AC 2008-2311: CENTRIFUGAL PUMP DESIGN, FABRICATION AND CHARACTERIZATION: A PROJECT-DRIVEN FRESHMAN EXPERIENCE

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Centrifugal Pump Design, Fabrication and Characterization: A Project-Driven Freshman Experience

Abstract

Students beginning the first year of an engineering program generally have limited experience with the tools engineers can harness to solve problems. Teaching students how to use problem solving tools at the point when they fully appreciate the nature of a problem is a powerful method of instruction. Real problems do not present themselves in response to the existence of a tool; rather, tools are developed to assist in solving existing problems.

A project centered around a centrifugal pump has been developed that is effective in impressing upon freshmen the need for learning analytical tools commonly used in engineering. Approximately 350 first term freshmen work in groups of two to design and fabricate centrifugal pumps that they then characterize. The project is quite sustainable, as the cost of materials per pump is only a few dollars. The freshman students participate on an individual basis in a broad range of activities that enhance their appreciation of the importance of engineering tools and analysis.

Students design their pump using solid modeling software, giving them experience with part modeling and assemblies. The designs are also fabricated by the students using milling machines and rapid prototyping. The parts are assembled, yielding a working pump. Each student develops a pump curve by measuring flowrate versus head and applying plotting and regression techniques in a spreadsheet. Students also measure voltage and current supplied to the pump motor to characterize pump efficiency. This gives them a practical feel for conservation of energy and deeper understanding of electrical power.

This paper describes our experiences with implementing this project in a college-wide freshman curriculum and includes student survey data regarding the effectiveness of the project. This project is a part of a larger program designed to impart rich, hands-on experiences to students to solidify their understanding and retention of engineering concepts. The program is being developed with funding from the National Science Foundation. The centrifugal pumps described here are used in a project in a subsequent course in which students develop a salinity- and temperature-controlled fish tank.

Introduction

There is a proverb that is attributed alternately to the Chinese and to Native Americans that says "Tell me and I'll forget; show me and I may remember; involve me and I'll understand." Educators in engineering who are forward-thinking have realized for a long time that when passive, lecture-based instruction is replaced with hands-on, project-based learning, the result is the development of students who are confident in their ability to accomplish real achievements with their learning[1]. The move toward project-based freshman curricula began in the United States in the 1990s; with key motivation arising from the National Science Foundation

Engineering Education Coalitions[2-5]. Many universities across the United States have implemented freshman programs with significant design and fabrication components[6-8].

At Louisiana Tech University, a sequence of three two-hour courses spanning the freshman year has been implemented with the aim of fostering the ten attributes defined by The Engineer of 2020[9] in our students. In this sequence, a steadily increasing level of independence is required from the students as they design and build projects with a steadily growing degree of complexity. In their first course, freshmen undertake the centrifugal pump project described in this paper. In the next course, the pumps are used to circulate salt water in a "fishtank"- a system in which the students use a microcontroller to control the temperature and salinity of a small volume of water using temperature and conductivity sensors they make and calibrate along the way. The final course of the freshman year requires the students to complete an open-ended innovative design project where they conceive, design and fabricate a "smart product" based on a "bug list" that they compile over a period of several weeks.

The centrifugal pump project, as depicted in Figure 1, is the first major project in the freshman curriculum and is designed to provide a vehicle with which to show the practical importance of tools used in engineering. Engineering software tools covered in the first course in the freshman sequence are solid modeling (with Solid Edge®), spreadsheets (with Excel®), and computer algebra (with Mathcad®). All three of these software programs are required for the completion of the centrifugal pump project. Engineering fundamentals covered in the first course in the freshman sequence include basic circuits, linear regression, and conservation of energy. The testing phase of the pump project requires that students apply knowledge of each of these three engineering fundamentals. Fabrication and measurement skills are also developed as the students perform various physical tasks to complete the project.

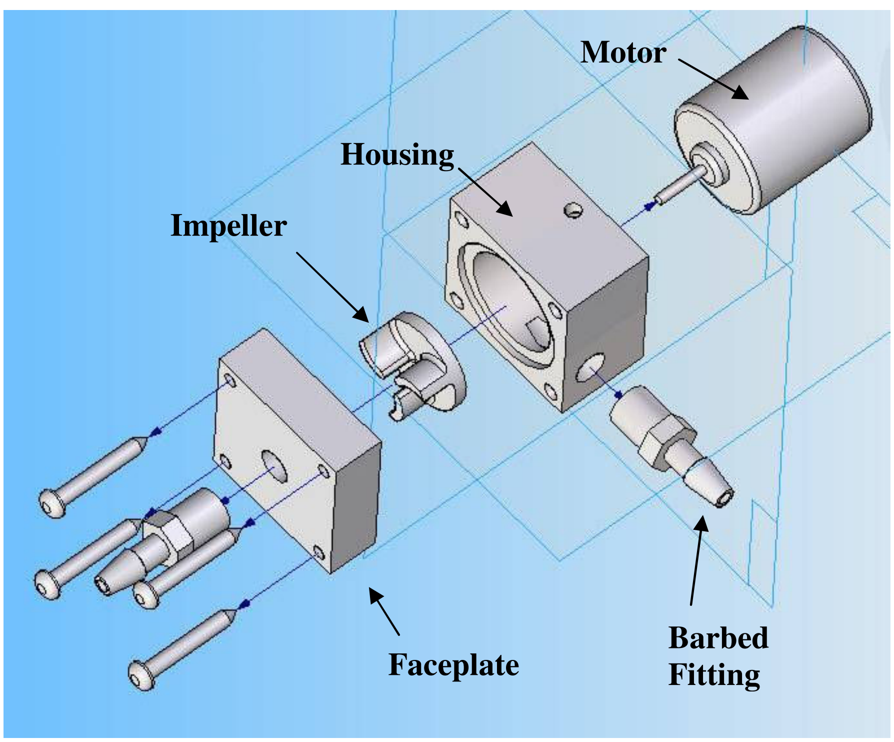


Figure 1 - Exploded Solid Assembly of Centrifugal Pump

Preliminaries: Activities Taking Place Before the Pumps are Fabricated

Before beginning pump construction, students were given the task of modeling all of the parts in a solid modeling package as shown earlier in Figure 1. First, the students modeled the simpler geometries such as the housing and the faceplate. As their skills became more refined, they were asked to model more complex shapes such as the barbed fittings and the impeller. Before designing their impellers, the freshmen were asked to research how centrifugal pumps worked and to find various impeller designs. Each student designed his or her own impeller as a solid model and submitted their models for automated production in a Dimension 1200 Series rapid prototyping machine, as shown in Figure 2. The rapid prototyping machine produces usable parts from ABS plastic in a layer-by-layer process. The result is that each student has an impeller that went from their idea to a real part (Figure 3), literally overnight.

