AC 2010-1327: WATER TURBINE: IMPROVING A PROJECT FOR REINFORCING MACHINE COMPONENT DESIGN

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Water Turbine: Improving a Project for Reinforcing Machine Component Design

Abstract

A competitive water wheel design assignment has recently been revised for use as the culminating project for the Manufacturing and Machine Component Design course at the United States Military Academy (West Point). The project integrates material from other engineering courses and uses the skills and machining techniques from the current course. Previously, the project proved to be anticlimactic, relegated to the corner of a lab at the end of course, and had mixed reviews from instructors and students alike.

A concerted effort was made to improve the project to maximize its potential. The most dramatic change was made possible through the use of a mobile test stand constructed to allow two water wheels to test simultaneously as the focus and challenge for the final phase of the course. The mobile test stand enhances the students' learning and performance with the design project. As a stand-alone, portable unit, the mobile test stand can be moved to different rooms or auditoriums allowing more students to observe the employment of their devices. Use of the stand allows the students to directly observe the outcomes of their design decisions as gear teeth shear, shafts deflect, and fasteners fail while each turbine produces power. The side-by-side comparison also allows the students to gauge their performance against their peers in a challenging yet low threat environment. Their grades are determined by the device's performance on a predetermined scale; however, bragging rights are tied to their performance, relative to their peers.

This paper illustrates some of the project details employed to enrich the course and provides a qualitative assessment of the benefits of the mobile test stand through a comparison of this year's results to previous semesters. The assessment uses student grades and performance, quality and performance of the water wheels, and course end feedback and surveys. The results of this assessment should be useful for any program seeking to implement a competitive project.

Introduction

Competition has been touted as a useful tool for teaching engineering. Competitions are strong motivators for encouraging students to perform.[1,2] They also support the "student involvement theory" of education. Student involvement refers to the amount of physical and psychological energy that the student devotes to the academic experience.[3] A great deal of analysis has been devoted toward analysis of competitions used to support design courses. These competitions range from multiyear competitions such as the North American Solar Challenge to national annual events such as Mini Baja to institution-specific contests for a given course.

Group projects have proven to be effective methods to teach the design process.[4] They tend to be open-ended designs that focus on the process used to determine an appropriate solution to the problem. They also rely heavily on commercially available components or prototyping kits such as Technic®, K'nex®, or Erector®.[5] At West Point, a competitive group project is used to directly support instruction in manufacturing and machine component design. The focus for the project is on experiential learning and using machining skills to manufacture components for the device.

Students majoring in mechanical engineering at West Point are taught the design process through a three-course sequence during their junior and senior year. ME403 is the first course in the sequence and is an introduction to mechanical manufacturing machinery and machine component design. The second course in the sequence, ME404, is dedicated to learning and applying the design process. ME404 covers the process from gathering customer requirements to creating and implementing a test plan to ensure the product successfully meets those requirements. The students work through an in-class example based on an illumination device and develop their own solution to a storage container out of class. They are required to produce a prototype of their container using skills from ME403. The final course, ME496, is dedicated to a senior group capstone project that the student selects. This course allows the student to apply the design process to a more complex problem and relies heavily on the manufacturing skills previously learned.

The formal design process is purposefully taught second in the sequence to provide the students with as much hands on experience as possible to ensure design alternatives are appropriate and feasible. The majority of students have minimal experience and/or confidence with the equipment found in a basic machine shop. It is paramount to instill confidence in the students to allow them to feel comfortable creating components in later designs. The ability to use an ad hoc design process during ME403 on a simple device allows the students to learn firsthand the implications for not using a systematic process on more complex projects.

The Course

ME403 in its current form has been taught for the past five years. It was conceived to fill a void in the students' skill set. This class is an introduction to mechanical manufacturing machines and machine component design. The first portion of the course covers fundamental engineering science applied to machine components. These topics include load, stress, and strain analyses; impact; fatigue; and surface damage. The course then progresses to the study of machine component design to include mechanical components such as fasteners, springs, bearings, gears, and shafts. The class then moves to a safe, hands-on experience with manufacturing machines and equipment. Students have an opportunity to work with manufacturing machines that are common in machine, woodworking, and sheet metal shops such as a mills, lathes, grinders, belt sanders, drill presses, and bandsaws. The course also provides a hands-on experience with welding techniques and equipment. ME403 culminates in a team-based design of a water turbine using the techniques, tools, machines, and equipment that were developed and taught throughout the semester.

The Problem

The water wheel has been the final project with relatively minor changes since the inception of ME403 and has met with mixed results from the students and faculty. The students complained of the time required to build the device and openly questioned the applicability of the design.

The faculty lamented the crude workmanship and mediocre designs. The lab technicians grew frustrated as they retaught the same basic machining skills.

