Three Freshman Team Design Projects

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Abstract

This paper contains a detailed description of three design team-projects developed for a freshman course in mechanical engineering. All projects include the research, design, prototyping, testing, and analysis phases of the design process, and can be completed within half of a two quarter-credit course. They are detailed and in-depth, spanning beyond the typical "hobby-shop" freshman projects.

The three team-projects are the design and testing of a wind turbine, a door handle, and a flywheel. The description of each includes the list of project requirements, learning objectives, design performance measures, testing setup, assignments, timeline, and design considerations. The paper contains examples of students' work, such as design sketches and prototypes manufactured on a stereo-lithography machine (3-D printer), and rubrics used to evaluate the student's individual and team performance. Also included is an example of how assignment grades are linked to ABET (a-k) Program Outcomes.

I. Introduction

This paper describes three design team-projects developed for MEGR 181, a freshman engineering design course, offered in the Mechanical Engineering Department at Seattle University. The course has eight learning outcomes.

At the completion of the course students should be able to:
1. Apply the design process to solve an engineering problem,
2. Identify functional requirements and constraints for a design problem,
3. Develop a prototype design,
4. Work effectively in small teams,
5. Document knowledge and product designs through written memorandums and reports,
6. Use oral presentation to present design and test results,
7. Retrieve information from archival literature, and
8. Run an experiment and analyze the results.

To achieve these outcomes, students participate in a major team design project. The design project is conducted by in-class teams or via a learning community[1-4]. In the first case, teams are comprised of only students from the class. In the second case, the learning community, teams include students in MEGR 181 as well as students in a freshman graphics course and in a high school technology course. In the learning community, freshman graphics students provide technical drawing support, whereas high school students fabricate the parts designed in MEGR 181 using a stereolithography machine (3-D printer). MEGR 181 has been offered either as a separate class or in a learning community setting and when compared, the learning community setting provided enhanced learning experience for both the university and the high school students[4]. This paper provides examples generated in the learning community setting.

The following sections describe the three design projects used in MEGR 181. Section II describes the projects themselves and includes examples of student work. The handouts for one of the projects, which include project description and report guidelines, are included in the Appendix. Section III outlines how the projects were implemented, including a timeline, description of relevant assignments and grading rubrics. Section IV describes how the project grading scores were linked to ABET Criteria III (a-k)[5]. The paper is concluded with recommendations for future modifications.

II. Description of Design Projects

The design projects developed for MEGR 181 are: 1) a wind turbine rotor, 2) a door handle, and 3) a flywheel design. These projects are described below. The description for each project includes learning objectives, formulated based on Felder's recommendations[6], test setup schematics, and examples of student work. The examples of the built prototypes shown herein are those built using a stereolithography machine (3-D printer) at the high school. However, the part geometry is simple enough that students could have also fabricated the parts themselves. Also included are examples of the freshmen design sketches, the test setup, and generated experimental results. For each design project, students are given three handouts. The first handout describes the project. The second and third describe requirements and grading criteria for the research memorandum, and the project report, respectively. The project description and report guideline handouts for the flywheel design project are included in the Appendix.

Wind Turbine Project

In this project, students design a wind turbine rotor for the production of electrical power. The students should optimize the blade geometry and rotor inertia to maximize the power output of the turbine. For a successful design, the students must consider the number, shape, and angle of the blades, hub, and assembly of the rotor with the shaft. Upon completing the design, teams participate in a design competition. The winning turbine is the one that produces the maximum power at a specified wind velocity.

At the end of the project students should be able to:

1. Explain how the wind turbine works,
2. Explain pros and cons of utilization of wind turbines for power,
3. Explain the lift force on an airfoil,
4. Explain how the generator works,
5. Explain Faraday's Law,
6. Use the library to find at least one peer-reviewed archival reference,
7. Calculate power for the generator knowing voltage and resistance,
8. Use a breadboard to set up a network of resistors in series or in parallel, and
9. Measure voltage and current.

A turbine rotor, designed by the freshman design students and manufactured on a stereolithography machine, is shown in Figure 1. To test the performance of the turbines, the turbine rotor is joined to a metal rod, coupled with a small generator, and placed in a wind tunnel (see Figure 2). In our setup, we use a low cost DC motor for the generator. Power output by the turbine is determined by measuring the voltage from a loaded generator at specified wind speeds. The test setup schematic is shown in Figure 3. Test results are plotted as power produced by the generator versus the speed of air in the wind tunnel. An example plot for five competing teams is shown in Figure 4.