Figure 2 – Rapid Prototyping Machine

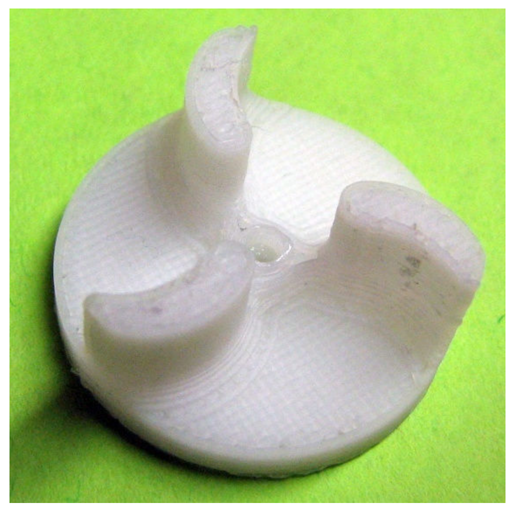


Figure 3 – Rapid Prototyped Impeller

Fabrication of the other pieces of the pump was performed manually using drilling processes. Faculty supervision of these processes was deemed to be necessary for safety, but not for specific individual instruction. To streamline the productivity of each student group, a detailed PowerPoint presentation showing each step in the process was prepared and distributed to the students. Each student group (groups of two students are used for the pump project) had a laptop running PowerPoint and could reference the pump fabrication presentation for guidance during the fabrication class period.

Student groups are expected to perform all material removal steps of the pump fabrication during a single 1 hour and 50 minute class period. To “encourage” students to carefully review the pump fabrication presentation BEFORE the fabrication class period, the homework assignment due on the day of fabrication requires that students draw the pump body and faceplate in Solid Edge® and apply layout markings on the workpieces to streamline the fabrication process. The kit containing all of the parts to construct the pump is provided to students prior to beginning the project, as shown in Figure 4 and summarized in Table 1. In this way, students enter class on the day of fabrication with the parts they need and with an understanding of what to do.

Figure 4 – A Part Kit Ready to Distribute

Table 1 – Parts List for Pump Project

	Description	Source	part number	how supplied?	quantity required	item cost	cost per pump
1	1 1/2" x 1 1/2" UHMW PE Bar	McMaster-Carr	8702K133	by the foot	0.9 inch	8.15	$ 0.68
2	1 1/2" x 1/2" UHMWPE Bar	McMaster-Carr	8702K84	by the foot	1.5 inch	3.16	$ 0.40
3	1.6 mm wide, 2.2 mm ID o-ring (viton)	McMaster-Carr	9263K131	pack of 25	1	3.45	$ 0.14
4	1 1/16" ID x 1 1/4 OD o-ring with 3/32" width	McMaster-Carr	9452K85	pack of 50	1	4.32	$ 0.09
5	PVC clear tubing - 3/16" ID x 5/16" OD	McMaster-Carr	5233K532	100 ft. length	2 feet	11	$ 0.22
6	nylon barbed fitting - 3/16" tube ID, 1/8 NPT male	McMaster-Carr	5116K82	pack of 100	2	2.31	$ 0.46
7	#6 sheet metal screws - 1" long	McMaster-Carr	90190A153	pack of 100	4	4.79	$ 0.10
8	7/32 brass tubing segment ~ 1/8" long	Local Vendor	691089	1 ft. bar	1/8 inch	1.69	$ 0.01
9	8" cable ties (~0.095" wide)	Walmart	51213	pack of 20	2	0.97	$ 0.10
10	9-30V, 0.35A,4930 rpm,44.5 g-cm DC motor (shaft: 0.090" OD & 0.45" long	Jameco Electronics	206949	each	1	1.73	$ 1.73
				Total Pump Cost:			$ 3.92

We believe that a very important step of the experience is having students learn about the sources of engineering parts and supplies. Students are required to locate each of the parts listed in Table 1 either at a local vendor or online, providing the part numbers, costs and specifications of the items that they locate as they estimate the cost of a single pump for themselves. Laying this foundation early on in a student's learning helps them to begin to see the bigger picture of what many engineers do on a day-to-day basis and more importantly gives them confidence that they can locate the parts they will need at the end of the freshman year when they develop a their "innovative" product. Students also begin to learn that "shopping" by scanning supply catalogs or browsing online is a form of brainstorming that will help them to more successfully complete projects. We consider that we are sowing the seeds required for innovation by planting latent knowledge in the mind of the student that they can draw on when needed.

