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Design of an Engineering Experiment and Data Driven Design in Secondary Education

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Design of an Engineering Experiment and Data Driven Design in Secondary Education

by

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Report

Presented to the Faculty of the Graduate School of

The University of Texas at Austin

in Partial Fulfillment

of the Requirements

for the Degree of

Master of Arts

The University of Texas at Austin

August 2013

Dedication

This work is dedicated to my wife, Christina.

Without her support, patience and understanding this work would not have been possible.

Acknowledgements

Acknowledgements

I would like to thank Dr. David Allen for his continual support and guidance throughout this process, and to Theresa Dobbs who encouraged me to enter the program and gave me great support from the very beginning. In addition I want to thank my wife Christina for all her support and encouragement through the past three years. Lastly thanks to all my fellow cohorts that made the experience so enjoyable and stimulating.

Abstract

Design of an Engineering Experiment and Data Driven Design in Secondary Education

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Pre-tests and post tests were used to assess the effectiveness of an engineering high school unit on experimental design and data driven design. The engineering data acquisition unit examined in this report used project based learning to teach the design of an engineering experiment and data driven design as part of the engineering design process. The project consists of the design of a building that can safely withstand an earthquake. Students construct, test and collect data on baseline buildings, with and without load using a shaker table and data acquisition. Students' then design experiments to evaluate design modifications that will meet the customer's needs. Overall, although the number of participants was limited, the survey instruments indicated that understanding of experimental design improved among high school students participating in the unit. Based on this pilot implementation of survey instruments, some of the survey questions were clarified.

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Chapter 1

Introduction

Problem Statement:

As the United States continues to push education toward twenty first century skills including critical thinking, evidence based reasoning, problem solving, and scientific thinking, STEM (Science, Technology, Engineering and Mathematics) Education has become a major initiative throughout the country. As part of the STEM initiative in Texas, the Texas Education Agency (TEA) has added the following Engineering courses to the High School curriculum through Career and Technology Education: Engineering Design and Presentation, Advanced Engineering Design and Presentation, Engineering Mathematics, and Engineering Design and Problem Solving (TEA, 2010). Texas has also passed HB 5, which includes amendments to double the number of CTE courses, including rigorous STEM courses, available for high school students. House Bill 5 also changes high school graduation plans to include diplomas in specialized areas or "endorsements"; one of which is a STEM endorsement graduation plan that will require several STEM courses with a capstone class (Texas Legislature, 2013).

On the national scene, Senator Kirsten Gillibrand (D-NY) and Representatives Paul Tonko (D-NY) and Joe Kennedy (D-MA) introduced legislation recently that would help boost science, technology, engineering, mathematics (STEM) education programs in the nation's elementary, middle and high schools. The Educating Tomorrow's Engineers Act (Gillibrand press release, 2013) would help increase student achievement and interest in science and engineering disciplines by removing barriers at the federal level that prevent schools from expanding math and science to include innovative, hands-on learning through engineering design experiences. (Tonko press release, 2013)

"America is home to the world's strongest economy, the greatest colleges and universities, and the world's brightest minds," said Senator Gillibrand (Gillibrand press release, 2013). "But if we are going to continue to lead, we need to prepare our children for the jobs of the future. Our bold legislation can spark greater interest in science, technology and engineering, equipping students today with the skills they need to lead in the new economy. When we teach America's third graders to build rockets and fifth graders to build robots, it will be them who make the next big scientific breakthrough that changes the world, and ignites our economy." (Gillibrand press release, 2013)
"Engineering education helps all students understand the world around us and how things work," said Congressman Tonko (Tonko press release, 2013). "Exposing more students to engineering will prove to be a tremendous asset as we work to enhance the quality of education they receive. Our future leaders will benefit greatly from this legislation and I look forward to working with my colleagues in the House of Representatives to fight for its passage into law. I am thankful for the opportunities I had in engineering education, and I thank Senator Gillibrand for her leadership on this issue in the Senate." (Tonko press release, 2013)

"STEM education is the critical link between a new generation and the jobs of tomorrow," said Congressman Kennedy (Tonko press release, 2013). "From precision manufacturing to clean energy to life sciences: the industries that will power this country's future depend on a highly-skilled and innovative workforce. This legislation will help ensure that more students are exposed to the creative problem solving skills that an engineering curriculum can provide. I'm proud to join Senator Gillibrand and Congressman Tonko, who have both led the way in ensuring we prepare our students to compete and lead in a global economy." (Tonko press release, 2013)

These initiatives in the State of Texas and at the federal level recognize the role of engineering in education, yet most students in the United States have never enrolled in an engineering course, and a vast majority of schools do not offer opportunities for students to take engineering courses. Fortunately, a growing number of states, schools, and teachers are recognizing the importance of engineering design and problem-solving skill sets and have begun to integrate these concepts into their classrooms. ETEA is designed to help encourage all states to follow this path and to remove barriers at the federal level so that K-12 engineering education can be adopted more broadly (Tonko press release, 2013).

To accomplish these goals, ETEA builds upon existing federal education policy in several key areas:

Expands Student Exposure to Engineering Design Skills:

The current federal rules under the Elementary and Secondary Education Act (ESEA) require states to develop "science" standards, but they are often perceived as being related to simply the traditional areas of science - as a result, engineering is rarely a component of these standards.

ETEA would require states to ensure engineering design skills and practices are integrated into their science standards - but would not require states to establish a separate set of standards specifically for engineering. It also provides flexibility to states to enable the use of current State Assessment Grants under ESEA to support the integration of engineering concepts into science standards and assessments (Tonko press release, 2013).

Expands teacher professional development:

Many schools already face shortages of math and science teachers, and these teachers often have little background in how to teach engineering design skills. Further, there is rarely an extensive curriculum available to help support the teaching of these skills. ETEA addresses these issues by targeting a portion of current Title II funds under ESEA (Teacher and Principal Training and Recruitment Fund) for states to award grants to support professional development and instructional materials for STEM education.

Schools seeking to expand engineering education find that key federal education programs limit their ability to use funds for such purpose. ETEA addresses this issue by clarifying the ability for these funds to be used to support engineering education. Specifically, ETEA amends the current Math and Science Partnership (MSP) program by expanding the program to all STEM subjects, including engineering and computer science. Similarly, the legislation amends the 21st Century Learning Centers program (providing funds for after school activities) and the Rural and Low-Income School program by expanding uses of funds to support programs for all STEM subjects (Tonko press release, 2013).

Promotes Federal Research in the Area of Engineering Education:

The Department of Education's Institute of Education Sciences (IES) is tasked with funding a wide variety of education research, including extensive work in the areas of mathematics and science education. However, the agency does little work in the area of engineering education, in part due to the current law establishing IES (Gillibrand press release, 2013).

ETEA amends the Education Science Reform Act of 2002 to expand the mission and duties of IES beyond mathematics and sciences and for the first time, to include all STEM subject areas. The bill also directs IES to specifically support key studies and evaluations related to K-12 engineering education, including identifying best practices and promising innovations (Tonko press release, 2013).

The growth of economies throughout the world has been driven largely by the pursuit of scientific understanding, the application of engineering solutions, and continual technological innovation (National Academy of Engineering, 2007). To help protect future innovation, competitiveness, and the standard of living in the United States from declining the National Research Council, the National Science Teachers Association, the American Association for the Advancement of Science, and Achieve have developed the Next Generation Science Standards (NGSS, 2013). Strengthening the engineering aspects of the Next Generation Science Standards will clarify for students the relevance of science, technology, engineering and mathematics to everyday life (NGSS, 2013).