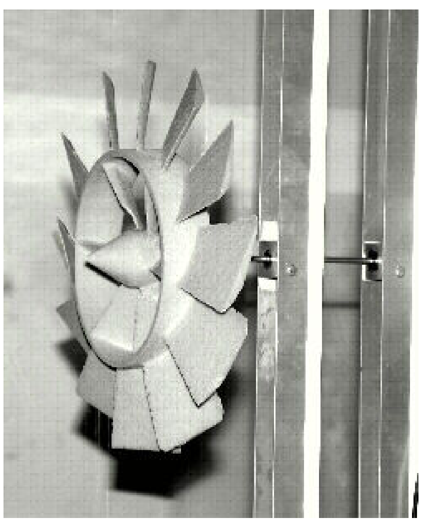

Figure 1. Wind turbine rotor

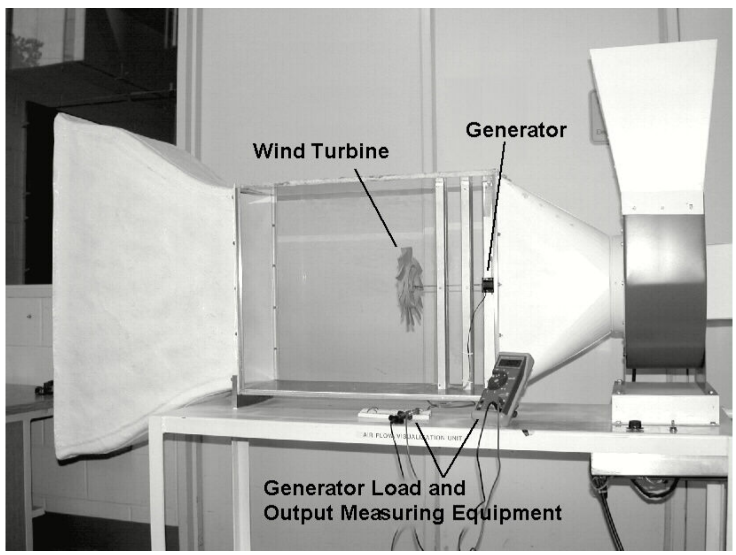

Figure 2. Wind turbine experimental setup

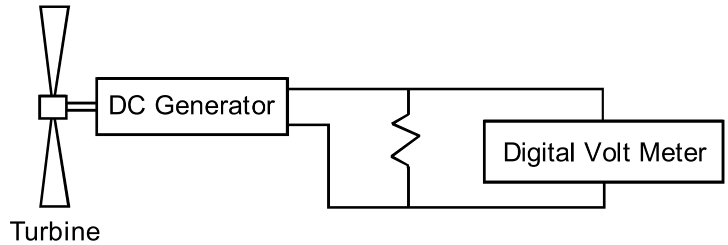

Figure 3. Wind turbine test setup schematic

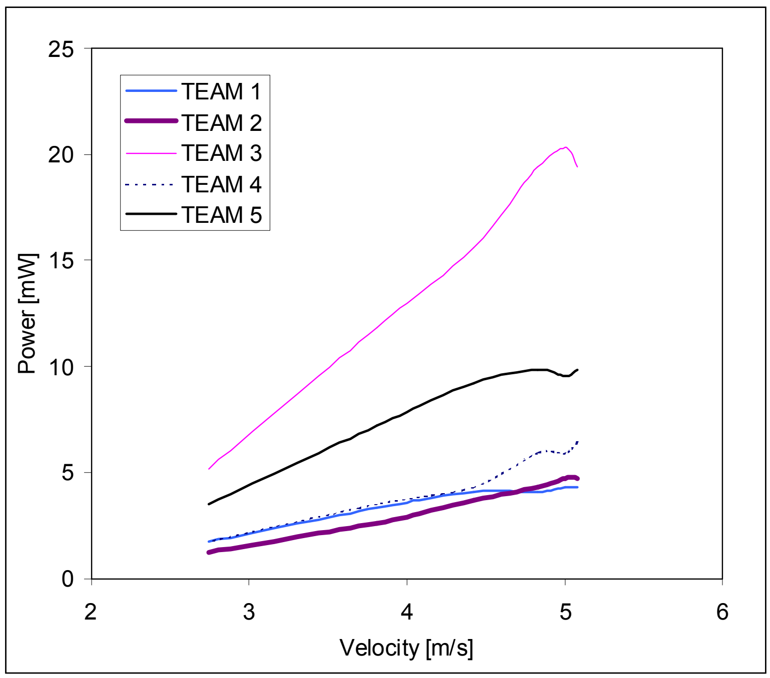

Figure 4. Example plot of power produced by the generator coupled to the wind turbine shaft versus the speed of air in the wind tunnel.

Door handle project

In this project, students must design a handle with a maximum torque-to-weight ratio. The students should select the length, thickness and shape of the handle, in order to optimize the torque-to-weight ratio of their handle. For a successful design, the students must consider the geometry of the handle, direction of the layers of the material deposited by the 3-D printer, and method for positioning the handle on the test stand. Upon completing the design, teams participate in a design competition. The handle with the highest torque-to-weight ratio wins.

At the end of the project students should be able to:
1. Explain torque,
2. Describe methods for measuring torque,
3. Explain tensile and shear strength,
4. Determine approximately the type of stresses in the door handle,