The original test stand created to support testing the water wheels was identified to be a limiting factor. It was an extremely crude contraption that was located in the corner of a lab room. It consisted of garden hose and a 20 gallon tank suspended on the rafters. Its placement was dictated by the location of an available drain and water source. A pair of C clamps would hold the device in place as it lifted a pile of mismatched weights. The location of the test stand in the corner limited the ability of the students to operate their devices and observe their peers' devices in action. The quality of the stand also set a poor example for the students to emulate.

Figure 1. Original Test Stand

As a result, the final artifacts for the project were poorly performing devices that were crudely built. The students opted to use hand tools and less accurate power tools to cobble together a device that met the minimum requirements because of the perception that it was "faster". They also felt the mill, lathe and drill press were "too hard" to use.

The lab technicians were also spending increased amounts of time during the ME404 and ME496 courses to reteach basic machining skills to students. This time constraint was limiting the support they could provide to faculty and staff. It also was limiting the quality and quantity of output of the students during construction of their senior capstone prototypes.

The Approach

A concerted effort was made to revitalize the water turbine project. The goal was to increase the student's confidence, skill in the machine shop, and abilities. The project had evolved over the previous four years. A set of rules already existed that was clearly defined and had been vetted to ensure that they were fair and would yield the desired outcome. A series of in-progress reviews were incorporated into the course to ensure that each team was meeting milestones and remained competitive throughout the process. The grade for the design was based on both a written report and the performance of the device. The grade for performance was based on the weight the device successfully lifted. The scale used to assign a grade was provided at the beginning of the course and was selected to ensure that success could be achieved by all groups. The winner was awarded bonus points which represented a modest but official reward for success. These controls ensured that the students operated in a high challenge yet low risk atmosphere.

The first modification was to have the course changed from a three credit hour course to a three and a half credit hour course. This increase allowed the course to occupy two adjacent periods on the students' schedule. This better met the student's expectation of the required work load, and it also provided additional time during the day to work on the water turbine. The course only uses seven of the lab periods for instruction. The remaining 33 are available for the students as discretionary time. During the design studios dedicated to the water turbine, they were able to work for 2 hours at a time without being interrupted by another class.

The second change was to reorganize the course so that the instruction in the machine shop occurred immediately before the period in the course dedicated to constructing the water turbine. During Spring 2008, the block of instruction in the machine shop occurred during the first half of the semester within the first ten lessons of the course. The skills learned during that period were not used extensively until after Spring Break starting with Lesson 30, and retention of machining skills was an issue. The reorganization allowed a natural progression from the initial instruction on the machinery to application on the final design. It represented a potential time savings as the lab technicians would not have to provide refresher training.

The final improvement, a mobile test stand, was constructed to make the testing of the turbine interactive for the entire class. It allowed the students to set-up and test two devices simultaneously. The device could be moved to any room in the building using built-in casters. The test stand used a sump and a pair of pumps to capture and recirculate water to allow testing without an external water source. The creation of the test stand improved the project experience in several ways:

1. Water turbines could compete side-by-side for head-to-head competition.
2. It doubled throughput by allowing two teams to setup and test simultaneously.
3. It could be used in the center of the room to allow maximum viewing by the entire class. Students directly observe the outcomes for their design decisions.
4. It provided a positive role model for a device that had been created by students to meet a specific need.
5. It recycled water, conserving resources.

Although the credit hour change and the sequencing of the course would likely have some effect on overall outcome of the course, they were not individually investigated. This research focused on the effect of changes made directly to the water turbine competition.

Water Turbine Test Stand

The test stand used a pair of pumps to recycle water for multiple tests without an external water source. Water in the rear holding tank is pumped into the holding tanks on the top of the test stand. Each tank holds 40 L and is filled until a float switch indicates that the tank is full. The improved test stand replicates the head available from the earlier test stand and also provides the same duration of flow. This allows an objective comparison of the performance data of water turbines between years. The turbines are located via two pins and clamped to the test stand. Spectra® fishing line is used to connect the drum of the water turbine to the weight stack. A weight stack from a personal trainer was adapted to provide a simple yet effect system to measure the force the turbine could generate. The turbine must move the weight 12 inches before the water supply is exhausted. As water flows through the water turbine, it is collected in the bottom of the front testing tank and pumped to the storage tank. Once testing is completed, the top tanks are refilled. The process takes a little over a minute to reset the test stand. At a minimum the water turbine must move a 2.5 lb weight 12 inches vertically to be considered a working device. The team selects the increments to increase weight and the number of test runs to make during their test window. Testing is complete once the turbine fails, the testing window elapses, or the turbine cannot lift the increased load.

