Review of Project-Based Learning in a Junior Level Mechanical Engineering Course

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Abstract

The use of project-based learning in a junior level mechanical engineering course, Machine Design, is reviewed and discussed in this manuscript. The Machine Design course focuses on application of engineering analysis to the design and selection of machine elements. A significant part of the course is an open-ended design experience via project work. The project component was typically a semester long exercise, culminating in a formal written report. Project goals were to provide a realistic mechanical engineering design experience for the students, similar to what a new graduate engineer might do, but to a limited degree. The specific project varied from year to year. In some instances students were allowed to suggest and vote on projects, while in other instances projects were developed without student input.

Starting with a machine functional description, operating conditions, and limited specifications/ design requirements, students interpreted the given information in engineering terms of parameters and values, creating detailed engineering specifications. All projects required visualization and modeling. Stress analysis was performed using a combination CAD models and hand calculations. Students were tasked with developing static, dynamic, and cyclic loads. Fatigue life and maximum loadings were to be considered in the stress analyses. Students were limited to designing specific engineering elements to focus their efforts into time-appropriate projects. Design work included making an engineering drawing of the device assembly, determining power requirements, stress analysis of major frame/body in critical locations. Shafts, threaded fasteners, springs, , power transmission (belts, chains or gearing), keys, couplings, and bearings were also required design elements, selecting actual commercial components where possible, applying appropriate vendor engineering data in lieu of generic textbook data. Students were required to critic their final design, suggesting revisions based on their final design results.

Variations in the project implementation were reviewed and analyzed over 10 years for success, with varying project content and structure. Course size also varied and had much to do with the project structure.

Project implementation was compared to those found in the current literature for project-based learning, focusing on machine design.

Keywords

Mechanical engineering, machine design, projects.

Background

As the "capstone" mechanical design course, machine design has a role to provide students a realistic engineering design experience through open-ended project work. It is the author's belief that the experience is best accomplished individually, allowing each student the opportunity to design, make assumptions, decisions, and develop their engineering skills in all the areas of focus of the project. However, group work was often employed.

Integrating design into the curriculum has been a significant effort for many, if not all undergraduate engineering programs[1,2,4]. While it is important to keep students interested and active in design at each academic level (Freshman through Senior), the design experience in the capstone subject course, such as machine design, is critical to develop many of the skills crucially need in their senior design and in engineering practice. Much of the success of the student's design experience depends on the project(s) and project structure.

While this paper discusses the use of open-ended projects in various sized classes. Pervious work by Hsu[3] describes project work for open-ended design experiences in large classes, specifically. In this manuscript a small process-focused design structure of several smaller projects was found a successful alternative to a single semester long project.

Class Size Matters

With smaller class sizes (25 students or less), project work consisted of a single, end-of-semester project by individual students culminating in a final report. This approach resulted in much of the student work being performed at the end of the semester with quality and content varying, due to student schedules, other course assignments, or procrastination. For some students the semester-long task appeared too daunting. A partial submission was next added in later implementations to prevent students from saving all work until the end of the semester.

As class size exceeded 30 students, individual projects became unmanageable. Group projects were given, but work was usually divided amongst the group members. This resulted in students having a limited or segmented design experience. In many groups work was not equally divided.

With class sizes approaching 50 students, another approach was taken to even the course load for the students and the instructor. Two smaller, focused projects of a more limited scope were employed rather than the semester long project. The goal of providing a realistic design experience remained.

Single Semester Projects

The project began with a description and a limited set of specifications. Usually the class was solicited for design project ideas. Students were given choices of two offered projects. Specification limits (power, speed, acceleration) and determination of appropriate loadings were to be developed by the students. Estimation of maximum and cyclic loadings were key parts of the project. A significant amount of engineering and judgement was needed in the development of performance specifications and loadings. A typical project is listed in Table 1 from a recent course offering. To add structure and limit the design extent to a doable student task, project design and analysis requirements were focused and limited. Design tasks were set to an achievable number, while allowing the student to have an opened-ended experience in the machine design areas studied in class. Table 2 lists the requirements of the students for their design tasks and for their reports.