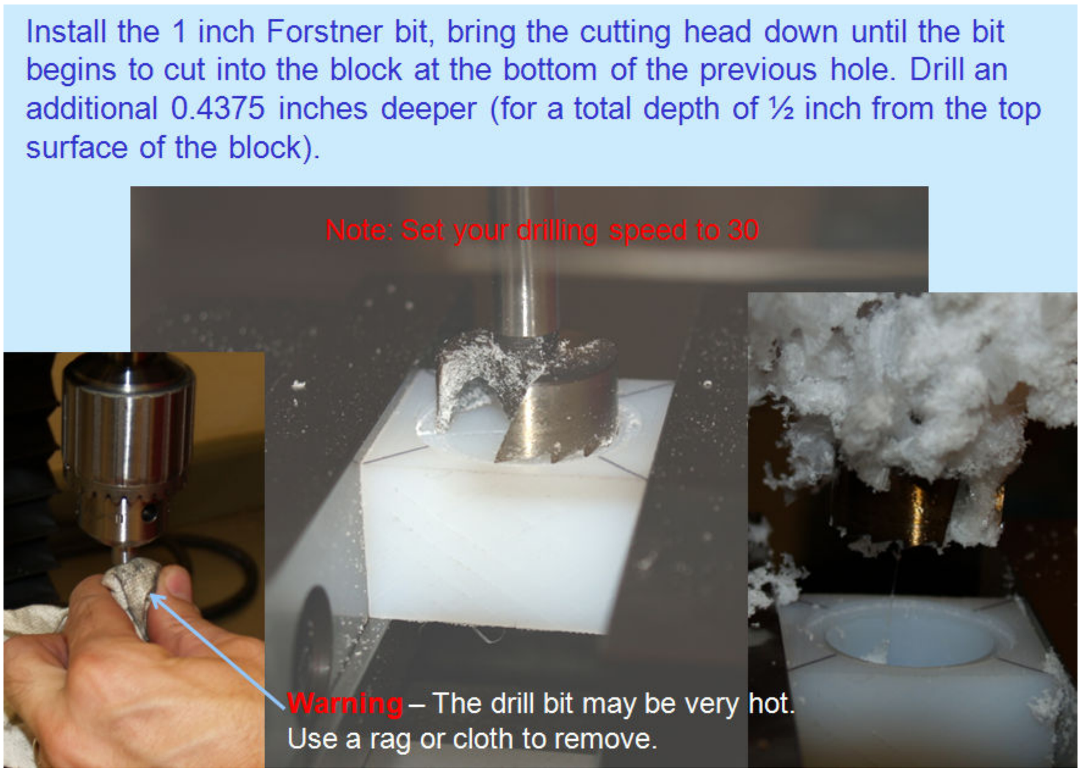
Other prerequisite activities include the fundamentals required to complete the analytical portions of the pump project. The first half of the course is spent learning about circuits though the use of a Parallax® Boe-Bot[10] that each student purchases for themselves. This robot serves as the overall platform for laboratory and design activities throughout the freshman year and is really the backbone for the curriculum. Its use is not discussed further here. However, it does provide an opportunity for students to implement working circuits on a breadboard and to measure both current and voltage well before they are required to compute the electrical energy usage of the pump during the analysis stage of the project. Students also learn about linear regression and learn to use Microsoft Excel® just before starting the pump project. The final thing that students do is to review the operation of the milling/drilling machine and complete a safety quiz and agreement stating that they will obey the rules and act responsibly.

Pump Fabrication: Drilling, Tapping and Assembly

When the day for pump fabrication arrives, half of the students in the class of 40 are assigned to work on one of the ten milling/drilling machines, as shown in Figure 5. These machines are equipped with a digital read out, and the z-direction readout allows students to accurately monitor the depth of the holes they drill into the pump body. Even though students are somewhat aware of the operation of the machine before coming into the class (based on their review of the PowerPoint fabrication presentation), the instructor takes about five minutes to have them move the x-, y-, and z-stages to get a feel for how the machine works. Students also are required to load a drill bit, close the safety shield, turn on the spindle, and change machine speed before beginning work.

Figure 5 – Milling/Drilling Machine (Even Groups of Two Can Be One Too Many)

The PowerPoint pump fabrication presentation contains over 40 slides describing the individual steps of the fabrication process. Several of these steps, taken directly from the PowerPoint pump fabrication presentation, are illustrated in Figures 6, 7, and 8. Note that the layout marks for Figure 7 should be completed when the students come to class.



