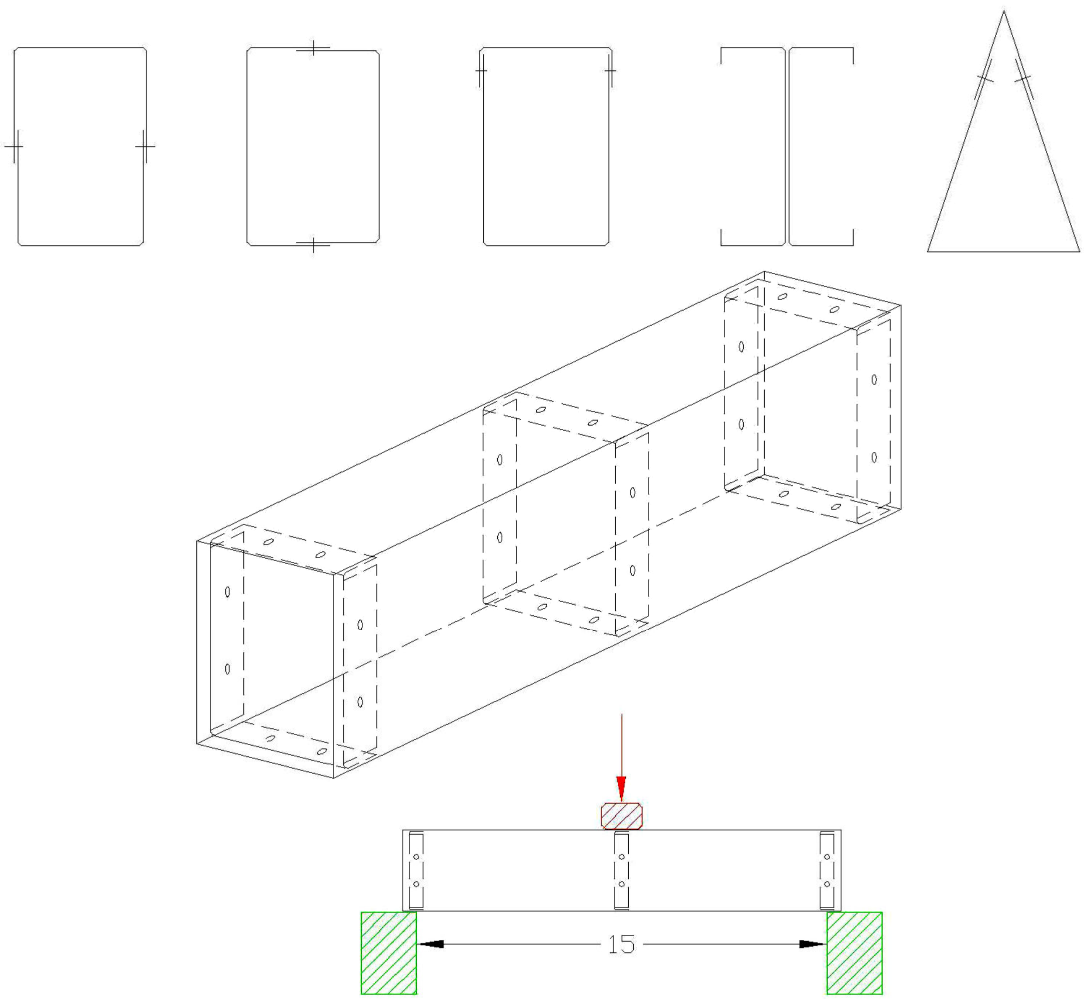

Figure 3: Suggested beam cross-sections, Assembled beam with bulkheads, and loading schematic. Full dimensioned drawings are available at http://home.sandiego.edu/~dmalicky

The students' beams held between 405 and 1188 lbs, substantially below their theoretical capacities. For the rectangular-section beams, failure was typically local buckling of the thin aluminum sheet (Figure 4). Specifying a thicker material would help prevent premature failure from local instability. This buckling clearly illustrates the compressive stresses acting on the upper flange. For the I-section beams, failure was typically lateral-torsional-buckling (Figure 5). Seeing both of these non-ideal failure mechanisms first-hand helps prepare students for the complexities of real-world design.