Table 1. Typical Project: Mini trash crushing compactor

1. Design a Mini trash crushing compactor for home use.
2. Should be no larger than a standard dishwasher.
3. Use hand power or an electric motor as the power source for indoor use. (Note: 110 V-AC, 15 A is available.)
4. Should be movable.
5. Should reduce standard household waste to significantly smaller volumes, the design should reduce volume by at least 50%, more compaction is better.
6. Design for a minimum life of 10 years.
7. A minimum safety factor of 2 is required.

Table 2. Project Design Requirements

1. Specifications defined
2. Develop power, force, acceleration and geometry requirements
3. Design concept developed a
4. General drawing of device embodiment showing overall dimensions
5. Free body diagrams of forces and reactions, static and dynamic
6. Stress Analysis: Major element frame/body 2 most critical locations, consider maximum and fatigue loading
7. Shaft design (1 location)
8. Select fasteners (2 different locations/loadings)
9. Spring design and selection
10. Coupling and selection
11. Power transmission design: Gears, Chains, or Belts and selection of components
12. Key design and selection
13. Bearings selection for shaft designed

By performing the design work in these projects students become accustomed to using industrial sources for common mechanical hardware, applying the appropriate design theories and engineering procedures, using industrial resources. Students were given an opportunity to learn to how to make good assumptions in the design process. They were required to decide which parts or components were most critical to analyze, and how to analyze them.

Students applied finite element analysis, computer aided design, use and selection of standard commercial components using industrial standards in their design. The design work also included determining and estimation of the maximum and cyclic loads to evaluate.

Students investigated and applied human factors and ergonomics in their designs decisions, and force estimations. Requirements were often provided to them in laymen's terms or human use terms for their interpretation and development into numerical specifications. For example a seat height should adjust to accommodate a 5th percentile female and a 95th percentile male.

Two Focused Design Projects

In the first implementation of using smaller, but focused design projects, two projects were given. The first was a seat bracket design for a lawn mower, and is defined in Table 3 and the required design elements given in Table 4. The second project was a gear box design for a small (~10 kW) wind turbine. General requirements are provided in Table 5 with Table 6 detailing the required design elements. Benefits of multiple focused projects include reviewing a typical design for the procedure used in the initial project.

Table 3. Project : Lawn Mower Seat Support

1. Design a seat support attached by bolts for the given lawn mower seat to mount the ¼-inch 1020 steel decking platform of a riding mower.
2. Consider using aluminum or steel for your seat support. Specify which specific type. Use sheet or plate or extruded shapes available from McMaster-Carr .
3. Select the attachment bolts (type size and length) and specify the bolt preload.
4. Design for a minimum life of 10 years, or infinite life.
5. A minimum safety factor of 2 is required for the bracket, bolts, and joint separation.
6. Consider the acceleration and breaking of the mower to be +/-40 ft/s/s.
7. Design for a person weighing 300 pounds will be sitting in the seat.
8. Determine an appropriate height for the seat based on average male anthropomorphic data.

Table 4. Project Design Requirements for the Lawn Mower Seat Support

1. Specifications defined
2. General drawing of seat and support showing overall dimensions
3. An engineering/manufacturing drawing of your bracket is required
4. Determine loading (mean and alternating forces and moments).
5. Free body diagram
6. Stress Analysis of frame 2 most critical locations or FEA, consider maximum and fatigue loading.
7. Select fasteners (2 different locations/loadings)