All of these initiatives suggest a growing role for engineering education. As secondary engineering curricula are developed, key learning objectives must be defined. For engineering courses to satisfy science and math requirements in Texas, some of the Texas Essential Knowledge and Skills are: a) use clear and concise written, verbal and visual communication; b) identify and describe the fundamental processes needed for a project; c) use problem-solving techniques to develop solutions; d) apply design concepts to problems; e) develop and test the model; f) think critically, identify the system constraints, make fact-based decisions and apply decision-making strategies when developing solutions; g) improve a product design to meet a specified need; h) use a data acquisition system to measure and analyze mathematically data; i) identify the inputs, processes, outputs, control, and feedback associated with open and closed systems; j) determine the design parameters associated with an engineering problem; k) test and evaluate proposed solutions using methods such as models, prototypes, mock-ups, simulations, critical design review, statistical analysis, or experiments; l) apply structured techniques to select and justify a preferred solution to a problem; m) predict performance, failure modes, and reliability of a design solution (TEA, 2010).

This study will consider two aspects of the engineering design process, integrated into secondary engineering education; first, the design of an engineering experiment and second, how experimental data is used in design. Using a specific project based lesson developed by UTeach*Engineering*, the study will consider how the lesson affects students' ability to determine the design parameters associated with an engineering problem and to use a data acquisition system to measure and analyze mathematically data.

Specifically, this study will examine the following issues:

1. Design of an experiment: does the data acquisition lesson affect; how students analyze and select criteria when designing experiments in an engineering setting, and their understanding and use multiple levels of experimental design?

2. Data driven design: does the data acquisition lesson affect; how students use data collected from experiments in their design process decision making? Does the lesson teach students to consider a hierarchy when looking at data; identify and use specific criteria; and consider multiple factors?

Chapter 2 provides a literature review relevant to these issues. Chapter 3 describes the methods employed in the work. Chapter 4 presents results; Chapter 5 summarizes the findings and Chapter 6 describes the relevance of the results to the practice of secondary engineering education.

Chapter 2

Literature Review

STEM Education:

President Obama in 2009 launched the "Educate to Innovate" campaign to elevate achievement of American students in science and math through STEM education. "Reaffirming and strengthening America's role as the world's engine of scientific discovery and technological innovation is essential to meeting the challenges of this century," said President Obama. "That's why I am committed to making the improvement of STEM education over the next decade a national priority." (The White House, 2009)

The goal of STEM education is to improve science, technology, engineering and mathematics understanding; improving critical thinking and foundational knowledge in math and science can be promoted through engineering (Svarovsky, 2011) and the development of engineering habits of mind. Specifically, National Academy of Engineering (NAE, 2009) has presented three important principles for pre-college engineering; a) an emphasis on engineering design; b) the development of appropriate math, science, and technology skills; and c) the development of engineering habits of mind and ways of thinking (Svarovsky, 2011). Engineering habits of mind and critical thinking are promoted through authentic project based inquiry lessons, and these types of lessons also increase awareness of and interest in the role engineers play in supporting and advancing humanity (Brophy, 2008).

Problem-based learning (PBL) is believed by some to be one of the most important pedagogical innovations in the history of education (Jonassen, 2000). PBL experiences in engineering education engage students in problems that include resolving problems that contain the complexities and ambiguities of workplace problems (Jonassen, 2000). Identifying what is important in a problem is often very difficult for students at the beginning of a design project; they need to be taught how to identify all the parameters that may influence a design. Basing design decisions on thorough research and testing reduces the amount of redesign work needed in the end. Students must be able to show that they understand the design challenge's problem statement and all the parameters and constraints before beginning the design process. Students should create functional descriptions of what a viable solution should do to be successful. A design problem's most critical issues must be discovered and identified before a solution can be considered. Part of this process is conducting valid experiments to learn about the materials, key design variables and how the system works. Good in-depth experiments that include all components and how they affect each other and the system are crucial to creating a valid design solution.

Experimental design can be used to reduce design costs by speeding up the design process and reducing engineering design changes. Atman et al.(2007), found that a significant difference between college engineering students and advanced engineers was that engineers spent significantly more time problem scoping and information gathering and covered more categories in their information gathering. Spending more time in the design of the decision making process leads to more time generating and evaluating solutions and thus a creating a better design. Students often want to jump immediately to designing a final product when posed with an engineering design problem without considering all the many aspects of the problem and the design process. Students must learn the habits of mind of an engineer and see the benefit of determining and testing all aspects of a design problem's criteria thru systems thinking.

In this work, student understanding of design of experiments and the systematic analysis of engineering data is probed through a lesson developed through UTeach*Engineering* as part of the Engineering Your World engineering science course (EYW, 2012). The lesson has students study earthquakes and their effects on buildings using models and a National Instruments shaker table (myQuake) (National Instruments, 2013). To begin the lesson, students are introduced to earthquakes and discuss what happens during an earthquake and the inherent dangers posed; they investigate different videos of earthquakes and discuss any personal experiences they might have had. Students are introduced to the northeast region of India where their scenario is located and to interviews of stake-holders, so they can begin a *Know Need to Know List* (EYW, 2013) and create a customer needs statement that leads into a list of Requirements and Constraints (EYW, 2013).

In the second unit of the lesson students learn more about what causes earthquakes how they are measured, what effects earthquakes have on buildings, and what type of earthquakes they will need to design for. Students determine the need for a method of simulating earthquakes and discover how earthquakes are measured on a large scale and are given a demonstration of the myQuake shaker table, accelerometers and software that they will use to collect data on a smaller scale. This leads the students into the design of an experiment. Students should decide what type of building(s) should first be tested. The customer is interested in height of the building and the presence and or position of a load in the building. The students develop a 2 x 2 matrix for their experiment containing short and tall building each with and without a load. This leads the students into first creating two scale models: one short and one tall. Students are required to create scale drawings of their buildings and plan out the construction process in detail in their design notebooks. Once the two models have been built, students begin unit three and determine how they will test each building. Students must consider where they are going to place the two accelerometers, the requirements and constraints for the load on the building, and what speed and frequencies will be tested. Students will produce frequency versus acceleration graphs to use for analysis. Using the results, the students will be able to create their own design to meet the customer needs.

The third unit has the students' test the baseline small building first with the accelerometers placed at the roof of the building. Students' collect acceleration data to see how acceleration is affected by shaking frequency and visualize the data on a standard seismic spectrum graph. Students then add load to the roof and repeat the tests. Students should notice that mass does affect the acceleration and that certain frequencies bring about the most acceleration. Students' then repeat the tests on the taller structure to complete the 2 x 2 Design of Experiment matrixes and see how height and mass shift the graph.

In the fourth unit students find class means and standard deviation from the data collected in unit 3 to determine if either the short or tall building falls into the designated safe frequency. Students find that neither building is safe and learn more about the causes of acceleration patterns so they can avoid creating problematic designs later. Students' learn about the idea of interactions and think about the causes of this interaction. Then they learn about resonance and discover how height and mass change resonant frequency of a system. Students' update their constraints and requirements to avoid unsafe resonance and begin generating ideas to create a design that will produce a safe building.

Chapter 3
Methods

This study examined the following issues:

1. Design of an experiment: does the data acquisition lesson affect; how students analyze and select criteria when designing experiments in an engineering setting, and their understanding and use multiple levels of experimental design?
2. Data driven design: does the data acquisition lesson affect; how students use data collected from experiments in their design process decision making? Does the lesson teach students to consider a hierarchy when looking at data; identify and use specific criteria; and consider multiple factors?

Two different populations were used to investigate the effectiveness of the lesson: high school students, and in-service and pre-service teachers participating in the UTeach*Engineering* degree programs enrolled in the Engineering Energy Systems course at the Cockrell School of Engineering at the University of Texas. The in-service and pre-service teachers were used to gain the teachers perspective of the lesson.