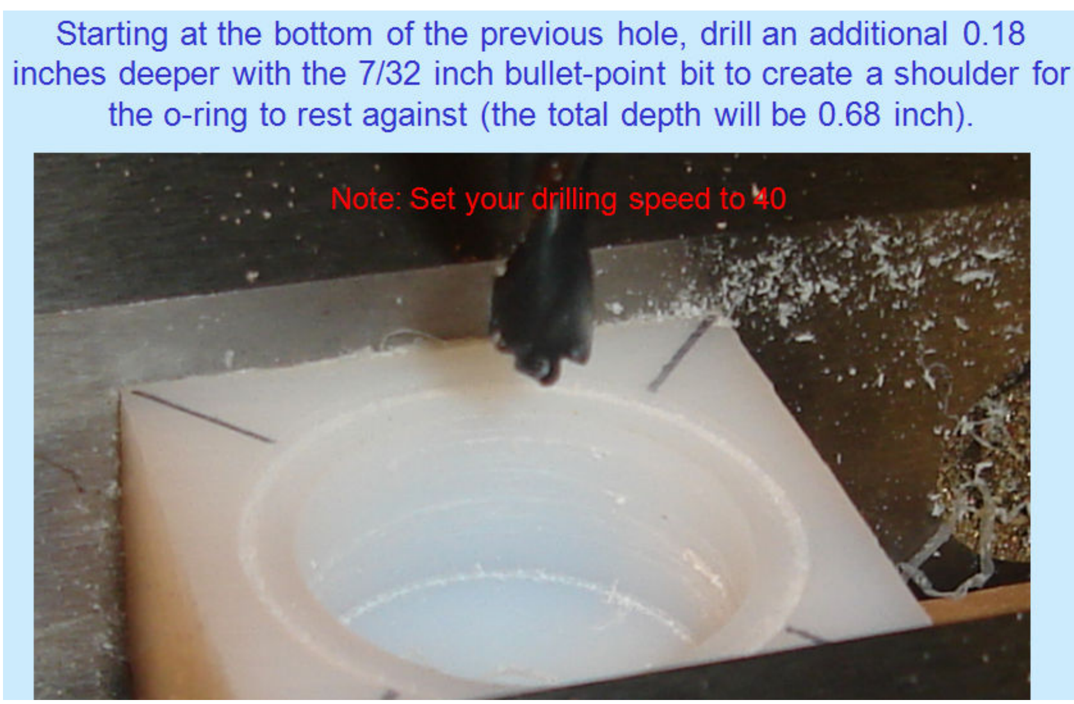


Figure 6 – Drilling out the O-ring Seats for the Upper and Lower O-Rings

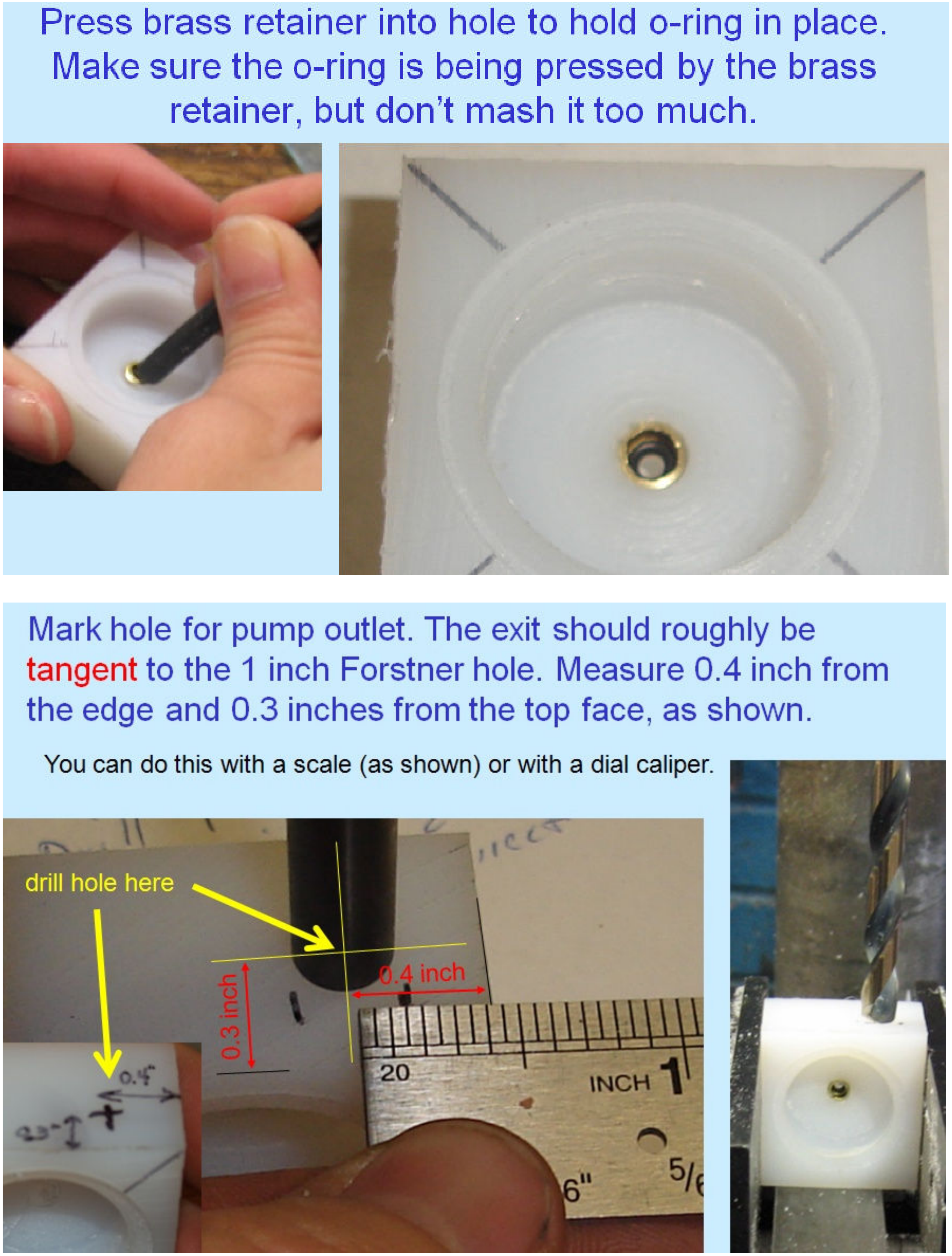
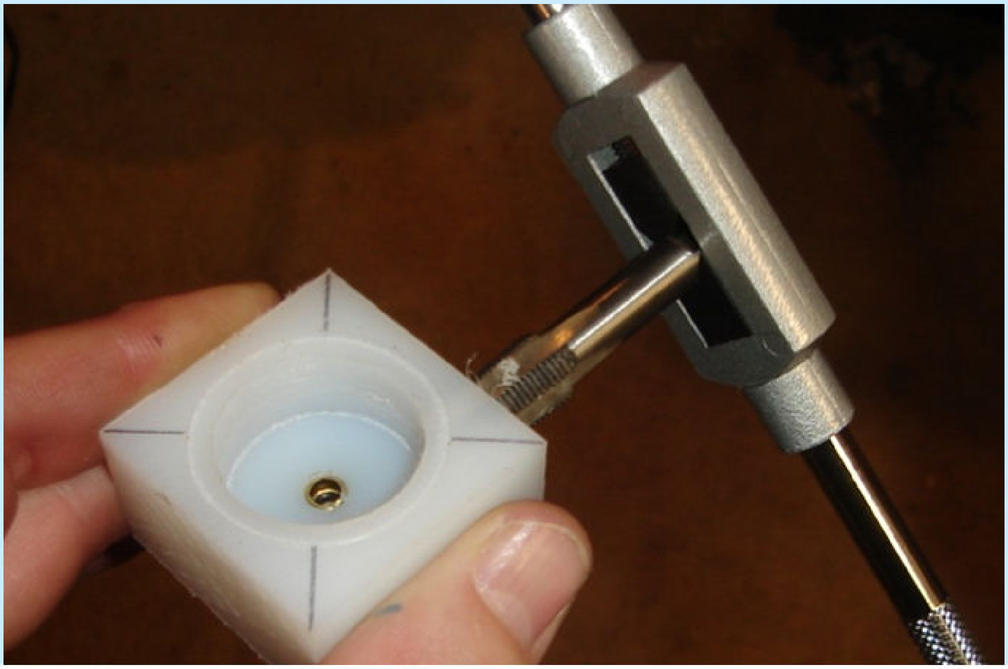


Figure 7 – Pressing in O-Ring Retainer (Top) and Preparing to Drill Water Exit (Bottom)

Tap pump exit for a barbed fitting to attach tubing.