5. Describe a cantilever beam, and the stress distribution in the beam,
6. Describe how stress concentration can cause a part to break, and apply that to the design,
7. Use the library to find at least one peer-reviewed archival reference, and
8. Calculate torque-to-weight ratio based on measured force, distance, and mass of the door handle.

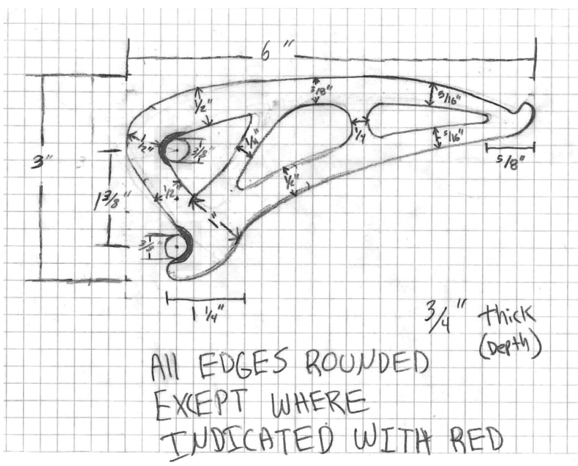

Figure 5. Original conceptual sketch of a handle

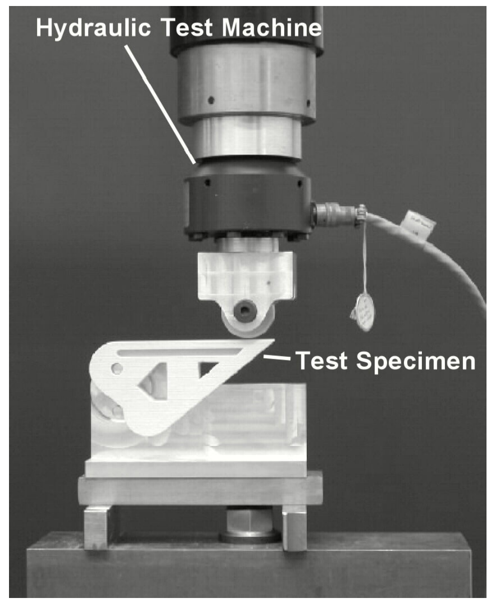

Figure 6. Door handle test setup

A typical student design sketch is shown of Figure 5. To test the performance, the handles are loaded until failure using an axial testing machine, as shown in Figure 6.

Flywheel Design

In this project, students must design a flywheel for energy storage. The students should select the size and geometry of the flywheel to optimize the energy storage capability (energy density) of the flywheel. For a successful design, the students must consider the geometry of the flywheel and assembly of the rotor with the shaft. The material, dimensional and manufacturing design constraints are set by the manufacturing and testing equipment. Upon completing the design, teams participate in a design competition. The flywheel that stores the most energy per unit weight is the winner.