Figure 4: Sample rectangular cross-section beam in test fixture, after failure.

Figure 5: Sample I-beam in test fixture, exhibiting lateral torsional buckling.

The various beam cross-sections will be analyzed when they take Mechanics of Materials, where students can calculate the moment of inertia, shear forces on the rivets, and theoretical maximum load for their beams. Then, they can compare their analyses to their own experimental specimens and data and recommend changes to the design. The construction and testing of the beams provides a direct experiential basis for the development of beam theory, following inductive learning principles.

Machining Project: Compressed Air Engine

The primary project of MENG 351 is the machining, assembly, and testing of small one-cylinder compressed-air engines, as has been done at other institutions[8-12]. In addition to teaching machining skills (Figure 6), this project initiates inductive learning pathways through multiple courses: Machine Design, Manufacturing Processes, Thermodynamics, and others. The engine design is based on previous simple oscillating air/steam engines[e.g.,13] with updates such as a bronze bearing for the crank journal. The students followed dimensioned drawings developed by the instructor, incorporating some GD&T notations (Figures 7 and 8). Students were encouraged to modify this design for more power or better vibration characteristics. Students learned to use these machine tools for this project: 12"x36" Engine Lathe with DRO (Birmingham, Sony), Manual Milling Machine with DRO (Lagun, Sony), Horizontal Bandsaw (Jet), Tool Grinder, Drill Press, Dial Caliper, and Vernier Micrometer. Before starting machining operations, all students developed Operation Sheets for each part, which were reviewed by the instructors. On the lathe, almost all students successfully held a +/-0.0005" tolerance for their piston diameter. Additional practiced skills included print-reading, use of machinist tables, press-fitting, tapping, assembly, and shop professionalism. A sample student engine is shown in Figure 9.

Figure 6: A student team machining the cylinder for their air-engine.

The importance of holding tolerances becomes extremely clear to many students during the assembly phase. For example, holes intended for a press-fit often required rework due to a reamer that was cutting oversize. Or, the smoothness of running was occasionally hampered by a non-perpendicular cylinder bore. Students then learned various techniques for overcoming such difficulties, and in the end, all engines ran.

Engines were tested on a simple Prony-brake dynamometer (Figure 10) for minimum pressure required to run (typically 1-2 psi), minimum speed at that minimum pressure (200-300 RPM), speed at 30psi (1200-3000 RPM), and shaft output torque and rpm at 30psi, from which they calculated power (3-6 watts).

The kinematics of the inverted slider-crank mechanism will be analyzed in their first Machine Design course, and the theoretical output power will be examined in Thermodynamics. Valve port flow may be analyzed in Fluid Mechanics. Numerous manufacturing details of the engine will be drawn-upon the following semester in Manufacturing Processes. The engine design-build-test project develops precision machining skills and forms the basis for multiple inductive learning processes.

