# Project-Based Laboratory Experiences in Mechanical Engineering

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## ABSTRACT

In this paper we describe project-based laboratories in Mechanical Engineering designed to provide semester-long team experiences which mimic the real life industrial processes of design, development, testing and optimization. The labs are focused on courses at the sophomore level and thus require special attention to constraints of student backgrounds and experience. This paper describes laboratory projects in Dynamics and Fluid Mechanics.

**Keywords:** Project-based, Laboratories, Mechanical Engineering

## INTRODUCTION

At introductory levels in Mechanical Engineering and Mechanical Engineering Technology, students often face challenges in connecting lecture material to real-life experiences. All too frequently, students may not see the relevance of theoretical concepts being presented until they themselves apply those concepts to a practical and concrete problem. Short (one class and or one week) problem-based projects can assist in bridging the gap between theory and practice. These experiences though typically do not provide students with an experiential understanding of the process by which engineering is actually done in industry and academia. This process includes working with others to take the required outcome and develop a strategy for accomplishing it in a manner which seeks to optimize outcomes while working within practical engineering and business constraints, evaluating materials available and conducting cost benefit analyses of various designs, actually constructing the selected design, testing the prototype for desired qualities, optimizing the design and prototype and preparing and presenting team reports on the final results. The goals of the semester-long project-based laboratory experiences being developed at Naugatuck Valley Community College are to enhance student learning, motivation, comprehension and retention by providing students the opportunities to form connections between theory and practice, to learn teamwork skills, to build understanding of how engineering is done in the real world, and to develop an appreciation for the entire process of project engineering.

## DYNAMICS LABORATORY

Students in Dynamics spent a semester developing designs for, constructing, testing and optimizing trebuchets. Students' background at the start of the course included a minimum of one semester freshman level Statics course and one semester of Calculus. The majority of the students had little to no experience in team project situations. The students were divided into teams and provided with a task (build a trebuchet), desired qualities to incorporate (long range projectile toss relative to size of throwing device, accuracy and repeatability), constraints (cost, size, materials) and timelines for project completion. Over the course of the semester, as a team, they were required to design, in CAD, their own trebuchet, construct it, test it, optimize it, compare results with theory and prepare written and oral reports on the results. Each phase of the project including design, construction, testing, report writing, etc. had its own different team leader chosen from among the team members. An element of competition was introduced as a motivating factor, with the team in the class having the most repeatable projectile toss and the team having the longest toss scaled by trebuchet size garnering extra points.

A sample of information provided to the students at the beginning of the first lab is given below. Students were asked to design, build and test a trebuchet using materials provided. They had to get prior approval of the instructor to use any additional materials to build the trebuchet. The cost of additional material (if any) was the students' responsibility. Students were divided into teams of 3 or 4 students and over the course of the semester they designed the trebuchet in CAD or neatly by hand, built it to the specifications below using only the materials provided, and had to be able to launch projectiles over some distance repeatably. The design had to include not only the overall trebuchet, but also a retaining/firing mechanism so that the projectile fires when the mechanism is activated, and, if using a sling (which was highly recommended), a release mechanism for the sling. The team then compared their experimental data with calculated results using the theory learned in the lecture portion of the class. *Objectives:* 1) Throw the projectile the greatest distance scaled to the size of the overall design 2) Throw the projectile repeatedly to the same spot. *Specifications:* 1) The fulcrum (or the firing arm pivot) must be less than 2 feet from the ground. 2) The energy for the firing must come from the falling counterweight i.e. gravity-powered (no springs, elastic bands or hand powered units etc.). Students were encouraged to make the trebuchet as small as they would like. 3) The trebuchet had to be freestanding and be able to safely launch the projectile. The base of the trebuchet could not be more than 3 feet by 3 feet. 4) Students could add wheels (at their own cost), but these should fit within the overall base and height requirements. Materials supplied to each group were listed. Notes on some major theoretical issues to be considered in construction were given. Since designs were to include parameters which are variable such as counterweight mass, etc., suggestions for experiments which could be conducted by varying these parameters were noted. Students were asked to designate a team leader for each portion of the task (Design, Construction, Testing, Report Writing etc.). Other than the overall dimensions and the materials provided, the design was entirely up to the group, which was encouraged to be creative. The design had to be the group's own, not copied (or closely adapted) from any source. The team leader provided a verbal progress report to the instructor each week. The team leader was specifically asked about the performance of the other members of the team, and this report had an impact on the individual grade of the team member. All team members were expected to be in the lab during lab times to work on the project. A tentative schedule for the lab is shown in Table 1 below.