The high school students were drawn from two classes of approximately twenty students each at John B. Connally High School, who were taught the earthquake unit. Of the forty students, twenty-two agreed to be participants in the research; within the twenty-two participants half were concurrently enrolled in upper level math and sciences courses while the remainder was enrolled in regular level math and science courses. Only three of the twenty-two students were female. Connally High School is run on an A – B block system where each class period is 80 minutes and meets every other day. Over the course of four weeks near the end of the 2012-2013 school year, each class met ten times.

Twenty-one UTeach*Engineering* in-service and pre-service experienced the unit under the direction of Dr. David Allen. Fourteen of the participants were in-service teachers currently enrolled in the Master's of Arts in Engineering Education program, while the other eight were undergraduate students earning degrees that would lead to credentialing as science teachers. Ten of the participants were female. Each of the 5 days of the unit consisted of a three hour block of time.

Both groups were administered pre-tests. All of the participants were given two pre-tests; one focused on experimental design, while the other focused on design driven by data analysis. For the high school students the Experimental Design Pre-Test was administered on the first day of the unit, while the Data Driven Design Pre-Test was administered on the third class period. This was done to avoid possible overlap of information or methods from the Data Driven Design Test to the Experimental Design Test. For the pre-service and in-service teachers there was not a concern of overlap, both pre-tests were administered on the first day of the unit.

The Experimental Design Test is shown in Table 3-1. Questions one and two of the Experimental Design Test were multiple choice questions to allow for quick concise coding. Question three was a short answer broken into four parts dealing with a specific design problem to allow the students to express their thought processes. The last question was an open-ended question to assess an overall view of design of an experiment. Question 1 of the Experimental Design Test (Table 3-1) was designed to assess the students' ability to recognize, analyze and select criteria from multiple parameters of an engineering experimental design. Question 2 was designed to assess the students' knowledge of possible combinations or multiple levels of parameters found in a multifaceted experimental design. The remaining questions are focused on the students' ability to analyze and understand multiple levels of experimental design. Question 3a also considers combinations specifically targeting the design of an experiment in regards to the number of tests that need to be conducted. Question 3b assesses the students' perception of possible variation in data. Question 3c was designed to assess the students' knowledge of variability or 'noise' in data. Question 3d focuses on the students' ability to reduce variability factors through experimental design. Question 4 assesses all aspects of Design of an Experiment by asking students to create an experimental design for a specific situation.

A group of engineering students is designing a rocket; they have determined from research that the number of fins on most existing rockets to be: three, four or six located near the bottom. They have also found that secondary fins are often used part way up the rocket, and there are two basic shapes of fins.

1. What parameters should they consider when designing their experiment for testing?
   a. Number of bottom fins
   b. Number of secondary fins
   c. Use of secondary fins
   d. Position on fuselage of secondary fins
   e. A and B
   f. A and C
   g. A, B, and D
   h. A – D
2. After further research and interviews with engineers the students decide to test: 3, 4 or 6 fins at the bottom; 2 or 3 fins located in two different positions. How many different combinations should the group test?
   a. 3
   b. 12
   c. 7
   d. 18
3. You work in a product design company and are creating a new alarm clock for children. You want to find the best sound for the alarm clock that wakes children up the fastest. The plan is to design a multi-factorial experiment to test different sounds on sleeping children. Your team has identified three variables of interest to test, with two levels for each variable. The variables are:

- alarm intensity (quiet vs. loud)
- pitch (low vs. high), and
- sound type (musical vs. buzzer).

a) What is the minimum number of experimental tests you should do, and why?

b) Your teammate suggests that you repeat each test on three different children. Do you agree to do this, and why or why not?

c) What might be sources of noise or variability in your data?

d) What procedures could you follow to control or reduce the noise in your data?

4. An engineering team is going to redesign a wind turbine. The team is going to consider the number of blades and pitch of the blades. Theoretically the pitch could range from 1^0 to 89^0, and the number of blades could range from 2 to 12. The region that the turbine will be used in has winds that vary from 1 mph to 30 mph. Create and describe in detail an experimental design that you would use to determine the best blade configuration for the region. Be sure to include what you would measure, how you would take measurements, how you would present the data.

Table 3-1: Experimental Design Pre-Test

The Data Driven Design Test is shown in Table 3-2. Questions one through three of the Data Driven Design Test were multiple choice questions to allow for quick concise coding. Question four was an open-ended short answer question to assess the students' reasoning when an additional constraint was introduced. How students' use data collected from experiments in their design process decision making? Does the lesson teach students to consider a hierarchy when looking at data; identify and use specific criteria; and consider multiple factors? Question 1 of the Data Driven Design Test (Table 3-2) was designed to investigate the students' awareness of using averages of the data collected when considering data to choose a design element. Question 2 focused on a single section of the data and how the student would consider each pitch for all three wind conditions and averages in that section by identifying and using a specific criteria. Question 3 was designed to evaluate the students' ability to recognize maxima and minima and the necessity of using a minimum value when guaranteeing an outcome instead of a maximum or average, thus considering a hierarchy. Question 4 was developed to understand if students' realized the importance of constraints created by multiple factors and how constraints affect design choices.

Three groups of students (Group A, Group B, and Group C) collected data from three identically set up wind turbine systems. Each group tested three blade configurations (3, 4, and 6); each with five different blade pitches (5^0, 10^0, 15^0, 20^0, and 25^0) at three wind speeds. The data collected is shown in the table below. You and your team will duplicate the testing procedure to collect data to help you design the best configuration to pump the maximum amount of water. Using the data below you will predict what your results will be.

Pitch	3 blades A ml/sec	3 blades B ml/sec	3 blades C ml/sec	4 blades A ml/sec	4 blades B ml/sec	4 blades C ml/sec	6 blades A ml/sec	6 blades B ml/sec	6 blades C ml/sec	Wind speed
5.0	0.0	0.0	0.0	3.2	0.0	0.0	6.0	8.2	5.8	Moderate
10.0	3.4	0.0	5.2	9.8	9.8	9.4	10.5	11.0	10.2	Moderate
15.0	7.8	5.6	6.3	11.2	10.8	11.0	12.0	11.4	10.5	Moderate
20.0	7.8	6.1	6.6	11.7	10.4	10.0	11.8	10.4	7.0	Moderate
25.0	6.6	0.0	3.3	8.7	7.8	9.0	9.7	3.7	7.2	Moderate
5.0	0.0	0.0	0.0	0.0	0.0	0.0	0.0	0.0	0.0	Low
10.0	0.0	0.0	0.0	0.0	0.0	0.0	3.3	0.0	0.0	Low
15.0	0.0	0.0	0.0	4.2	0.0	0.0	5.7	0.0	3.2	Low
20.0	0.0	0.0	0.0	4.8	0.0	0.0	6.1	0.0	0.0	Low
25.0	0.0	0.0	0.0	1.8	0.0	0.0	4.1	0.0	0.0	Low
5.0	0.0	0.0	6.0	9.3	12.6	9.2	9.6	12.2	5.7	High
10.0	11.0	12.4	12.6	14.0	14.0	15.0	14.0	15.2	15.0	High
15.0	13.6	13.8	13.0	16.0	15.8	15.0	15.0	16.0	16.0	High
20.0	13.0	11.9	12.0	14.6	14.6	14.8	14.6	14.4	15.0	High
25.0	11.0	10.3	9.6	12.7	12.4	13.0	13.0	5.8	12.0	High

Your goal is to design a blade configuration that will pump the maximum amount of water in a location that has equal amounts of Low, Moderate and High wind conditions. Using the data in the table.

1. How many blades would you choose for your design? Explain the basis of your decision.
   a. 3
   b. 4
   c. 6

b. What pitch would you use for the situation in problem number one? Explain the basis of your decision.
   a. 5^0
   b. 10^o
   c. 15^0
   d. 20^0
   e. 25^0

c. If you are using a three blade system in a location that has only moderate wind conditions; what pitch would you use to guarantee a flow of 6ml/sec? Explain the basis of your decision.
   a. 5^0
   b. 10^o
   c. 15^0
   d. 20^0
   e. 25^0

d. Would your design change if you where designing for a village with limited finances? Explain, be specific.