The new test stand was designed and built as a capstone project by a team of four students. These seniors used the previous test stand during the 2008 offering of ME403 and were personally aware of its shortcomings. They were provided the following requirements for the device:

- Unit is self-contained
- Fit through a standard double doorway
- Can be transported by the building's cargo elevator (size and weight)
- Two turbines can test simultaneously
- Budget of $3,000

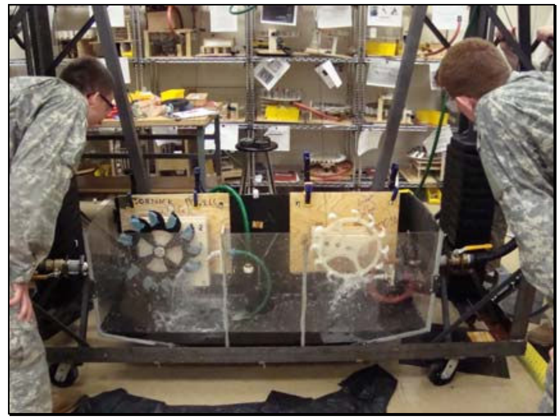

Figure 2. New Test Stand

Assessment

Several indicators suggest that the changes to the water turbine project were successful in achieving the course director's goals. Course-end feedback is collected on all courses at West Point. The students are asked a series of open-ended questions. The students are asked "If you were course director, what would you keep in the course next year? Why?" The following are representative of the answers received for this question with regard to the water turbine.

- *"The water turbine project- it assimilated everything and I learned more about engineering from it than anything in my engineering career so far."*
- *"…I'd also keep the Water Turbine Project because it allows students to enhance their skills of the machines."*
- *"The Water Turbine because it was all inclusive and fun."*
- *"…turbine project helps us put everything together that we learned in the course"*
- *"I would keep … and the depth of the water turbine. The water turbine taught me the most about design and manufacturing by requiring me to apply all of the things we had learned in the course."*
- *"The water turbine project. Nothing teaches better than experience".*

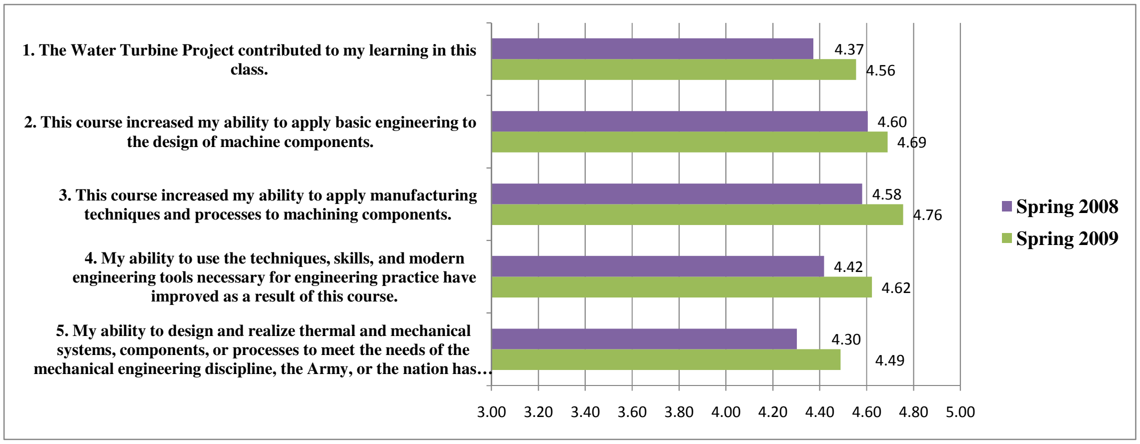

Figure 3. Course End Feedback Questions Applicable to Water Turbine

The students also answer a battery of institution, department, division, and course questions on a five point Likert scale. The results for the five questions are shown in Figure 3. An increase is seen across the board for questions that are related to the water turbine project. The increase provided encouragement as to the success of the improvements, but the data was analyzed to determine if it was statistically significant. Historical data back to 2006 was available for analysis. Each year's value is an average of approximately 45 responses. This sample size represents roughly 50 percent of each course. The distribution was assumed to be normal and a mean value and 95 percent confidence interval for the question from 2006-2008 responses were calculated. The question's mean for 2009 was compared to the upper limit of the confidence interval to determine if the increase was statistically significant. The results of the analysis are provided in Table I.

Table I Statistical Analyses of Survey Data

	Mean 2006-2008	Upper Limit 2006-2008	Mean 2009
1. The Water Turbine Project contributed to my learning in this class.	4.343±0.165	4.508	4.556
2. This course increased my ability to apply basic engineering to the design of machine components.	4.490±0.122	4.612	4.689
3. This course increased my ability to apply manufacturing techniques and processes to machining components.	4.529±0.121	4.651	4.756
4. My ability to use the techniques, skills, and modern engineering tools necessary for engineering practice have improved as a result of this course.	4.343±0.141	4.484	4.622
5. My ability to design and realize thermal and mechanical systems, components, or processes to meet the needs of the mechanical engineering discipline, has improved as a result of this course.	4.255±0.144	4.399	4.489

The responses to all five questions indicate an increase over the previous three years that is statistically significant. Questions two through four are supported by the water turbine project but an increase is not solely dependent on that project. The survey will be repeated for Spring 2010 to see if the students will provide similar responses for these questions.