Table 1: Lab Schedule

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|---|---|
| Week 1-2 | Introduction, Team Formation, Research |
| Weeks 3-5 | Design; Finalized designs due by week 5 |
| Week 6-9 | Construction (Prototype ready by week 9) |
| Weeks 9-12 | Test and Modify (Final working *trebuchet* ready Week 12) |
| Weeks 12-15 | Data Collection, Report Writing, Preparation for Presentation (Final Report Due week 15 Presentation to class on week 15) |

The final report and the presentation was a coordinated effort between all the members of the team. Each member was able to assess the performance of the other members of the team at the end of the semester. 40% of the final individual lab grade was based on the final lab report, 20% on the presentation of findings to class, 20% on the progress reports and the instructor's assessment of each student during the semester, and 20% was based on the scoring of the projectile "fling" based on the scaled distance and repeatability. The "fling" was scored as follows: 10% to the team with the largest scaled distance calculated by averaging five farthest distances flung from the front of the trebuchet in feet divided by the (base dimensions * height to fulcrum) of the trebuchet in cubic feet, 8% to the next lower, 6% to the next, 4% to the next etc. 10% to the team with the most repeatable launch, 8% to the next most repeatable, 6% to the next etc.

Students designed both large and small trebuchets. Figures 1 show sample student teams' CAD designs and constructed trebuchet prototype.

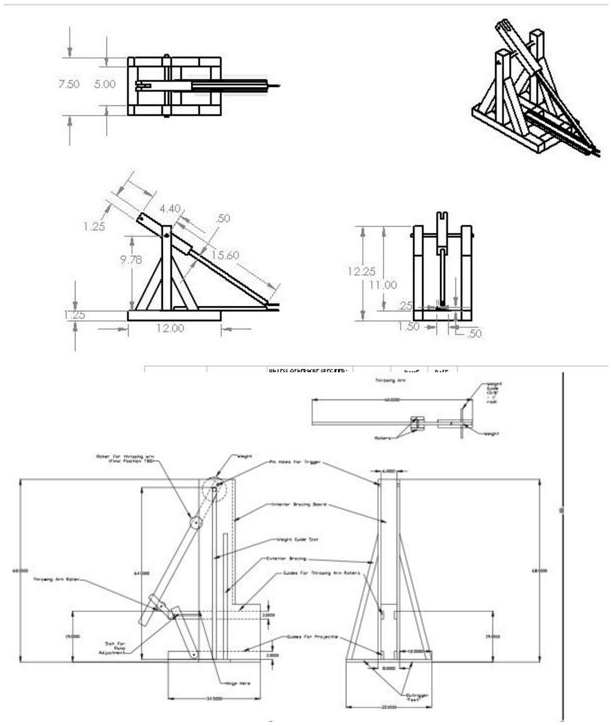


Figure 1: CAD design of trebuchet

Figure 2: Trebuchet Prototype

## FLUID MECHANICS LABORATORY PIPE FRICTION PROJECT

Two different semester-long team fluid mechanics laboratory projects were developed. Students in this course had no calculus or dynamics background at the start of the class. They had completed Statics and Trigonometry. The first project asked students to imagine working for an industrial facility in which they had to develop a mechanism to test friction losses in their piping systems. The second project asked students to become "municipal water engineers" and design a system for delivering water to a series of communities. Each laboratory followed general steps of design construction testing and reporting as discussed in the Dynamics Lab example.