Table 3-2: Data Driven Design Pre-Test

Question one of the Experimental Design Test was coded correct when students chose answer choice ‘h’ which included all of the parameters. Question 2 was coded correct for answer choice ‘b’ (12 possible combinations). For Question 3a to be coded correct the student had to answer 8 and include either the mathematical calculation or an equivalent explanation. Question 3b was coded correct if the student answered yes with an explanation of needing more than one child due to children’s differences in sleep patterns, ability to wake or sound preference, or an answer of no because they needed more than just three subjects. Question 3c was coded correct if the explanation included at least one reasonable factor like: not having enough data or test subjects, variability in children, variability in depth of sleep, or variability in hearing. Question 3d was coded correct if the explanation matched a reduction of variability noted in Question 3c such as using more subjects, creating duplicate environments, checking hearing. For Question 4, a code of correct had to include testing of each of the three variables in some type of matrix form and an explanation of how the results would be presented. All coding was made solely by the author.

Coding for the Data Driven Design Test was as follows: Question 1 was coded correct for answer choice ‘c’, the explanation should have implied 6 blades consistently/on average producing/pumping more water. Question 2 was coded correct for answer choice ‘c’ and possible explanation included having a better average output. Question 3 was coded correct for answer choice ‘c’ and the explanation should have included that a 15^{o} pitch was the only pitch that produced 6ml/sec for all groups with the 3 blade system. Question 4 was coded correct if the student answered yes and included reasoning that mentioned meeting the customer's needs or if the student answered no with an explanation that justified the increased possible cost being off-set by financial gains in the future due to increased output.

The high school classes were then led through the first three units of a nine unit data analysis lesson, and then were given two post-tests, identical to the pre-tests. For the high school students, the Post Tests were given near the end of the third unit near the end of the school year, after all the State mandated standardize testing had finished. Due to time constraints of the school year the fourth unit which contains the use of data to drive design was not taught which limited the Data Driven Design data. Several students assumed that the post-tests were completely identical and choose to write "I already did this" and not complete the post-tests (four on the Experimental Design Post Test and seven on the Data Driven Design Post Test).

At the end of the *UTeachEngineering* Graduate/Under-Graduate class, in-service teachers were not given the post-tests as there was limited room for improvement. In-service teachers were given two reflection questions, to help determine if the lesson might need modification to obtain the goal of helping students understand engineering design of experiments and data driven design:

1) The design of the earthquake resistant structure had multiple degrees of freedom (outer beam size and configuration, bracing size and configuration). Are the degrees of freedom in the design to great, too limited or about right for a high school classroom?

2) Is the degree of data analysis too great, too limited or about right for a high school classroom?

These questions were design to obtain insight from experienced teachers as to the appropriateness of complexity of the data analysis for a high school classroom.

Chapter 4
Data Analysis and Results

Experimental Design High School Analysis:

Twenty-one students took the Experimental Design Pre-Test, while fourteen students took the Post-Test. There were a total of twelve students that took both the pre- and post-tests with equal number of advanced level and regular level math and science students. The results are summarized in Table 4-1.

All Students	n	Mean	Standard Deviation	Minimum	Maximum	Median
Pre-Test	21	39.6	24.9	0	71.4	45.9
Post-Test	14	55.1	16.95	14.3	85.7	57.1
Matched Students Pre-Test	12	32.1	21.9	0	57.1	35.7
Matched Students Post-Test	12	54.8	14.1	14.3	71.4	57.14

Table 4-1: Experimental Design Pre and Post-Test Statistics

The mean of the students' scores showed an increase of 15.5 points overall for all students taking the tests. When comparing the 12 matched students that took both pre- and post-tests there was a 22.7 increase. This indicates that the lesson was beneficial to the students' understanding of design of an engineering experiment.

Table 4-2 shows the statistical results of the students that were enrolled in advanced level math and science core classes.

Advanced Level Math and Science Students	n	Mean	Standard Deviation	Minimum	Maximum	Median
Pre-Test	11	51.9	23	0	71.4	57.1
Post-Test	7	65.3	10.4	57.1	85.7	57.1
Matched Students Pre-Test	6	38.9	22.8	0	57.1	50
Matched Students Post-Test	6	61.9	6.7	57.1	71.4	57.1

Table 4-2: Experimental Design: Advanced Level Students: Pre and Post-Test Statistics

Advanced level math and science students showed slightly less improvement of 13.4 points overall, but when comparing matched student data, there was a 23 percent increase in score.

Table 4-3 shows the statistical results of the students that were enrolled in regular level math and science core classes.

Regular Level Math and Science Students	n	Mean	Standard Deviation	Minimum	Maximum	Median
Pre-Test	10	25.7	18.95	0	57.1	14.3
Post-Test	7	44.9	16.1	14.3	57.1	57.1
Matched Students Pre-Test	6	26.2	19.2	0	57.1	21.4
Matched Students Post-Test	6	47.6	15.8	14.3	57.1	57.1

Table 4-3: Experimental Design: Regular Level Students: Pre and Post-Test Statistics

Regular level math and science students showed a substantial increase of 19.2 points in the mean of scores for all students and a 21.4 percent increase for matched students.

Table 4-4 shows the percent of improvement of matched individual student statistics from the Experimental Design Pre-Test to Experimental Design Post-Test

Experimental Design Pre-Test to Experimental Design Post-Test	n	Mean	Standard Deviation	Minimum	Maximum	Median
All Students	12	22.6	22.2	-14.3	57.1	14.3
Advanced Level Students	6	23.8	19.6	0	57.1	14.3
Regular Level Students	6	21.4	24.4	-14.3	57.1	21.4

Table 4-4: Experimental Design: Matched Student Improvement Statistics

Only one student's score dropped from the pre-test to the post test. The average improvement for the twelve students was 22.6 indicating that the lesson was successful in increase the students' knowledge of designing engineering experiments.

Tables 4-5 through 4-11 show the results of each individual item of the instrument.

Table 4-5 shows the results for Question 1 on the Experimental Design Test

Experimental Design Question 1:

A group of engineering students is designing a rocket; they have determined from research that the number of fins on most existing rockets to be: three, four or six located near the bottom. They have also found that secondary fins are often used part way up the rocket, and there are two basic shapes of fins.

What parameters should they consider when designing their experiment for testing?

	% Correct Pre-Test	% Correct Post-Test	% Change
All Students	36	57	21
Advanced Level Students	64	57	-7
Regular Level Students	9	57	48
All Matched Students	25	50	25
Matched Advanced Students	33	50	17
Matched Regular Students	17	50	33

Table 4-5: Experimental Design Question 1

The large increase in percentage correct for regular level students of 48% helped bring the overall percentage above the mean of improvement for the entire group. When comparing matched student data all groups improved. This shows that students with less background in experimental design benefit the most from the lesson.

Table 4-6 shows the results for Question 2 on the Experimental Design Test

Experimental Design Question 2:

After further research and interviews with engineers the students decide to test: 3, 4 or 6 fins at the bottom; 2 or 3 fins located in two different positions. How many different combinations should the group test?

	% Correct Pre-Test	% Correct Post-Test	% Change
All Students	55	21	-34
Advanced Level Students	73	29	-44
Regular Level Students	36	14	-22
All Matched Students	50	25	-25
Matched Advanced Students	50	33	-17
Matched Regular Students	50	17	-33

Table 4-6: Experimental Design Question 2

For the Post-Test an additional two shapes of fins was add to the question, which seemed to cause a drop in all categories. Ninety-one percent of the students that answered the post test question incorrect chose answer choice ‘b’ which was the correct response for the pre-test. This seems to indicate that the students did not fully read the question and possibly assumed it was exactly the same as the pre-test.