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At the end of the project each student should be able to:

1. List two pros and two cons of using flywheels as energy storage devices,
2. Explain torque,
3. Explain angular velocity,
4. Explain kinetic energy of a rotational object, and it's relation to power,
5. List which parameters, (such as mass or velocity,) and by what relation, kinetic energy depends on, and describe which design considerations would maximize kinetic energy,
6. Explain why the centrifugal force causes tension in the flywheel and which design consideration can address that effect,
7. Describe how stress concentration can cause a part to break, and apply that to the design,
8. Use the library to find at least one peer-reviewed archival reference, and
9. Calculate energy density based on measured voltage, current, time and mass.

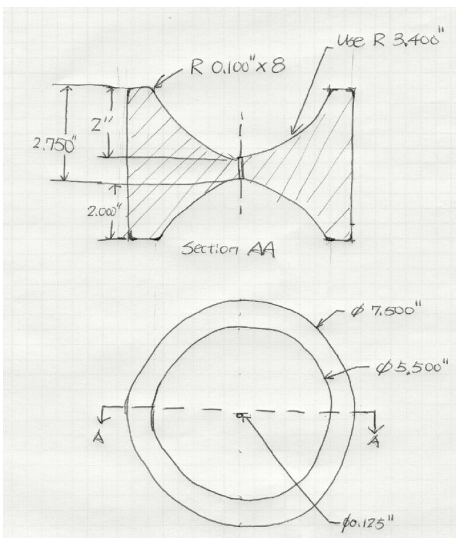

Figure 7. Original flywheel design sketch generated by MEGR 181 students.

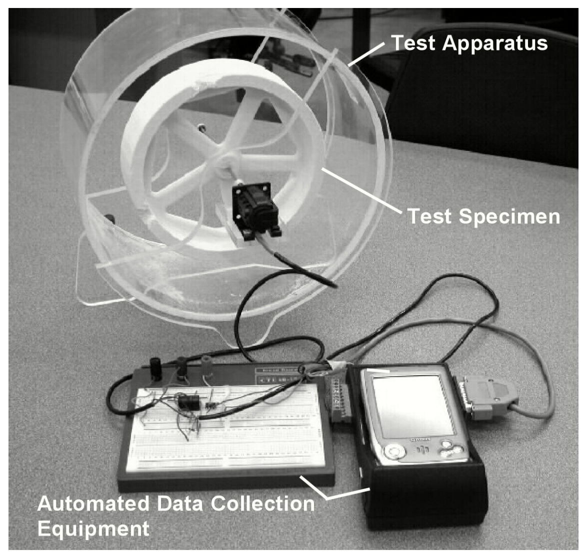

Figure 8. Flywheel test setup

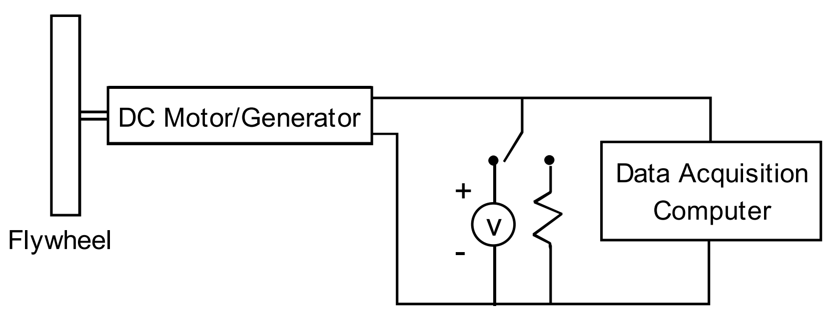

Figure 9. Test setup schematic for flywheel project

A typical student design sketch is shown of Figure 7. To test the performance of the flywheel, the flywheel is attached to a metal rod, which is coupled to a DC motor/generator and a load (see Figure 8). A schematic of the test setup is shown in Figure 9. During the test, the motor spins the flywheel until maximum RPM is reached. Then, power is disconnected from the motor, and the motor, now acting as a generator, is connected to a load. Output from the generator is recorded using a data acquisition system and plotted versus time.