The first Fluid Mechanics Lab, which was the friction losses in piping laboratory experience, provided information to student teams including that given below. Students were asked to design, build and test an apparatus to measure the friction losses in piping systems and their components. They were divided into teams of 3 or 4 students and over the course of the semester designed a piping network, built the network by purchasing all components and tested their design to see how well their experimental data matched their theoretical predictions. In order make the labs mimic a real design process, each team was required to stay within a budget, determined by the instructor. If the cost of their apparatus exceeded a particular threshold points were deducted from the final lab grade. If the team completed the project under a given threshold budget they received extra credit. The apparatus had to contain the following minimum requirements: 1) A test section that measures the friction loss in straight length of pipe (minimum two feet). 2) Minimum ½" ID pipe. 3) A test section that measures the friction loss in at least one fitting (i.e. a valve, an elbow, a contraction or an expansion). In order to determine the friction loss in a length of pipe students were reminded that they needed to know the pressure drop across it, the length of the pipe section across which they were measuring pressure, the average of the velocity of the fluid in the test section of the pipe and the diameter of the pipe. In order to determine the friction loss in a fitting they were also reminded to consider the pressure drop across it, the average of the velocity of the fluid (entering or leaving the fitting) and the K-values for the fitting (which is available in tables). For their designs each team had to determine 1) How many feet of piping to buy (and what diameter) 2) Where pressure gauges needed to go and how many they needed to buy 3) How many fittings they needed and which one(s) would be the test fitting(s). (They were also reminded that they might need elbows, tees etc. just to set up the apparatus and not as test fittings) 4) How they were going to measure velocity of the fluid 5) Other fittings/components needed (e.g. shut-off valves, connecting fittings, plumber's glue, plywood to mount the apparatus to, ties to mount the components to the plywood, hose, measuring bucket, stopwatch etc.). Other parts needed depended on the selected design 6) How much all of the parts needed would cost. Figures 3, 4 and 5 show sample student CAD designs, calculations and prototype for this project.

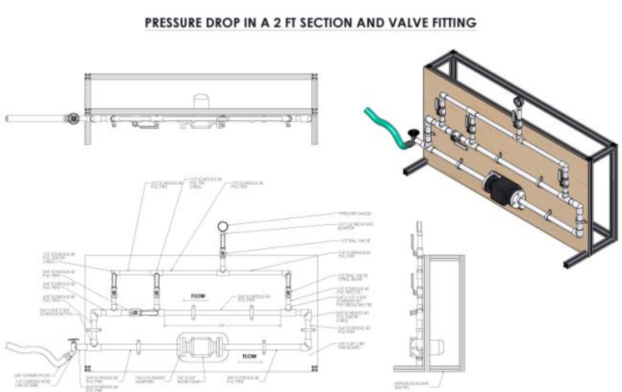


Figure3: Student SolidWorks Design

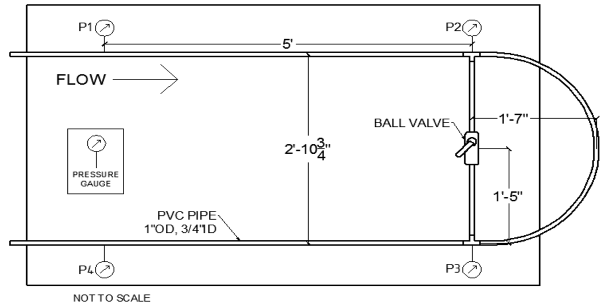


Figure 4: Student CAD Design

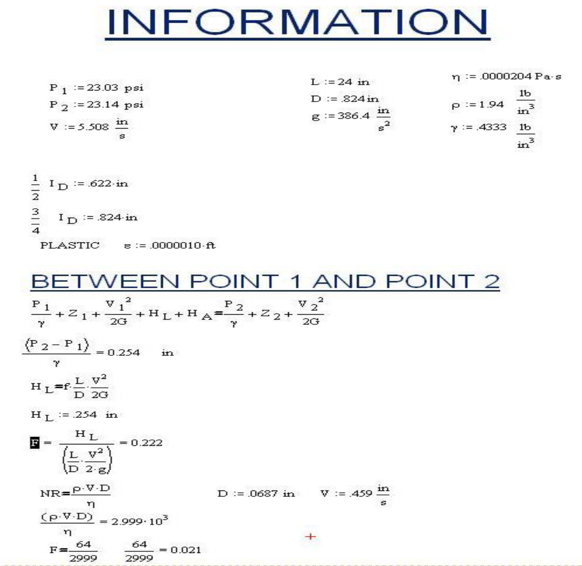


Figure 5: Sample Student Calculations for Fluid Friction Losses Project

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**FLUID MECHANICS LABORATORY WATER DISTRIBUTION PROJECT**

The second Fluid Mechanics lab provided students an opportunity to design and build a municipal water supply system. The following information was provided to the students at the beginning on the semester. As a Municipal Water Engineer, the student was asked to design a water tower that could supply a minimum of 24-hour's water requirement for a housing development in town. The proposed development has three neighborhoods with a combined average water usage of 500 gallons/minute. Within the development, Neighborhood N1 will need ½ of the total water supply, Neighborhood N2 will need 3/10ths of the total water supply and the remainder will go to N3. The layout of the neighborhood complex is shown below. The students' responsibility was to supply the requisite amount of water to the location of the water meter (WMs on the map) in each neighborhood. It is the developer's responsibility to supply the water to each house. After arduous negotiation, it was contended, the town had secured three possible locations for the placement of the water tower.