Experimental Design Question 3 a -d:

You work in a product design company and are creating a new alarm clock for children. You want to find the best sound for the alarm clock that wakes children up the fastest. The plan is to design a multi-factorial experiment to test different sounds on sleeping children. Your team has identified three variables of interest to test, with two levels for each variable. The variables are:

- alarm intensity (quiet vs. loud)
- pitch (low vs. high), and
- sound type (musical vs. buzzer).

Table 4-7 shows the results for Question 3a on the Experimental Design Test

Experimental Design Question 3a) What is the minimum number of experimental tests you should do, and why?

	% Correct Pre-Test	% Correct Post-Test	% Change
All Students	36	57	22
Advanced Level Students	72	57	-15
Regular Level Students	0	57	57
All Matched Students	25	58	33
Matched Advanced Students	50	50	0
Matched Regular Students	0	67	67

Table 4-7: Experimental Design Question 3a

Again regular level students showed a marked improvement with the matched regular level students making the greatest gain of 67%. Advanced level students dropped 15% and advanced level matched students showed no gain.

Table 4-8 shows the results for Question 3b on the Experimental Design Test

Experimental Design Question 3b) Your teammate suggests that you repeat each test on three different children. Do you agree to do this, and why or why not?

	% Correct Pre-Test	% Correct Post-Test	% Change
All Students	86	71	-15
Advanced Level Students	91	71	-20
Regular Level Students	82	71	-11
All Matched Students	83	67	-16
Matched Advanced Students	83	67	-16
Matched Regular Students	83	67	-16

Table 4-8: Experimental Design Question 3b

There was an unexplained drop from the pre-test to post-test.

Table 4-9 shows the results for Question 3c on the Experimental Design Test

Experimental Design Question 3c) What might be sources of noise or variability in your data?

	% Correct Pre-Test	% Correct Post-Test	% Change
All Students	0	64	64
Advanced Level Students	0	86	86
Regular Level Students	0	43	43
All Matched Students	0	75	75
Matched Advanced Students	0	100	100
Matched Regular Students	0	50	50

Table 4-9: Experimental Design Question 3c

Pre-Test data showed a clear miss-understanding of the question by the students, due to the use of the term ‘noise’, which was taken out of the question on the post test. The marked improvement in all categories suggests that the students better understood the question once the term ‘noise’ was taken out. It cannot be determined if the students’ improvement was affected by the lesson.

Table 4-10 shows the results for Question 3d on the Experimental Design Test

Experimental Design Question 3d) What procedures could you follow to control or reduce the noise in your data?

	% Correct Pre-Test	% Correct Post-Test	% Change
All Students	5	64	59
Advanced Level Students	18	86	68
Regular Level Students	18	43	25
All Matched Students	17	67	50
Matched Advanced Students	33	83	50
Matched Regular Students	17	50	33

Table 4-10: Experimental Design Question 3d

Being consistent with the previous question for the post test the term 'noise' was replaced with variability, which seems to have improved all the students' understanding of the question resulting in great improvement.

Experimental Design Question 4:

An engineering team is going to redesign a wind turbine. The team is going to consider the number of blades and pitch of the blades. Theoretically the pitch could range from 1^0 to 89^0, and the number of blades could range from 2 to 12. The region that the turbine will be used in has winds that vary from 1 mph to 30 mph. Create and describe in detail an experimental design that you would use to determine the best blade configuration for the region. Be sure to include what you would measure, how you would take measurements, how you would present the data.

Table 4-11 shows the results for Question 4 on the Experimental Design Test

	% Correct Pre-Test	% Correct Post-Test	% Change
All Students	27	57	30
Advanced Level Students	45	71	26
Regular Level Students	18	43	25
All Matched Students	25	58	33
Matched Advanced Students	50	67	17
Matched Regular Students	17	50	33

Table 4-11: Experimental Design Question 4

Answers for question 4 were more detailed for all students and showed improvement in all categories. The improvement of students' responses for this question solidifies the overall effectiveness of the lesson, as it encompassed all aspects of design of an engineering experiment.

Overall the data seems to show that the lesson is effective in improving the students' ability to design an engineering experiment. Question 3b did show a drop in all categories and thus needs to be re-examined and possibly reworded to ensure student understanding. The data also suggest that regular level students' benefited from the lesson more than advanced level students.

Data Driven Design High School Analysis:

Seventeen students took the Data Driven Design Pre-Test, while twenty students took the Post-Test. Only nine students took both the pre- and post-tests and only two of those were advanced level math and science students. The results are listed in Table 4-12.

All Students	n	Mean	Standard Deviation	Minimum	Maximum	Median
Pre-Test	17	61.8	27.3	25	100	50
Post-Test	12	52	33	0	100	50
Matched Students Pre-Test	9	`52.8	21.9	25	75	50
Matched Students Post-Test	9	55.6	36.9	0	100	50

Table 4-12: Data Driven Design Pre and Post-Test Statistics

Fewer students chose to take the Data Driven Design Post-Test. Along with the drop in participation there was a drop in mean score for all students. For the nine matched students that took both pre- and post-tests there was a very slight increase of 2.8%. This result is most likely due to the limited coverage of the unit by the high school classes. The high school classes in this study were only able to just finish the third unit: the data driven design is covered more extensively in units 4-9 and so close to replicate performance in the pre- and post-tests is expected.

Table 4-13 shows the statistical results of the students that were enrolled in advanced level math and science core classes.

Advanced Level Math and Science Students	n	Mean	Standard Deviation	Minimum	Maximum	Median
Pre-Test	7	85.7	18.2	50	100	100
Post-Test	4	50	17.7	25	75	50
Matched Students Pre-Test	2	75	0	75	75	75
Matched Students Post-Test	2	50	25	25	75	50

Table 4-13: Data Driven Design: Advanced Level Students: Pre and Post-Test Statistics

Three of the seven advanced level students did not take the post-test and there was a drop in mean score of 35.7%. Only two advanced level students took both tests and one did not answer all questions resulting in a 25% decrease.

Table 4-14 shows the statistical results of the students that were enrolled in regular level math and science core classes.

Regular Level Math and Science Students	n	Mean	Standard Deviation	Minimum	Maximum	Median
Pre-Test	10	45	18.7	25	75	50
Post-Test	8	53	38	0	100	37.5
Matched Students Pre-Test	7	46	20.8	25	75	50
Matched Students Post-Test	7	57	39.4	0	100	50

Table 4-14: Data Driven Design: Regular Level Students: Pre and Post-Test Statistics

Two of the ten regular level students did not take the post-test and there was a 13% increase in the mean for these students. For the matched students there was an 11% increase which included one of the seven students that did not answer half of the questions.

Table 4-15 shows the percent of improvement of matched individual student statistics from the Data Driven Design Pre-Test to Data Driven Design Post-Test

Data Driven Design Pre-Test to Data Driven Design Post-Test	n	Mean	Standard Deviation	Minimum	Maximum	Median
All Students	9	2.8	43.2	-50	75	0
Advanced Level Students	2	-25	25	-50	0	-25
Regular Level Students	7	10.7	44	-50	75	0

Table 4-15: Data Driven Design: Matched Student Improvement Statistics

Data Driven Design Questions:

Three groups of students (Group A, Group B, and Group C) collected data from three identically set up wind turbine systems. Each group tested three blade configurations (3, 4, and 6); each with five different blade pitches (5^0, 10^0, 15^0, 20^0, and 25^0) at three wind speeds. The data collected is shown in the table below. You and your team will duplicate the testing procedure to collect data to help you design the best configuration to pump the maximum amount of water. Using the data below you will predict what your results will be.