Before tapping, cut any burrs around the top edge of the hole off with knife - Make sure you run the tap all the way in to make the hole as large as possible to allow the barbed fitting to be screwed in.

Mark locations of screws to attach face place to body approximately 0.15 inches from edges, and drill 3/32 inch holes through the face plate.

Note: Set your drilling speed to 40

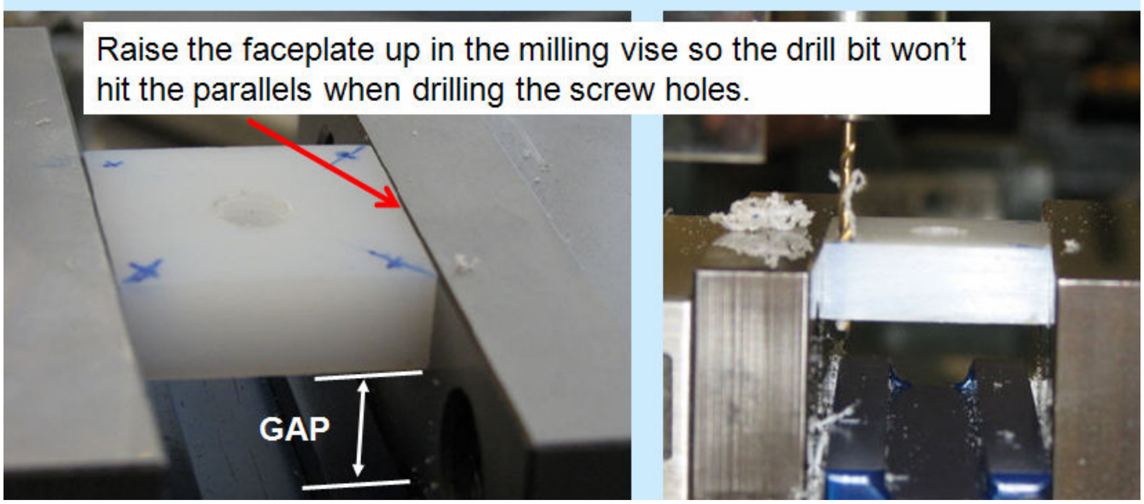


Figure 8 – Tapping Water Exit (Top) and Drilling Screw Holes in Faceplate (Bottom)

The major aim of the fabrication class is to complete the drilling and tapping operations <u>during</u> class. Every now and then, a student group will experience trouble such as drilling a hole in the wrong place or drilling a hole too deep. Student groups who have difficulties or don't finish during the regular class period are required to come back to the classroom after hours to complete the project. The faculty members teaching the course team up to monitor the work of these stragglers. The assembly steps can be completed outside of class.

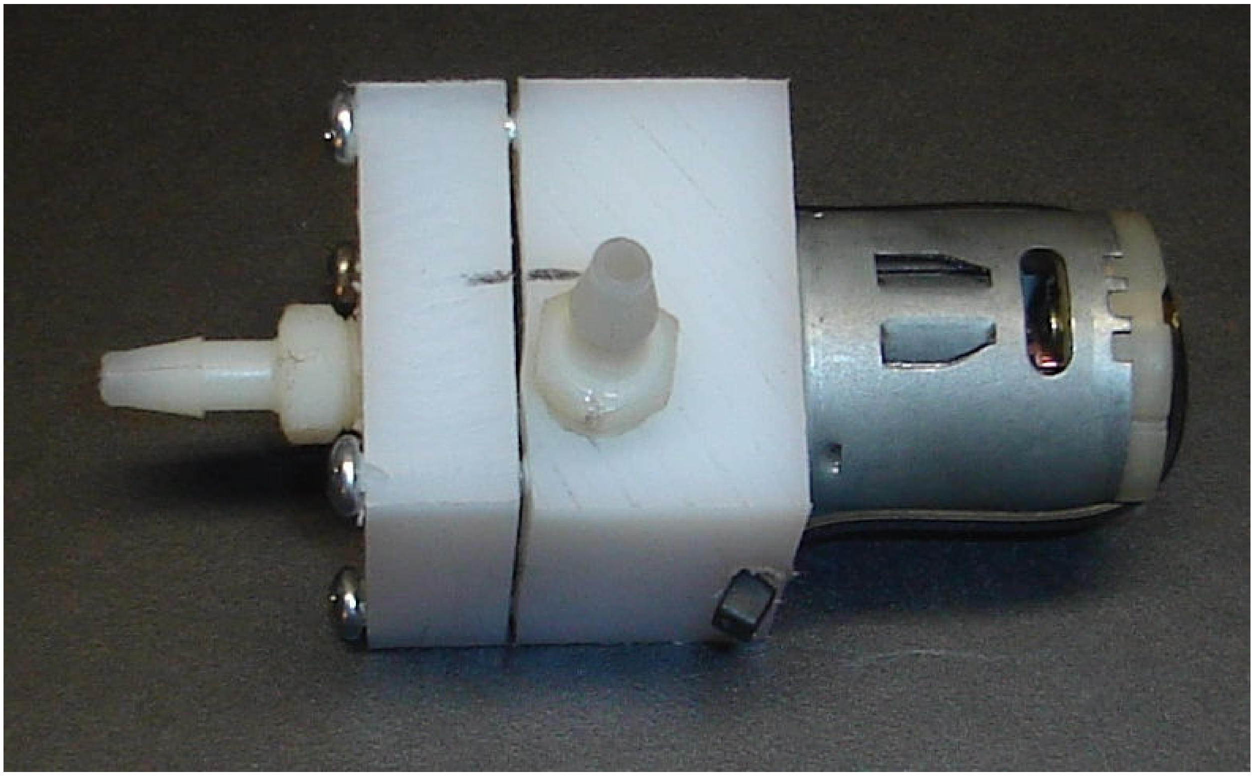


Figure 9 – Assembled Pump

With a class size of 40 students and a group size of 2, half of the class can work on their pumps at the same time since 10 fabrication stations are available in the classroom (Figure 10). The other half of the class works on drawing other pump parts (the barbed fittings, DC motor, and screws) and create an exploded assembly of the system in Solid Edge®.