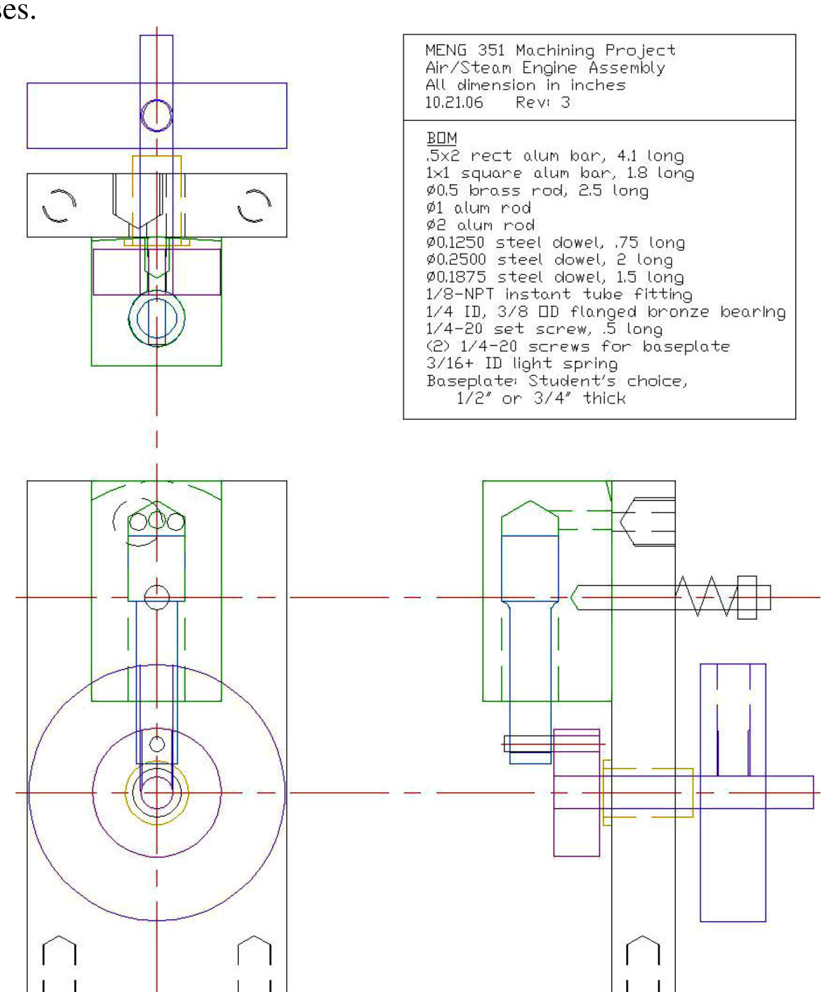

Figure 7: Assembly Drawing of Compressed-Air engine.