Pitch	3 blades A ml/sec	3 blades B ml/sec	3 blades C ml/sec	4 blades A ml/sec	4 blades B ml/sec	4 blades C ml/sec	6 blades A ml/sec	6 blades B ml/sec	6 blades C ml/sec	Wind speed
5.0	0.0	0.0	0.0	3.2	0.0	0.0	6.0	8.2	5.8	Moderate
10.0	3.4	0.0	5.2	9.8	9.8	9.4	10.5	11.0	10.2	Moderate
15.0	7.8	5.6	6.3	11.2	10.8	11.0	12.0	11.4	10.5	Moderate
20.0	7.8	6.1	6.6	11.7	10.4	10.0	11.8	10.4	7.0	Moderate
25.0	6.6	0.0	3.3	8.7	7.8	9.0	9.7	3.7	7.2	Moderate
5.0	0.0	0.0	0.0	0.0	0.0	0.0	0.0	0.0	0.0	Low
10.0	0.0	0.0	0.0	0.0	0.0	0.0	3.3	0.0	0.0	Low
15.0	0.0	0.0	0.0	4.2	0.0	0.0	5.7	0.0	3.2	Low
20.0	0.0	0.0	0.0	4.8	0.0	0.0	6.1	0.0	0.0	Low
25.0	0.0	0.0	0.0	1.8	0.0	0.0	4.1	0.0	0.0	Low
5.0	0.0	0.0	6.0	9.3	12.6	9.2	9.6	12.2	5.7	High
10.0	11.0	12.4	12.6	14.0	14.0	15.0	14.0	15.2	15.0	High
15.0	13.6	13.8	13.0	16.0	15.8	15.0	15.0	16.0	16.0	High
20.0	13.0	11.9	12.0	14.6	14.6	14.8	14.6	14.4	15.0	High
25.0	11.0	10.3	9.6	12.7	12.4	13.0	13.0	5.8	12.0	High

Your goal is to design a blade configuration that will pump the maximum amount of water in a location that has equal amounts of Low, Moderate and High wind conditions. Using the data in the table.

Table 4-16 shows the results for Question 1on the Data Driven Design Test

1) How many blades would you choose for your design? Explain the basis of your decision.

	% Correct Pre-Test	% Correct Post-Test	% Change
All Students	47	57	10
Advanced Level Students	86	40	-46
Regular Level Students	20	67	47
All Matched Students	33	56	23
Matched Adv. Students	100	100	0
Matched Regular Students	14	57	43

Table 4-16: Data Driven Design Question 1

Regular level math and science students who took both the pre- and post-tests had a 43% increase while the two advanced level students answered the question correctly on both tests.

Data Driven Design Question 2:

Table 4-17 shows the results for Question 2 on the Data Driven Design Test

2) What pitch would you use for the situation in problem number one? Explain the basis of your decision.

	% Correct Pre-Test	% Correct Post-Test	% Change
All Students	59	65	6
Advanced Level Students	71	80	9
Regular Level Students	50	50	0
All Matched Students	22	33	11
Matched Advanced Students	50	0	-50
Matched Regular Students	43	43	0

Table 4-17: Data Driven Design Question 2

All matched students showed an increase of 11% of the students' answering correctly.

Data Driven Design Question 3:

Table 4-18 shows the results for Question 3 on the Data Driven Design Test

3) If you are using a three blade system in a location that has only moderate wind conditions; what pitch would you use to guarantee a flow of 6ml/sec? Explain the basis of your decision.

	% Correct Pre-Test	% Correct Post-Test	% Change
All Students	65	70	5
Advanced Level Students	86	70	-16
Regular Level Students	50	50	0
All Matched Students	56	44	-12
Matched Advanced Students	50	50	0
Matched Regular Students	57	43	-14

Table 4-18: Data Driven Design Question 3

Data in the table was changed from pre-test to post-test and the output was change in the question, which may account for the drop in percentage of students who answered correctly.

Data Driven Design Question 4:

Table 4-19 shows the results for Question 4 on the Data Driven Design Test

4) Would your design change if you where designing for a village with limited finances? Explain, be specific.

	% Correct Pre-Test	% Correct Post-Test	% Change
All Students	76	80	4
Advanced Level Students	100	90	-10
Regular Level Students	50	80	30
All Matched Students	78	78	0
Matched Advanced Students	100	50	-50
Matched Regular Students	71	86	16

Table 4-19: Data Driven Design Question 4

Regular level math and science students' showed improvement on this question while advanced level students' dropped.

Since the students' were not able to get beyond the third unit due to time constraints it was expected that there would be little to no improvement from pre- to post-test. Many of the students did not understand the intent of the post-test and did not fill it out thinking that they had already taken it and thus did not need to do it again. Considering these factors makes the data collected from the Data Driven Design Tests inconclusive.

Pre-service and In-service Teacher Analysis:

Twenty-one pre- and in-service teachers took the Experimental Design Pre-Test and Data Driven Design Pre-Test. Ten were female eleven were male.

The statistical results for the Experimental Design Pre-Test are listed in Table 4-20.

Experimental Design Pre-Test	n	Mean	Standard Deviation	Minimum	Maximum	Median
All Students	21	74.1	20.5	28.6	100	85.7
Female	10	75.7	15.7	42.9	100	78.55
Male	11	72.7	23.9	28.6	100	85.7

Table 4-20: Pre-Service and In-Service Teacher Experimental Design Statistics

Female students overall scored higher than males by 3% points. Overall pre- and in-service teachers scored over 30 points better than the high school students' pre-test and over 20 points better than the high school students' post-test.

Experimental Design Pre-Test questions results are listed in Table 4-21 for the Pre-service and In-service Teachers.

Question	1	2	3a	3b	3c	3d	4
% Correct All	71.4	71.4	61.9	90.5	90.5	75.2	53.4
% Correct Female	70	70	70	100	100	70	50
% Correct Male	72.7	72.7	54.5	81.8	81.8	81.8	54.5

Table 4-21: Experimental Design Pre-Test for Pre-Service and In-Service Teachers

Question 3a was missed more by males and those both male and female misinterpreted the question and wanted more tests than the minimum that was asked for. Question four was the most missed question; those that missed question four did not consider the interaction of each variable and wanted to test one variable at a time.

The statistical results for the Data Driven Design Pre-Test are listed in Table 4-22.

Data Driven Design Pre-Test	n	Mean	Standard Deviation	Minimum	Maximum	Median
All Students	21	84.5	22.5	25	100	100
Female	10	77.5	28.4	25	100	87.5
Male	11	90.9	12	75	100	100

Table 4-22: Pre-Service and In-Service Teacher Data Driven Design Statistics

Data Driven Design Pre-Test questions results are listed in Table 4-23 for the Pre-service and In-service Teachers.

Question	1	2	3	4
% Correct All	76.2	85.7	85.7	90.5
% Correct Female	60	80	80	90
% Correct Male	90.9	90.9	90.9	90.9

Table 4-23: Data Driven Design Pre-Test for Pre-Service and In-Service Teachers

Question one showed the greatest difference between male and female. All of those that missed question one chose answer choice ‘b’ and explained that 4 blades seemed to be more consistent, instead of taking an average and finding 6 blades to be the best.

Testing Instrument Analysis:

Looking at the data collected and written explanations given by students' there seemed to be some changes in the testing instruments to make them more effective for future research of the lesson.

Question one of the Experimental Design Pre-Test seemed to be effective but should have some wording changes to make it clearer and test the students' ability to create an experimental design matrix.

Question 2 should also be changed to include the use of a matrix in the experimental design process as it is taught in the unit.

Question 3a elicited a variety of answers from in-service teachers and regular level high school students, indicating a level of confusion in interpreting what the question was asking and thus should be re-worded so there is a clear interpretation.

Question 3b also had a variety of answers that could be interpreted as incorrect or correct depending on the justification presented and thus should be re-worded to be clearer.