8. Specify preloads, determine your factors of safety for bracket, bolts, joint separation

Table 5. Project: Gearbox for 10kW Generator

1. Minimize component weight and size.
2. Have a nominal gear ratio of 14:1 to 15:1 for a speed increase from the input shaft
3. Input and output shafts must in the same vertical plane for symmetry/balance.
4. Axial (thrust) load at the input shaft is modulated by blade pitch to be about 50 lbs.
5. All but the first bearing will have only radial loads.
6. The turbine blade speed is regulated by the blade pitch to be a constant 55 RPM.
7. The turbine blades and hub together weigh 110 lb and are mounted/clamped directly on the input shaft, 3 inches from the gearbox.
8. The generator connects to the output shaft through a flexible coupling that transmits only torque, no forces.
9. The design life is 10 years of continuous operation.
10. Factor of safety of 1.5

Table 6. Project Design Requirements of Gearbox for 10kW Generator

1. Include an overall assembly drawing
2. Gear Specifications and Commercial Selection
3. Force Analysis Specifications
4. Bearings Specifications and Commercial Selection
5. Shafts Specifications and Commercial Selection

Figure 1 depicts the averages for the project submission score and the final project submission score over years 2003-2016. Years 2003, 2004, 2014, 2016 were years where all work was individual. All others were group efforts. 2016 was the first year of two focused smaller projects replacing one large project. Clearly the grading differences are small. However, the variation between the grade average for all project work and the final project submission was smaller than average values in 2016. 2016 scores were in the upper third for all years.

Conclusion

Data is very preliminary and may not be statistically significant. However, the use of two smaller projects to replace the single semester project was found to be more correctly and completely performed by the students in a larger size class, as compared to a single larger project in smaller class sizes.

Students also stated that they were less overwhelmed with the project work, while accomplishing very similar design tasks to a single larger project. The two projects were also more easily graded with the first project providing quality feedback for the second project. It is anticipated this approach will continue to be implemented.

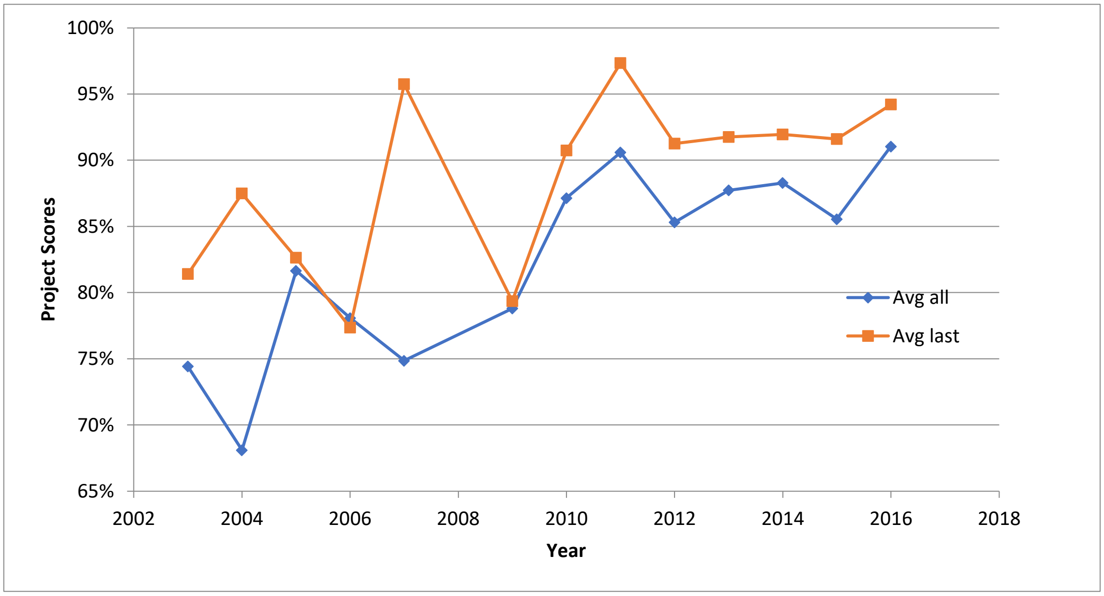

Figure 1. Average of All Project Work and Average of Final Project Submission

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