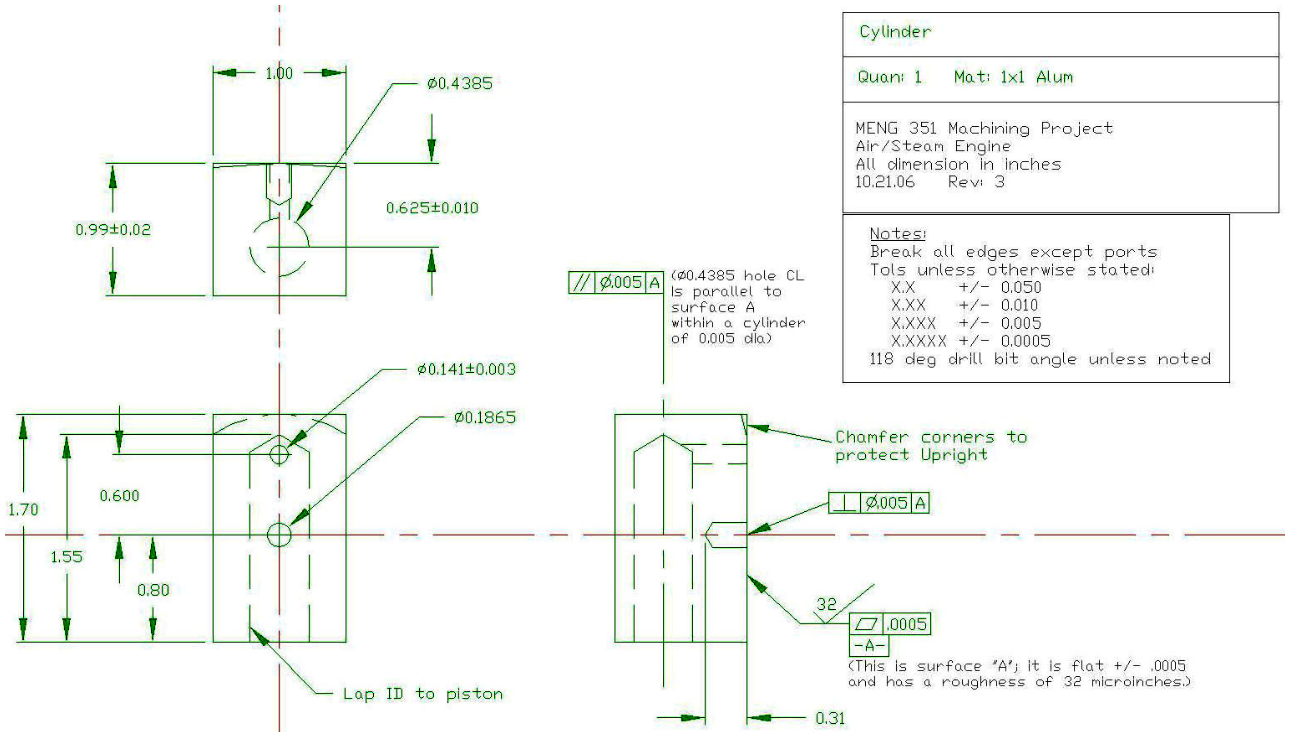

Figure 8: Cylinder drawing for compressed-air engine. All detail drawings are available at http://home.sandiego.edu/~dmalicky

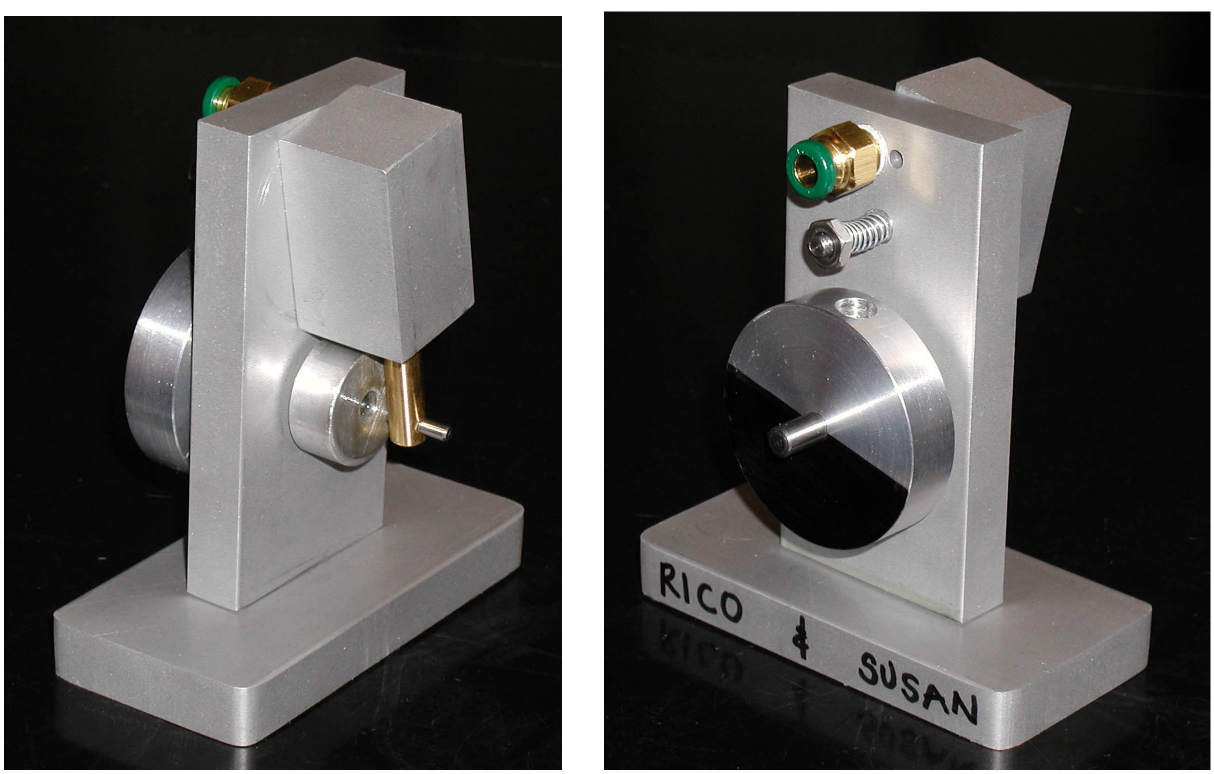

Figure 9: Sample student-machined compressed-air engine.