Figure 10 – Integrated Lecture / Laboratory / Shop Classroom

Post Fabrication: Analyzing Pump Performance

For the remainder of the pump project, student groups of two are paired to form larger groups of four students (or three students depending on the class size). This is necessary if ten groups of students are to have time to present the results of their findings in a SINGLE class period. Plus, this gives the students the experience of working cooperatively with a larger group. The group of students must decide whose pump works best and use this pump for their analysis.

Students are required to determine the efficiency of the pump system by measuring the electrical energy input to the motor and the potential and kinetic energy imparted to the fluid. Figure 11 shows a schematic of the pump testing configuration. Student groups are required to determine the efficiency of their pumps as a homework assignment. A slide from the pump performance presentation is shown in Figure 12. A total of six pump testing stations are provided for all freshman classes, and student groups sign up for 30 minute testing slots. The testing process is monitored by student workers who are familiar with the experiment.

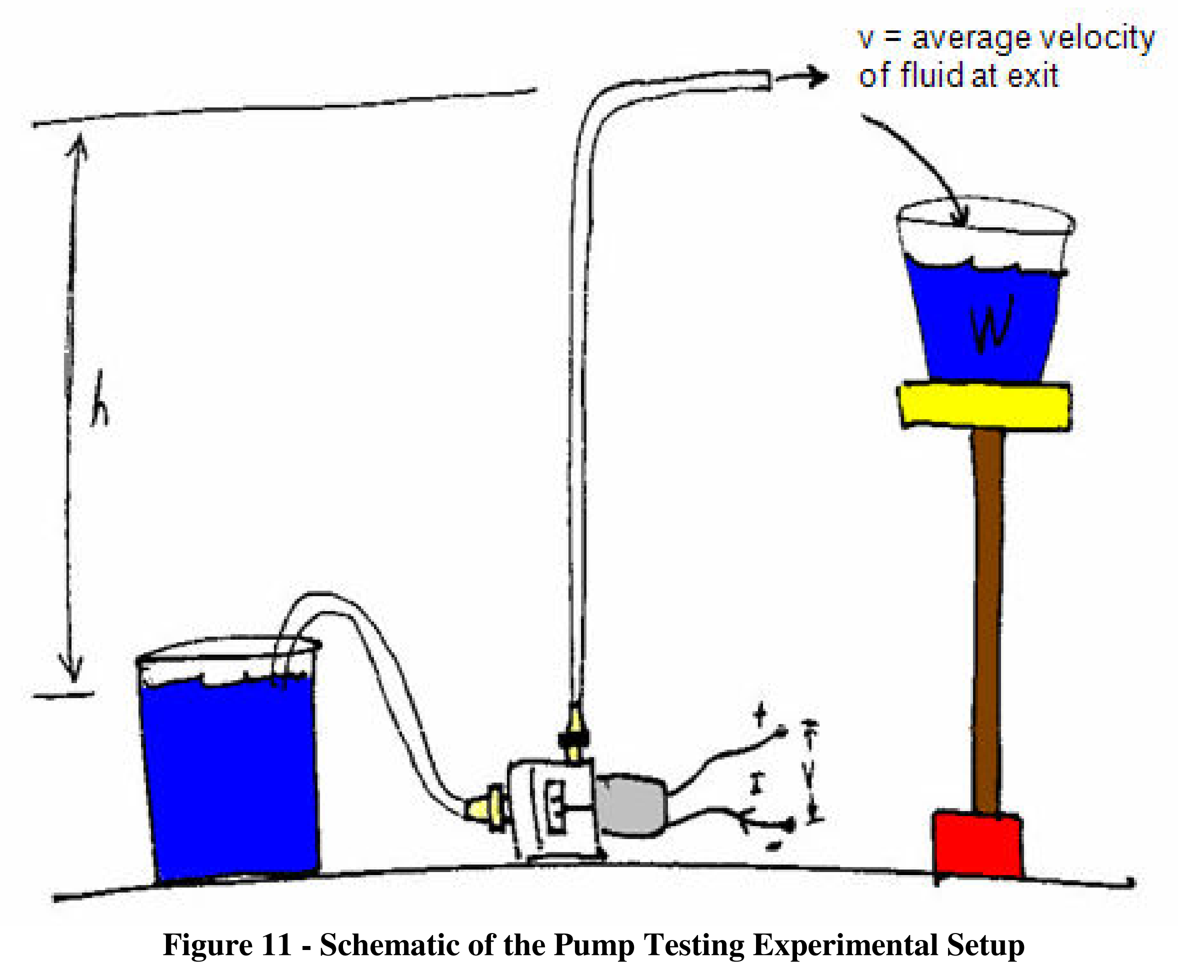
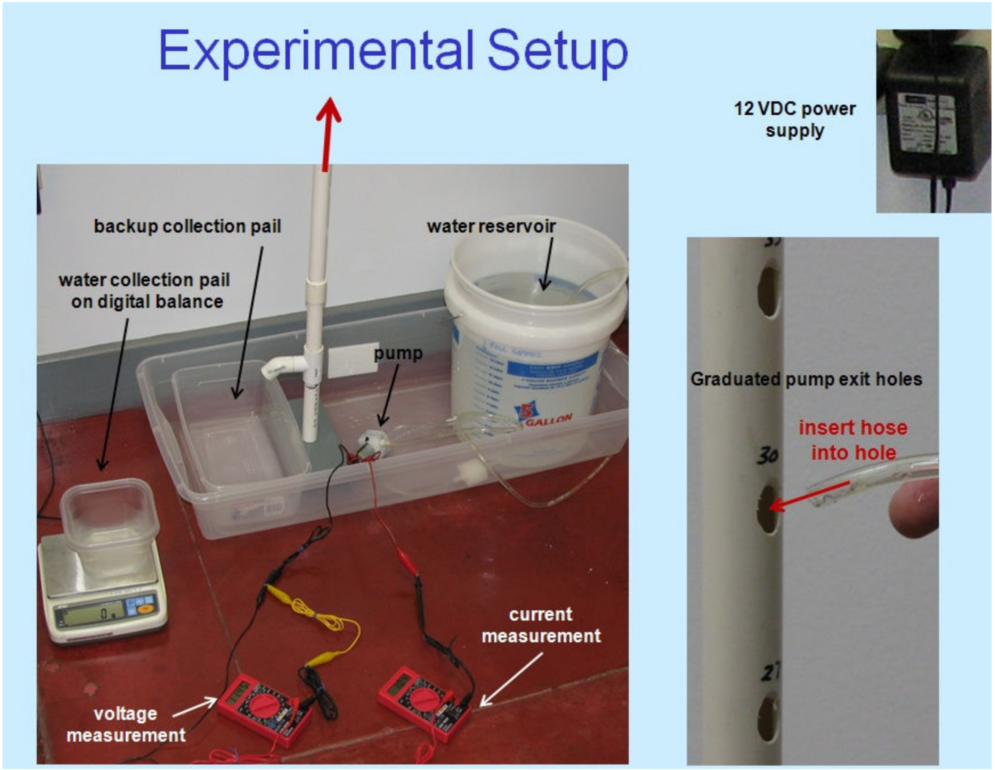