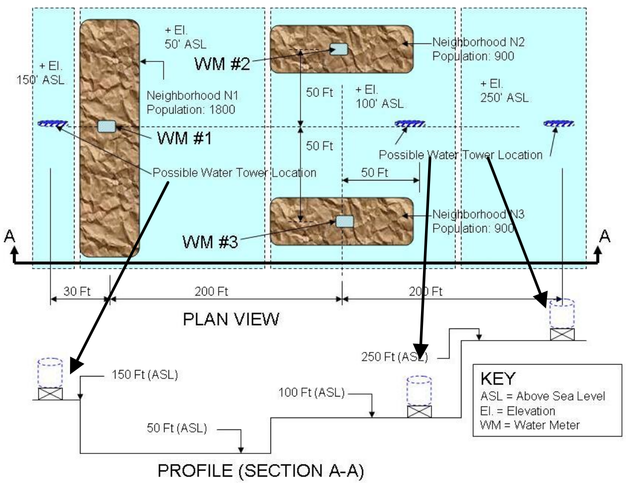


Figure 6: Map showing the plan view and a profile of the neighborhood

Using the following criteria, student teams were to design a water tower and water delivery system to the three neighborhoods: They had to assume that the cost of pumping the water into the tank was the same for any of the three tank locations provided, regardless of the height of your tank. These three neighborhoods had to have a minimum of 24-hour water supply, even if the pumps failed. The team's design of the water tank/delivery system should NOT rely on pumping to supply the water. At the location of each water meter (WMs on the map), there had to be a minimum water pressure of 50 psi and a target water velocity of 5 ft/s. Only PVC pipes were to be used. The pipe diameters available for use for the design were 12", 10", 8", 6", 5", 4", 3 ½" and 3". In the design, students had to allow at least one shut-off valve between the base of the tank and the farthest water meter. They could use as many other fittings, pressure measurement devices, connectors etc. as needed by their design. Students were provided guidance on theoretical concepts to be considered. For example, the rough estimate of pressure loss due to friction in piping system is given by $\Delta P = 0.01 \frac{L}{D} v^2$ where L is the length of pipe, D is the pipe diameter and v is the velocity of the water in the pipe. When students had learned the theory of friction losses in pipes/fittings they were able to calculate the actual pressure and velocity available at each water meter. Costs of construction of the piping systems were provided including cost of building the water tower support per foot in height and costs of various diameter pipes per foot. Students were asked to research and determine for their system the cost of the water tank itself, the cost of the valves used and any fittings there are in their design.

Based on the selected team design, students then built a scaled model of their water delivery system using the materials provided, tested the system and saw how well their design matched the theory. The assembled scaled model (including all support mechanisms for the piping/tank etc.) could not exceed the overall dimensions of 5.5 feet long by 2.0 feet wide by 3.0 feet high. Shut-off valves and pressure measurement devices had to be included consistent with their design of the full-scale system.

## CONCLUSIONS:

A series of project based semester-long laboratory experiences has been designed for sophomore level students in Mechanical Engineering. The projects allow students to experience not only the theory and practice of engineering, but also the process of engineering as it is actually done—in teams, with real world constraints of budgets and materials, with real-world goals and criteria. These projects are feasible even for students with limited theoretical and teamwork backgrounds and offer an excellent introduction to situations which they might encounter in future engineering careers. Student feedback from these projects was highly favorable. For example, 100% of students surveyed in the Dynamics Friction Project Laboratory felt that the project-based learning experience was well related to course goals, encouraged them to apply the course subject matter to laboratory activities, enhanced the course curriculum, and was fun too. Future work includes plans to develop project based learning laboratory experiences in additional sophomore level classes such as Thermodynamics, Materials Strength and Machine Design.

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