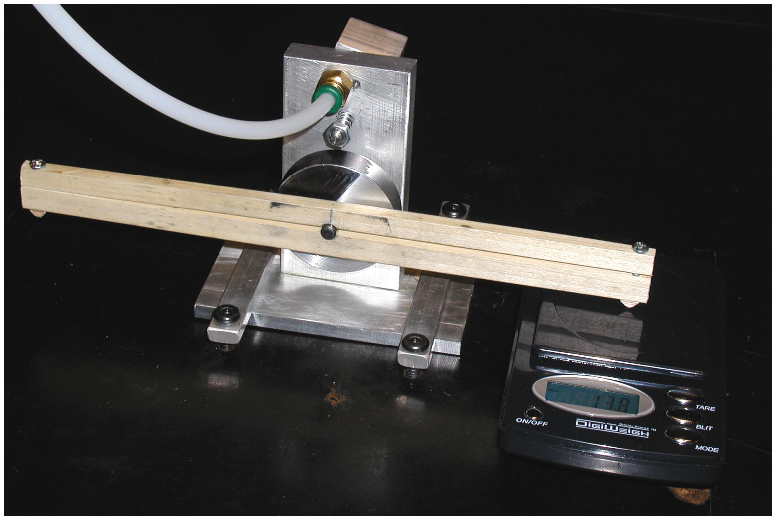

Figure 10: Prony-brake dynamometer setup. RPMs were measured using an optical tachometer pointing at the flywheel.

Systems Laboratory Design Project: Catapult

In our Mechanical Engineering Systems Laboratory, teams of 3-4 students build a catapult to serve as a Taguchi design-of-experiments project[14]. The catapults are of the students' own design, but must allow variation of three parameters in order to maximize distance, accuracy, and precision of each launch. Further, the catapults are stipulated to fit within an 18" cube. The teams built solid-models of their design and then constructed and tested their catapults. Teams selected tension springs and torsion bars for the energy-storage device. Instructors of both courses have found that combining the efforts of their courses around one project results in a more intensive and integrated learning experience.

Figure 11: Student-designed and built catapult during testing.

Assessment

The course outcomes define knowledge and skills that students are to obtain by the end of the course. The machine-shop related outcomes (related ABET a-k outcomes in parentheses) and instructor assessment are in the following table:

Course Outcome	Instructor Assessment (0-10)
1. Understand the capabilities and limitations of standard manual machine tools. (a,c,**k**)	7
2. Understand and demonstrate safe machine shop practices. (**f**,g,j,k)	9
3. Safely operate hand and power hand tools. (**k**)	9
4. Setup and safely operate manual machine shop equipment (lathe, mill, drill press, grinder, shear, notcher, brake) to manufacture metal parts. (a,c,e,**k**)	8
5. Setup and safely operate wood-working equipment (table saw, bandsaw, belt sander, drill press) to manufacture wood parts. (c,**k**)	8

Assessing the relationship of the learning experiences in this course to inductive student learning in future courses is ongoing; the first set of this data will be collected at the end of the Spring 2007 semester. Student ratings of this course were quite high, ranging from 4.8 to 4.9 (0-5 scale) for the overall questions "The course as a whole was..." and "Course content was...". Student enthusiasm for the course was strong and widespread, with a number of students commenting that it was their favorite course to date.

Conclusion

MENG 351 teaches hands-on machine shop skills that are fundamental for the development of the students' design and industrial abilities. But equally important, the integration of MENG 351 machine shop projects with other courses adds depth, ownership, and integration of the entire learning experience. Assessment of these effects is ongoing. As the projects were carefully chosen to integrate with content from concurrent and future courses, some of this enthusiasm carries over to these more theoretical courses. Further, the active learning design-build experiences provide students with an experiential base from which they may construct more theoretical knowledge structures. The model presented in this paper transforms the traditional deductive learning model into inductive and active learning.

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