An increase in the time spent out of class was also seen in the time survey data. Each lesson the students are asked to record the amount of time they spent on the class outside of the normal class period. The Department goal is that a course averages less than 120 minutes per lesson for preparation. In 2008 the average was 93.4 minutes per lesson. In 2009 the average increased to 111.0 minutes per lesson. The increase of 17.6 minutes per lesson represents an increase of 11.7 hours over the entire course. The increase occurred primarily during events that directly supported the water turbine. The amount of time dedicated to construction of the water turbine over the last four lessons doubled from 2008 to 2009.

A question is dedicated in the Course End Feedback to gauge the course's external time requirement. The students are asked to rate "The homework assignments, papers, and projects in this course could be completed within the time guideline of two hours preparation for each class attendance". In 2008 the student's average response was 3.14 on the five point scale while in 2009 the average response was 3.67. The amount of time dedicated to the course increased while the students perceived a decreased work load. The mean response for the prior years was 3.22 with a standard deviation of 0.12 which indicates a statistically significant increase. Despite a measurable increase in the time spent on the course outside class, the students perceived they were better able to accomplish the work required for the course. The fact that the students were able to work in the machine shop during time normally allocated for classes may have also altered the perception. Even though the second period is not officially part of class time, the students may not have made that distinction.

Figure 4. Sample of 2008 Turbine

Figure 5 Sample of 2009 Turbine

The performance of the actual devices indicates that the changes to the water turbine test stand had tangible effects. The winning device from 2008 lifted 102 lbs while the winning device from 2009 lifted 150+ lbs. The limiting factor for testing in 2009 was the inability of the Spectra® fishing line to hold a knot for loads above 150 lbs. The average weight lifted by the devices increased from 48.75 lb to 60.8 lb. The minimum weight lifted jumped from 1 lb to 20 lb suggesting that all teams experienced improved performance. Most notably, two teams in 2008 failed to lift the minimum 2.5 lbs while all teams lifted the minimum weight without issue in 2009. The quality of the build also improved from 2008 to 2009. In addition to lifting more weight, the turbines were of a much higher quality. Figures 4 and 5 are pictures of two devices that are representative of each year's devices.

Conclusion


Figure 6. Students Testing Turbine

The changes made to ME403 were implemented to improve the students learning experience and maximize the potential of existing course content. The water turbine project remained unchanged with regard to content, materials available, and facilities. The inclusion of a test stand tailored to promote competition significantly improved the confidence, skill, learning, and perception of the design. The test stand represented an investment of roughly $3,000 and 350 man-hours that yielded measurable results within the course. This represents a significant investment by the Department. However, by using it as a capstone design project, it also provided valuable instruction. During the Fall Semester of 2009 and Spring Semester of 2010 the long term effects for the students will be evaluated in their ME404 and ME496 courses. The effectiveness of a design course is limited to the "problem" being solved. If it is overly complex or simple, the students will fail to put forth their best effort. Even with an appropriate design problem the venue used to evaluate the artifact will greatly affect both the quality of the instruction and the quality of effort by the student. The use of the mobile test stand helped to tap into the competitive spirit of the student and measurably improve the turbine design project.

Recommendation

Some of the improvements presented are specific to the course, but the general concepts can be applied to any institution or course. The competition should be in as public a forum as possible. Allowing the maximum number of students to directly participate furthers the educational goal, and it serves as a positive reward for the time and energy the students invest in the process. Watching a gear shear teeth provides immediate feedback to everyone watching why understanding bending stress is important. The students must be given the tools to succeed at the project. These "tools" include stock materials, a framework to constrain their solutions, a workspace and the tools (hand, power, etc) necessary to complete the project. The students must also be taught how to use the tools and materials safely and with some proficiency. Without these "tools", they grow frustrated and will not live up to their true potential. Dedicated class time for the project will yield results both in the quality of the finished product, and the student's impression. Left to their own devices, students will underestimate the time required to complete the project and they will wait until it is too late. Dedicating class time early in the semester forces the students to think critically and start work early. The time spent on the project in class, also allows the teacher to drive home key learning objectives and gauge each group's progress. The students benefit by seeing their peers progress. This interaction allows collaboration between groups and provides positive peer pressure to perform. The grading of the event should be tied directly to the learning objectives for the project. Points can be awarded for performance, but the majority should be tied to intermediate requirements that directly support those objectives. In the water turbine project, winning the competition is not a requirement for top marks. A competitive project can be a valuable teaching tool as long as it is properly resourced and presented to the students in the right manner.

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