Question 3c was modified from the pre-test to the post-test due to the misinterpretation of the term 'noise' being taken as actual noise. To help the students' focus on variability the term noise was taken out for the post-test and should be further modified to include variability for each parameter.

Question 3d was also modified from pre-test to post-test by changing the term noise to variability and should be worded to include methods as well as procedures. For both Questions 3c and 3d the term 'noise' needs to be referenced to help students' become familiar with the term.

Question 4 needs to be re-worded to elicit a more detailed description from students'. The revised Experimental Design Pre-Test is shown in Table 4-24.

A group of engineering students is designing a rocket; they have determined from research that the number of fins on most existing rockets to be: three, four or six located at the bottom of the fuselage. They have also found that secondary fins are sometimes used part way up the rocket's fuselage, and there are two basic shapes of fins.

1. What parameters should they consider when creating their experimental design matrix for testing?
    a. Number of bottom fins
    b. Number of secondary fins
    c. Use or not use secondary fins
    d. Position of secondary fins on fuselage
    e. A and B
    f. A and C
    g. A, B, and D
    h. A, B, C, and D
2. After further research and interviews with engineers the students decide to test: 3, 4 or 6 fins at the bottom; 2 or 3 fins located in two different positions. How many cells would there be in a matrix designed to test all possible combinations of the parameters?
    a. 3
    b. 12
    c. 7
    d. 18
3. You work in a product design company and are creating a new alarm clock for children. You want to find the best sound for the alarm clock that wakes children up the fastest. The plan is to design a multi-factorial experiment to test different sounds on sleeping children. Your team has identified three variables of interest to test, with two levels for each variable. The variables are:
    - alarm intensity (quiet vs. loud)
    - pitch (low vs. high), and
    - sound type (musical vs. buzzer).

    a) What is the minimum number of experimental test combinations you should do, and why?

    b) Your teammate suggests that you run each test on at least three different children. Do you agree to do this, and why or why not?

    c) What might be sources of variability (sometimes referred to as 'noise') in your data for each parameter?

    d) What procedures or methods could you follow to control or reduce the variability ('noise') in your data?
4. An engineering team is going to redesign a wind turbine. The team is going to consider the number of blades and pitch of the blades. Theoretically the pitch could range from 1^0 to 89^0, and the number of blades could range from 2 to 12. The region that the turbine will be used in has winds that vary from 1 mph to 30 mph. Create and describe in detail an experimental design that you would use to determine the best blade configuration for the region. Be sure to include:
    a. What you would measure
    b. How you would take measurements
    c. What data would you collect
    d. How you would organize the data
    e. How you would analyze the data
    f. How you would present the data

Table 4-24: Revised Experimental Design Pre-Test

The Data Driven Design Tests were effective needing only small wording changes.

Several high school students and pre-service teachers made conjectures beyond the data by including possible costs when answering Question 1, therefore the question should be worded to emphasize the use of the data only.

Question 2 references Question 1, making more than one possible correct answer depending on how Question 1 was answered. To prevent this overlap Question 2 should specify which blade configuration should be analyzed.

Question 3 was clear and does not need any modification.

Question 4 was modified from pre-test to post-test to emphasize the customer's initial financial constraints. Students still made conjectures referring to using cheaper materials, so the question should include using the same quality materials no matter what design is chosen.

The revised Data Driven Design Pre-Test is shown in Table 4-25

Three groups of students (Group A, Group B, and Group C) collected data from three identically set up wind turbine systems. Each group tested three blade configurations (3, 4, and 6); each with five different blade pitches (5^0, 10^0, 15^0, 20^0, and 25^0) at three wind speeds. The data collected is shown in the table below. You and your team will duplicate the testing procedure to collect data to help you design the best configuration to pump the maximum amount of water. Using the data below you will predict what your results will be.

Pitch	3 blades A ml/sec	3 blades B ml/sec	3 blades C ml/sec	4 blades A ml/sec	4 blades B ml/sec	4 blades C ml/sec	6 blades A ml/sec	6 blades B ml/sec	6 blades C ml/sec	Wind speed
5.0	0.0	0.0	0.0	3.2	0.0	0.0	6.0	8.2	5.8	Moderate
10.0	3.4	0.0	5.2	9.8	9.8	9.4	10.5	11.0	10.2	Moderate
15.0	7.8	5.6	6.3	11.2	10.8	11.0	12.0	11.4	10.5	Moderate
20.0	7.8	6.1	6.6	11.7	10.4	10.0	11.8	10.4	7.0	Moderate
25.0	6.6	0.0	3.3	8.7	7.8	9.0	9.7	3.7	7.2	Moderate
5.0	0.0	0.0	0.0	0.0	0.0	0.0	0.0	0.0	0.0	Low
10.0	0.0	0.0	0.0	0.0	0.0	0.0	3.3	0.0	0.0	Low
15.0	0.0	0.0	0.0	4.2	0.0	0.0	5.7	0.0	3.2	Low
20.0	0.0	0.0	0.0	4.8	0.0	0.0	6.1	0.0	0.0	Low
25.0	0.0	0.0	0.0	1.8	0.0	0.0	4.1	0.0	0.0	Low
5.0	0.0	0.0	6.0	9.3	12.6	9.2	9.6	12.2	5.7	High
10.0	11.0	12.4	12.6	14.0	14.0	15.0	14.0	15.2	15.0	High
15.0	13.6	13.8	13.0	16.0	15.8	15.0	15.0	16.0	16.0	High
20.0	13.0	11.9	12.0	14.6	14.6	14.8	14.6	14.4	15.0	High
25.0	11.0	10.3	9.6	12.7	12.4	13.0	13.0	5.8	12.0	High

Your goal is to design a blade configuration that will pump the maximum amount of water in a location that has equal amounts of Low, Moderate and High wind conditions.

1. Considering only the data in the table above; how many blades would you choose for your design? Explain the basis of your decision.
    a. 3
    b. 4
    c. 6
2. What pitch would you use for a six blade turbine system? Explain the basis of your decision.
    a. 5^0
    b. 10^o
    c. 15^0
    d. 20^0
    e. 25^0
3. If you are using a three blade system in a location that has only moderate wind conditions; what pitch would you use to guarantee a flow of 6ml/sec? Explain the basis of your decision.
    a. 5^0
    b. 10^o
    c. 15^0
    d. 20^0
    e. 25^0
4. Would your design change if you where designing for a village with limited finances to use for the initial start up cost, while using the same materials? Explain, be specific.

Table 4-25: Revised Data Driven Design Pre-Test

Tables 4-26 and 4-27 respectively show the revised Experimental Design Post-Test and Data Driven Design Post-Test using the same revisions for the pre-tests.

A group of engineering students is designing a rocket; they have determined from research that the number of fins on most existing rockets to be: three, four or six located at the bottom of the fuselage. They have also found that secondary fins are sometimes used part way up the rocket's fuselage, and there are two basic shapes of fins.

1. What parameters should they consider when creating their experimental design matrix for testing?
    a. Number of bottom fins
    b. Number of secondary fins
    c. Use or not use secondary fins
    d. Position of secondary fins on fuselage
    e. A and B
    f. A and C
    g. A, B, and D
    h. A, B, C, and D

2. After further research and interviews with engineers the students decide to test: 3, 4 or 6 fins at the bottom; 2 or 3 fins located in two different positions; two shapes of fins. How many cells would there be in a matrix designed to test all possible combinations of the parameters?
    a. 4
    b. 12
    c. 9
    d. 24

3. You work in a product design company and are creating a new alarm clock for children. You want to find the best sound for the alarm clock that wakes children up the fastest. The plan is to design a multi-factorial experiment to test different sounds on sleeping children. Your team has identified three variables of interest to test, with two levels for each variable. The variables are:
    - alarm intensity (quiet vs. loud)
    - pitch (low vs. high), and
    - sound type (musical vs. buzzer).

    a) What is the minimum number of experimental test combinations you should do, and why?

    b) Your teammate suggests that you run each test on at least eight different children. Do you agree to do this, and why or why not?

    c) What might be sources of variability (sometimes referred to as 'noise') in your data for each parameter?

    d) What procedures or methods could you follow to control or reduce the variability ('noise') in your data?