III. Implementing the Design Projects

The projects described in the previous section were designed to be completed in eight, two-hour classes. A typical timeline for the design project is shown in Table 1. During this time the teams progress from initial research and brainstorming to prototyping and final testing. The breakdown of class activities and assignments is also shown in Table 1. The projects are graded using a method designed to help differentiate individual student performance and contribution from the overall team performance. Individual student grade is determined by combining the scores from an individual and two team assignments and the results of a peer evaluation survey. The assignments and the grading components are described below. It should be noted that in course offerings using the learning community[1-4] additional class time is devoted for communication with the high school team members.

Research Memorandum

Students must submit a memorandum containing results of their individual research. In the wind turbine project, the memo should explain pros and cons of using wind turbines for power, the lift force on an airfoil, and the Faraday's Law. In the door handle project, the memo should explain torque, how it is measured, tensile strength, and shear strength. In the flywheel project, the memo should explain the pros and cons of using flywheels as energy storage devices, kinetic energy of a rotating mass, the parameters affecting it, angular velocity, and torque. The memos should also include a description, rationale and critique of one design alternative. The rationale should be based on the understanding of the researched phenomena.

This assignment is submitted early in the design project and is used to assess how well each individual student understands major design features. A grading rubric for the research memo is given in Table 2.

Table 1. Design Project Timeline

Class period	Description of class activities	Classes in which assignments are given	Classes in which assignments are due	% of Project
1	Initial research and brainstorming	Research memo & Team peer evaluations		37.5
2	Formation of design alternatives		Research memo	
3	Prototype documentation and construction			
4	Prototype testing	Project report		37.5
5	Redesign	Project presentations		25.0
6	Final construction and testing			
7	Design competition			
8	Design presentations		Project report & Team peer evaluations	

Table 2. Research memorandum grading rubric

Category	Maximum	Score
Memo format (to, from, subject, date….)	3	
Brief introduction to the memo	7	
List two pros and two cons of flywheels as energy storage devices	10	
Answer to: What is the definition of the rotational kinetic energy? What parameters does it depend on	10	
Answer to: What is angular velocity? What is torque?	10	
One flywheel design alternative description	20	
Relate rotational kinetic energy and your design	10	
Figures - named and numbered; all referenced in the text	5	
Reference list – all references mentioned in the text	5	
Grammar and syntax	15	
Writing in third person (occasional first is OK)	-	-
Active/passive voice; singular/plural; correct tense	-	-
Concrete (non-narrative, not wordy, non-abstract)	-	-
Balanced (non-overloaded or clipped) sentences	-	-
Spelling, jargon, fad words	5	
Total	**100**	

Project Report

Student teams must submit a project report that contains project descriptions, design alternatives, description and rationale of the final design, final design's testing performance and evaluation, and design recommendations. Students are given a handout that describes the report requirements, structure, and grading rubric. The handout for the flywheel project is included in the Appendix.

Presentation

Teams must present their work at the end of the design project. The content of the presentation is similar to their written project report. Ten percent of the presentation score is allotted to the overall presentation quality.

Team Peer Evaluation

Team peer evaluation questionnaire was developed based on BESTEAMS Peer Evaluation Form[7]. In this questionnaire, each team member is asked to rate themselves and the other team members in fourteen categories, relating to the member's performance on the team. The BESTEAMS Peer Evaluation Form was modified by adding the following questions: "Does the team member contribute to:" 1) everyday hands-on work and drawings, 2) writing of the project report, 3) management of the design project, and 4) engineering and technical components of the project. This questionnaire is used to differentiate the team member grades on the report and the presentation.

Team Milestones

Teams are evaluated as to whether they completed design and communication milestones by the deadlines specified by the instructor. Those milestones include deadlines for prototypes, research memo, report, final presentation, peer evaluation, and others.

IV. ABET Evaluation

Student performance in the design projects was linked to ABET Program Outcomes using a two-step process, similar to that suggested by Felder[8] and Schumack[9]. First, student assignment grades are mapped to individual course outcomes for MEGR 181. Table 3 shows this mapping for a typical course offering. To obtain meaningful results for this mapping the instructor grades each assignment with respect to the course learning objectives. These grades are not necessarily the same as the assignment grades. For example, in the project report, scores are recorded separately for each category in the scoring rubric (see Appendix, Table 1). Then the categories that correspond to course learning objective are combined to form a weighted score presented in Table 3. For instance, categories 3 and 4 (Appendix, Table 1) are combined to create the score for the learning outcome: "Develop a prototype design" (see Table 3 below). At the end of the term, the instructor tallies the ABET grades, producing a score for how the student, or class as a whole, performed with respect to each of the course learning objectives.