Figure 11 - Schematic of the Pump Testing Experimental Setup



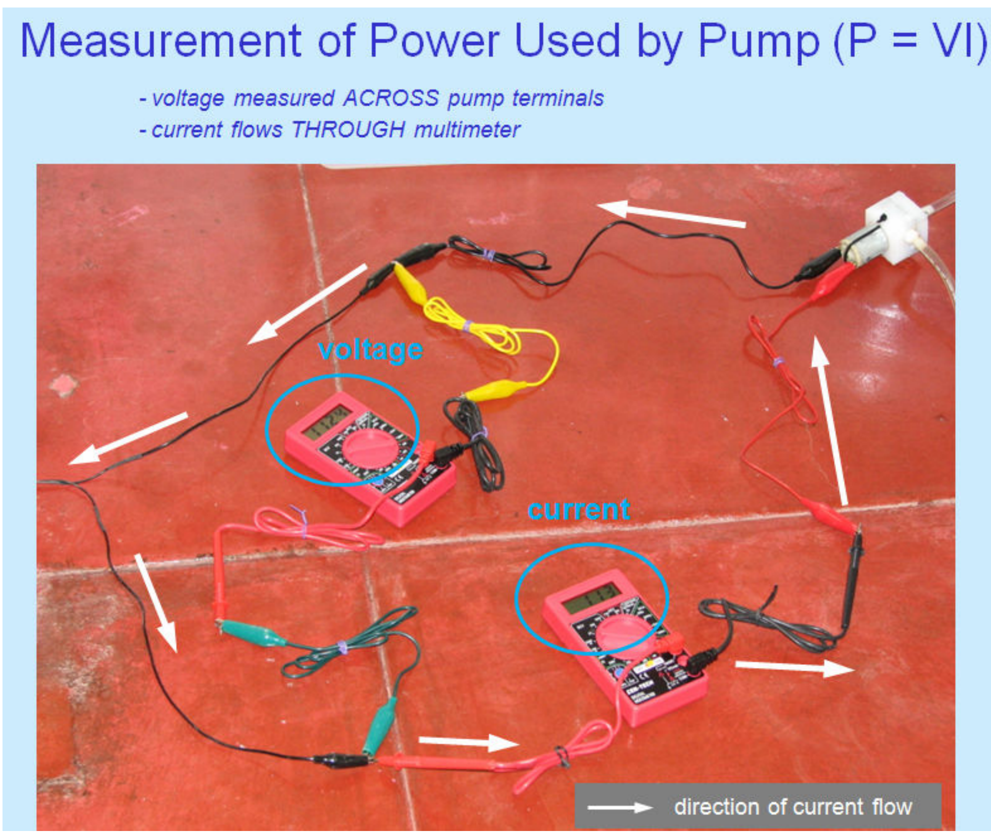


Figure 12 – Slides from the Pump Performance Presentation Provided to Students

A data sheet is provided to the students to help guide them through the process. Figure 13 shows another slide from the pump performance presentation indicating how a single data point is recorded.

Record the Data Point

height above water in supply bucket (in)	I to pump (amps)	V across pump leads (volts)	mass collected in 20 seconds (g)	time (s)
6				20
12				20
18				20
24				20
30	1.23	10.75	175	20
36				20
42				20

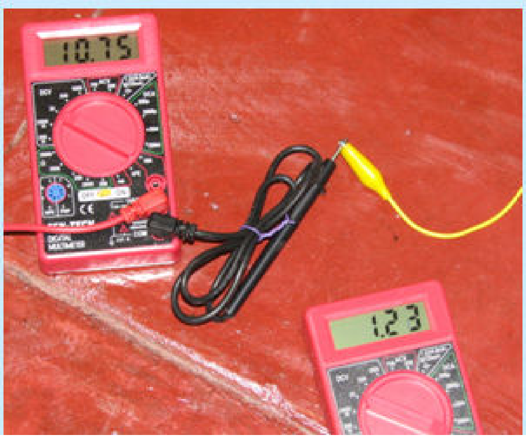


Figure 13 – One of Six Pump Testing Stations (Students Provide Their Own Multimeters)

After all data is recorded, students apply conservation of energy to evaluate the efficiency of the pump. The equation used to compute the efficiency η is

$$\eta = \frac{\frac{1}{2}mv^2 + Wh}{VIt} \cdot 100\%$$

where m is the mass of fluid flowing through the tube over time t, v is the exit velocity of the water from the tube, W is the weight of fluid collected over a period of time t, h is the pump head, V is the voltage measured across the DC pump leads, and I is the current flowing through the pump.