Table 3. Assignment to Leaning Outcomes Mapping

	Research Memo	Project Report	Presentation	Team Peer Evals	Overall
Apply the design process to solve an engineering problem				92	92
Identify functional requirements and constraints for a design problem		85	90		87
Develop a prototype design		78	80		79
Work effectively in small teams				92	92
Document knowledge and product designs through written memorandums and reports	90	75			82
Use oral presentation to present design and test results			85		85
Retrieve information from archival literature	90				90
Run an experiment and analyze the results		70			70

Table 4. Assignment to Leaning Outcomes Mapping

	Tallied Score from Tabel 3	ABET Cirteria										
		(a)	(b)	(c)	(d)	(e)	(f)	(g)	(h)	(i)	(j)	(k)
Apply the design process to solve an engineering problem	92			1								
Identify functional requirements and constraints for a design problem	87			1								
Develop a prototype design	79	1		1								1
Work effectively in small teams	92				1		1					
Document knowledge and product designs through written memorandums and reports	82	1						1				
Use oral presentation to present design and test results	85							1				
Retrieve information from archival literature	90									1		
Run an experiment and analyze the results	70		1									

(a) an ability to apply knowledge of mathematics, science, and engineering
(b) an ability to design and conduct experiments, as well as to analyze and interpret data
(c) an ability to design a system, component, or process to meet desired needs
(d) an ability to function on multi-disciplinary teams
(e) an ability to identify, formulate, and solve engineering problems
(f) an understanding of professional and ethical responsibility
(g) an ability to communicate effectively
(h) the broad education necessary to understand the impact of engineering solutions in a global and societal context
(i) a recognition of the need for, and an ability to engage in life-long learning
(j) a knowledge of contemporary issues
(k) an ability to use the techniques, skills, and modern engineering tools necessary for engineering practice

In the second step, course learning outcomes are mapped to ABET Program Outcomes (a-k). This mapping is shown in Table 4. This mapping reveals how each course learning outcome contributes to the (a-k) program outcomes. To simplify the process, the instructor provides either a 0 or 1 indicating whether the course outcome satisfies the ABET criterion (1) or not (0). These values are combined with the tallied scores from the previous step to provide a relative score as to how well students performed on the outcome.

The result of this two-step process is that we are able to directly link student performance with ABET objectives. Results from the mapping for the freshman design class are later combined with results from other courses to help identify strength and weakness of the overall program.

V. Recommendations

All three design projects have been used in MEGR 181 for the past three years with approximately half the offering using a learning community[1-4]. From the instructors' viewpoint, the projects are simple and require a minimum amount of hardware to build and test. From this perspective the projects work well. However, the projects do require a lot of writing from the students, which results in a heavy grading load for the instructor. A possible solution is to eliminate the memorandum and replace it with a short answer test. The test would cover the same material as the memorandum, but would be much simpler to grade.

The project report average grades were generally about 75% of the total, which is viewed as low. Many of the sections were poorly explained or missing. A solution is to divide the final report into two sections. In the first section, students would discuss only their research, requirements and constraints, and prototype development. In the second section they would discuss the final design, testing and results. The first section could be due midway in the project. This would better distribute the grading for the instructor, and would provide students with intermediate feedback about their writing and design solution. In our last offering of MEGR181, we divided the final report into two sections as suggested. We found that student's final reports were better written because they were able to incorporate the instructor's suggestion from the first section. The grading load at the end of the term was also reduced.

V. Conclusions

The paper describes three design projects that were implemented in a freshman design class operating either with in-class teams or with teams in a learning community setting. In the learning community setting, each design project is completed by design teams whose members are students from the design class, university freshman graphics course and a high school technology course.

Each design project includes the following phases: initial research and brainstorming, formation of design alternatives, prototype documentation and construction, prototype testing, redesign, final construction and testing, design competition and design presentations. The projects were successfully completed in eight, two-hour sessions, plus related homework. The design projects have proven to be simple and useful for freshman design. Students found the projects both challenging and enjoyable. Both the university and the high school students who participated in the learning community offering were particularly enthusiastic about the design project and the team design experience.

The course learning outcomes are scored using the project deliverables, and are mapped to the ABET Criterion 3, Program outcomes (a-k) to assess the overall contribution. The process is illustrated in the paper. The relatively high scores for this assessment demonstrate that the projects satisfied all of the related class learning outcomes. The class learning outcomes were satisfied in all nine course offerings.

Acknowledgments

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Author Biographies

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Appendix: Flywheel Project Description and Report Guidelines

Flywheel Design Project Description

1. OVERVIEW

Flywheels are rotating masses installed in rotating systems to act as storage reservoirs for kinetic energy. There are two main purposes of the flywheels: 1) flywheels are used to store energy in the form of kinetic energy; and 2) flywheels are used to deliver steady angular velocity and torque to the load. Flywheels are energized by power suppliers, such as a wind turbine, and deliver energy to the home when the power supply is not running, such as when there is no wind.

2. OBJECTIVE

The purpose of the Flywheel Design Project is to apply theoretical design process to a design of a functioning flywheel. The students are asked to optimize the size, the shape and the flywheel structure, while keeping the design within constraints. The goal is to win the competition for the highest energy density. The flywheel is coupled to an electric generator and a load. The electric power supplied to the known load is measured with a voltmeter. And, the power will be measured in a two-minute time. The students are also asked to conduct research into flywheel design, torque, and strength of materials.

3. PROJECT DESCRIPTION

After assigning the teams, the first step is to identify team roles and define a schedule. The next steps are outlined in the Section 3.1-3.4.

3.1 Problem definition phase

Identify functional requirements and constraints for the project. The primary requirement is to create the flywheel with the highest energy density. Energy density is defined as a ratio of useful energy and mass. Useful energy is defined as power delivered in a two-minute time interval.

The flywheel is to be designed for the material available at the Central Kitsap High School. The flywheel will be made on a stereo lithography machine, also known as the 3-D printer, and the specs for the object size and material properties need to be obtained from the high school.

The flywheel will be tested using the test procedure sketched in Figure 1.

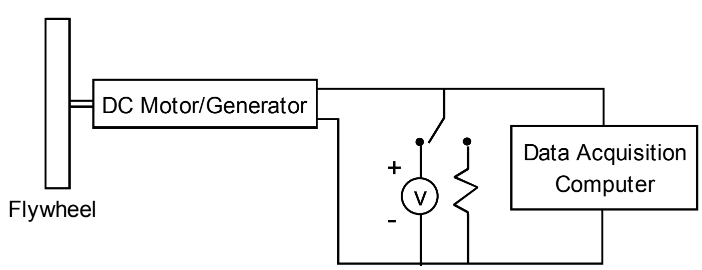

Figure 1. Testing description

3.2 Research phase

The research phase consists of obtaining the information on the physical phenomena related to torque and strength of materials. The particular following information is to be supplied: What is torque? What is angular velocity? What is kinetic energy of a rotational object? The students are asked to find at least one peer-reviewed archival reference, i.e., a book or a journal article, to substantiate their research. The peer-reviewed archival references can be found in the libraries. Some libraries and government agencies also publish peer-reviewed articles on the internet. However, please note that most web pages are not considered peer-reviewed archival references; hence some of them cannot be used as reliable resources. In order to avoid problems associated with gathering information from unreliable sources, students are asked to base their research in peer-reviewed archival reference publications. The form for referencing can be found in the textbooks. All textbook referencing styles are welcomed, and consistency is required. (That is, pick one style and use it for all the references in one document.)

2.3 Flywheel design

Engineering Design Considerations:

1) Energy density is defined as:

Energy density = [power * time (2 minutes)] / [flywheel mass]

To satisfy the maximum energy density requirement, you are required to supply maximum power by using the smallest amount of material.

2) The rotating flywheel needs to have axisymmetric geometry to avoid unbalanced dynamic forces caused by eccentric mass centers.

3) The cornstarch material is stronger in compression than in shear or tension. Different parts of the flywheel will experience different amounts of each type of force. The outer rim of the flywheel experiences significant centrifugal force ($=mr\omega^2$) causing tension.

4) Stress concentrations can cause a part to break at sharp corners. Avoid them.