Students are required analyze a single data point by hand and using Mathcad® which is a computer algebra system that allows the inclusion of units in the analysis. Perhaps the biggest analytical challenge for the pump project is the handling of the units (mixed units are used). A screen shot of a typical Mathcad® analysis is shown in Figure 14.

$$h := 6\cdot in \qquad Volts := 10.88\cdot V \qquad I := 1.19\cdot A \qquad mass := \frac{430}{1000}\cdot kg \qquad t := 0.5\cdot min$$

$$\rho := 1000\cdot\frac{kg}{m^3} \qquad Area := \frac{\pi}{4}\cdot\left(\frac{3}{16}\cdot in\right)^2$$

$$Q := \frac{mass}{\rho\cdot t} \qquad Q = 0.86\cdot\frac{L}{min}$$

Q is the flow rate

$$P := Volts\cdot I \qquad P = 12.947\,W$$

$$velocity := \frac{mass}{\rho\cdot t\cdot Area} \qquad velocity = 0.805\,\frac{m}{s}$$

$$efficiency := \frac{\frac{1}{2}\cdot mass\cdot velocity^2 + mass\cdot g\cdot h}{Volts\cdot I\cdot t}\cdot 100 \qquad efficiency = 0.201$$

Figure 14 – Screen Shot of the Mathcad® Analysis

Students are then required to enter all of the data points collected into Excel® and generate plots of pump head versus flow rate and pump efficiency versus head. Pump heads ranging from 6 to 72 inches in increments of 6 inches are considered. The regression analysis features of Excel® are used to determine polynominal fits to the data as shown in Figure 15. Notice that the efficiency of the pumps is VERY low, something we hope to improve on over time as the design evolves.

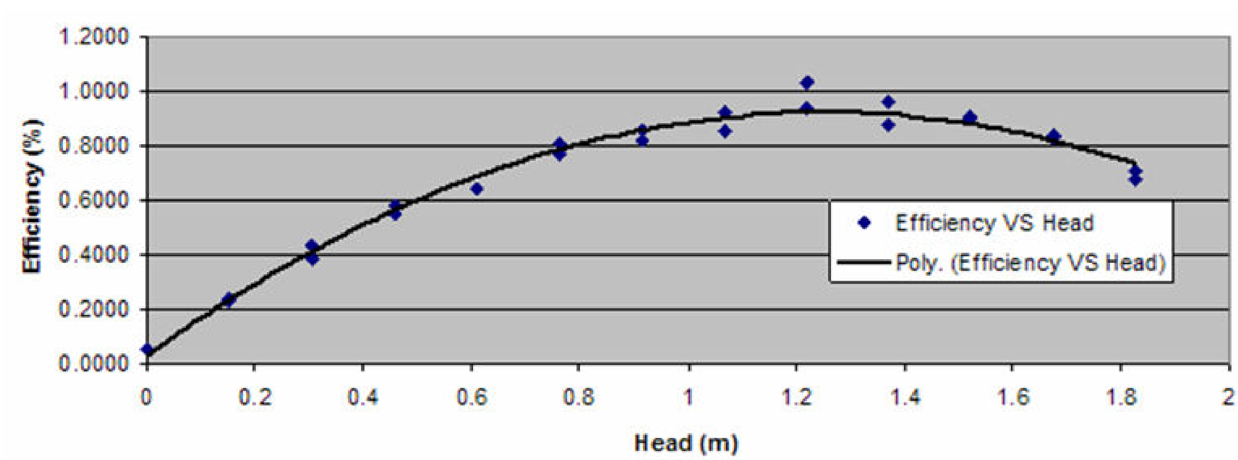


Figure 15 – Student Generated Plot of Pump Efficiency Versus Head

Finally, the groups are required to compile their work into a seven minute PowerPoint® presentation where they communicate their project to the class. Students are required to dress professionally, and all members of the presenting group are required to participate.

Assessment of Project on Student Learning

A survey was administered to a group of 30 students about 8 weeks after the pump presentation during the subsequent engineering class. The survey was given to a single class of students. The survey sought to measure how well the pump project motivated students to use engineering tools (Excel®, Mathcad®, and Solid Edge®) and to learn engineering fundamentals. The results of the assessment data are provided in Table 2. The scale used was . . .

1 = poor   2 = not that well   3 = OK   4 = pretty well   5 = very well

Table 2 reveals that the highest score occurred for question number 1. The students overwhelmingly felt that the skills gained in the first engineering course would be useful to them in the future. The students also agreed in all cases that the project motivated them to learn both the skills and the fundamentals that the faculty sought to build in the students. Our general observation is that students really enjoyed the pump project and appreciated the opportunity to build a working system. Since the freshman curriculum is project driven, the pump project incorporated almost every skill and fundamental topic that the students learned in the course, providing an opportunity for students to put their skills into action.

Table 2 – Summary of Student Survey Results for Pump Project

Survey Question	Score (1 to 5) (poor → very well)
1. How useful do you think the skills (Excel, Solid Edge, Mathcad, Regression, Programming, Measuring Current and Voltage with a Multimeter, Drilling, . . .) you gained will be to you in your future as a student and professional?	4.4
2. How well do you think the pump project motivated the usefulness of spreadsheets (e.g. Excel) in engineering?	3.8
3. How well do you think the pump project motivated the usefulness of data plotting and regression analysis in engineering?	3.8
4. How well do you think the pump project motivated the usefulness of computer algebra systems (e.g. Mathcad) in engineering?	3.5
5. Compare the pump project with the most "hands-on" project you have been involved with up to this point in your life (particularly scientific or mathematical projects). How relevant do you perceive the pump project to be in terms of helping to prepare you for a future in engineering?	3.9
6. How well do you feel the pump project demonstrated the concept of power and energy conversion (taking electrical power to produce fluid power)?	3.9
7. How well do you think the pump project demonstrated the concept of the EFFICIENCY of energy conversions (percentage of power that is changed into a useful state)?	3.6
8. The pump project gave me a practical feel for the importance of units of measure, beyond the appreciation I had before.	3.7

Conclusion

A new project-based curriculum has been implemented at Louisiana Tech University that includes three two-semester hour engineering courses. The major project in the first of these three courses involves the fabrication of a centrifugal pump. The project motivates student learning by requiring students to draw and assemble pump parts using solid modeling software, to render the 3D model of an impeller that they designed on a rapid prototyping machine, to fabricate the pump body through drilling, tapping and assembly operations, and to analyze the performance of the pump using conservation of energy. Students learned a host of other things along the way that we believe are important for building their skills, confidence, and creativity.

Acknowledgement and Disclaimer

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