5) When inspecting parts, watch for little cracks, notches, and impurities that may be causes for stress concentration. The stress concentration may initiate crack propagation and cause your flywheel to break or catastrophically fail.

2.4 Testing the Flywheel Design

Testing of the flywheel design will be done per description shown in Figure 1. The flywheel will be spun by an electric motor powered by a battery. Then, it will be hooked onto a known load and the voltmeter will be used to record potential difference generated. The potential difference is related to power produced. The potential difference, also called voltage, will be measured over a two-minute time period and integrated to give the total power produced. That number can be converted into energy delivered. That energy divided by the mass of the flywheel gives energy density of the flywheel. That energy density can be compared to the energy density of a battery.

Flywheel Design Project Report Guidelines

The objective of the design project prototype report is to inform the reader about the design process that leads to the creation and testing of a prototype. The report should be written and submitted by the entire team. The report should contain:

1. A brief project description, including functional requirements of the design project and constraints detected during the design.
2. A brief description of at least two prototypes considered during brainstorming, including the reasons why those were considered.
3. A detailed description of the prototype that was tested, including reasons why it was chosen for testing.
4. A description of the testing procedure and presentation of the results. Comment on the results by providing objective evaluation, and conclude by writing suggestions that you may have for the final design.
5. Sketches and charts, which should all be labeled as figures and referenced in the text. They can either be placed in the main body of the document or in the Appendices or both. Figures that may be disruptive to the reader, based on their size or number, should be placed in the Appendices.
6. References. All references should be called in the text and should be listed in the reference list. This list should contain references to all documents that were referred to in the text, not any more, not any less.

The report is due on ……. The report will be graded based on Table 1 below.
Structure and content
The following sections should be included and in the following order: title page, abstract, table of contents, introduction, prototype description, testing procedure and results, conclusions, and reference list. Each section should start on a new page, and sections of the main body of the document, i.e., introduction, prototype description, testing procedure and results, and conclusions, should be numbered (example: 1. Introduction). Below is the description of the content of some of the sections of the report.

Abstract

Abstract should provide a summary of the entire report, including major results and conclusions. It should be written last.

1. Introduction

(Please note that the Introduction is the first section of your report, hence it has a number 1 in front of the title.) The introduction should contain a brief project description, including functional requirements of the design project and constraints detected during the design.

2. Prototype design description

(Please note that the Prototype Design Description is the second section of your report, hence it has a number 2 in front of the title.) This section should contain a brief description of at least two prototypes considered during brainstorming, including the reasons why those were considered (for example, the thickness was reduced to decrease the weight). This section should also contain a detailed description of the prototype that was tested, including reasons why it was chosen for testing. A description is considered brief if the reader is able to picture the design. A description is considered detailed if the reader of the report can picture and replicate the design. The use of sketches is encouraged when describing the prototypes.

3. Testing procedure and results

This section should contain a description of the procedure used for testing the prototypes. The results need to be presented and explained. The purpose of this section is to provide enough information so that someone who has never seen the experiment could replicate it solely based on your description. The use of sketches and charts is encouraged when describing the tests and the results. This section should also contain suggestions for the final design derived based on the testing results.

4. Conclusions and recommendations

This section concludes the document by repeating the most important features of your report. Recommendations for potential redesign or testing improvement should also be included.

Table 1. Evaluation table for the prototype report

	CATEGORY	**POSSIBLE**	**SCORE**
1	Abstract content	5	
2	Report introduction	12	
	Brief project description	6	-
	Project constraints and requirements described	6	-
3	Description of at least two prototypes considered	15	
4	Reasons for choosing the tested prototype	5	
5	Testing description, results, and discussion	20	
6	Conclusions	8	
7	Structure/ professionalism (numbering and naming sections, each section-new page, title page, table of contents) / typed, clear drawings, consistent margins and font	5	
8	Figures - named and numbered; all referenced in the text	5	
9	Reference list – all references mentioned in the text	5	
10	Grammar and syntax	15	
	Writing in third person (occasional first is OK)	-	-
	Active/passive voice; singular/plural; correct tense	-	-
	Concrete (non-narrative, not wordy, non-abstract)	-	-
	Balanced (non-overloaded or clipped) sentences	-	-
11	Spelling, jargon, fad words	5	
	TOTAL	**100**	