4. An engineering team is going to redesign a wind turbine. The team is going to consider the number of blades and pitch of the blades. Theoretically the pitch could range from 1^0 to 89^0, and the number of blades could range from 2 to 12. The region that the turbine will be used in has winds that vary from 1 mph to 30 mph. Create and describe in detail an experimental design that you would use to determine the best blade configuration for the region. Be sure to include:
    a. What you would measure
    b. How you would take measurements
    c. What data would you collect
    d. How you would organize the data
    e. How you would analyze the data
    f. How you would present the data

Table 4-26: Revised Experimental Design Post-Test

Three groups of students (Group A, Group B, and Group C) collected data from three identically set up wind turbine systems. Each group tested three blade configurations (3, 4, and 6); each with five different blade pitches (5^0, 10^0, 15^0, 20^0, and 25^0) at three wind speeds. The data collected is shown in the table below. You and your team will duplicate the testing procedure to collect data to help you design the best configuration to pump the maximum amount of water. Using the data below you will predict what your results will be.

Pitch	3 blades A ml/sec	3 blades B ml/sec	3 blades C ml/sec	4 blades A ml/sec	4 blades B ml/sec	4 blades C ml/sec	6 blades A ml/sec	6 blades B ml/sec	6 blades C ml/sec	Wind speed
5.0	0.0	0.0	0.0	3.2	0.0	0.0	6.0	8.2	5.8	Moderate
10.0	3.4	0.0	5.2	9.8	9.8	9.4	10.5	11.0	10.2	Moderate
15.0	7.8	6.1	Pitch	11.2	10.8	11.0	12.0	11.4	10.5	Moderate
20.0	7.8	5.9	7.0	11.7	10.4	10.0	11.8	10.4	7.0	Moderate
25.0	6.6	0.0	3.3	8.7	7.8	9.0	9.7	3.7	7.2	Moderate
5.0	0.0	0.0	0.0	0.0	0.0	0.0	0.0	0.0	0.0	Low
10.0	0.0	0.0	0.0	0.0	0.0	0.0	3.3	0.0	0.0	Low
15.0	0.0	0.0	0.0	4.2	0.0	0.0	5.7	0.0	3.2	Low
20.0	0.0	0.0	0.0	4.8	0.0	0.0	6.1	0.0	0.0	Low
25.0	0.0	0.0	0.0	1.8	0.0	0.0	4.1	0.0	0.0	Low
5.0	0.0	0.0	6.0	9.3	12.6	9.2	9.6	12.2	5.7	High
10.0	11.0	12.4	12.6	14.0	14.0	15.0	14.0	15.2	15.0	High
15.0	13.6	13.8	13.0	16.0	15.8	15.0	15.0	16.0	16.0	High
20.0	14.0	11.9	12.0	14.6	14.6	14.8	14.6	14.4	15.0	High
25.0	11.0	10.3	9.6	12.7	12.4	13.0	13.0	5.8	12.0	High

Your goal is to design a blade configuration that will pump the maximum amount of water in a location that has equal amounts of Low, Moderate and High wind conditions.

1. Considering only the data in the table above; how many blades would you choose for your design? Explain the basis of your decision.
   a. 3
   b. 4
   c. 6
2. What pitch would you use for a six blade turbine system? Explain the basis of your decision.
   a. 5^0
   b. 10^o
   c. 15^0
   d. 20^0
   e. 25^0
3. If you are using a three blade system in a location that has only high wind conditions; what pitch would you use to guarantee a flow of 12ml/sec? Explain the basis of your decision.
   a. 5^0
   b. 10^o
   c. 15^0
   d. 20^0
   e. 25^0
4. Would your design change if you where designing for a village with limited finances to use for the initial start up cost, while using the same materials? Explain, be specific.

Table 4-27: Revised Data Driven Design Post-Test

An analysis of the two in-service teacher reflection questions design to obtain insight from experienced teachers as to the appropriateness of complexity of the data analysis for a high school classroom is presented below.

In-service teacher reflection question one: The design of the earthquake resistant structure had multiple degrees of freedom (outer beam size and configuration, bracing size and configuration) Are the degrees of freedom in the design too great, too limited or about right for a high school classroom? Just over 50% of in-service teachers that had been through the lesson believed that the number of degrees of freedom was too much for high school students and thought that lowering the degrees of freedom would allow the students to better see a causal relationship. Three thought it would be better if the students could isolate and test each variable separately. Those that felt the degrees of freedom could be handled by high school students noted that the high school students would definitely struggle, but that it would be a benefit to them.

In-service teacher reflection question two: Is the degree of data analysis too great, too limited or about right for a high school classroom? The entire group of in-service teachers thought the degree of data analysis was about right for a high school class. Two thought there might need to be more scaffolding or preset base data.

Chapter 5

Conclusion

The purpose of this study was to develop and test a survey instrument for assessing the effectiveness of a data acquisition unit in a high school engineering course. More specifically, this study focused on student's learning of Design of Engineering Experiments and Data Driven Design. As STEM education becomes a more integral part of secondary education and engineering education grows within STEM at an increasing rate, secondary education must create and adapt curricula that entices students toward engineering and prepares them for post-secondary engineering education. Within engineering education educators must identify the need for students to begin to master the design of an engineering experiment and the ability to use that data to create a design. These two aspects of the engineering design cycle are key components to creating a good design once a customer's needs have been identified.

The results of the application of the initial survey draft support the effectiveness of the lessons increasing student's ability to design an engineering experiment and showed some improvement in using the data to drive the creation of a design. The lack of substantial improvement in data driven design may have been affected by the students not having enough time to cover the units addressing this material. Further research needs to be completed using the entire 9 units in multiple high schools and classrooms to completely assess the effectiveness of the data acquisition unit in regards to design of an engineering experiment and data driven design. Using feedback from in-service teachers, there may be some modifications to the unit that are necessary to enhance high school students' ability to fully understand and embrace the unit.

Chapter 6

Application to Practice

Engineering Awareness:

UTeach*Engineering* has shown me how the engineering design process can be incorporated into any courses curriculum. As we traversed through our curriculum, I became more aware of the many engineering careers that are available to my students and have emphasized the opportunities to all of my students both in engineering classes and math classes. I have been able to develop project based lessons for my Algebra 2 classes that center around engineering. While teaching these lessons I reiterate to my students how the engineering design process can be implemented on any problem they encounter, whether it be in a Math or Science class or even an English class. When collaborating with my fellow teachers I constantly show them how using engineering processes can help their students learn specific content of the course they teach. Our district is teaming up with UTeach to train teachers, which will further allow me demonstrate to my Math Department ways of using engineering when developing Problem Based Learning and the 5E's. Through my work with UTeachEngineering, I have been able to add two engineering classes at our campus, and am planning to add more in the future; including Engineering Design and Presentation, and Geometry in Construction. My goal is to develop a complete Engineering endorsement graduation plan under the new TEA guidelines and thus, make my campus an Engineering Magnet School for our district.

Engineering Habits of Mind:

One of the engineering lessons that I developed as part of the MASEE program was the 'Hollow Ball Float' project for my Pre-AP Algebra 2 class. This project asks the students to work in teams to develop metal hollow balls of different diameters that will float at the surface of both salt and fresh water, and contain a minimum of 2ml of a liquid, with a density of 1.6 g/ml, for a defense contractor. As the students are guided through the design process they become aware of the different parts of the problem that make up system. As the teams work through the process, they always ask; what is the liquid? To which I respond, "You, need to figure that out, and consider who the customer is." They soon discover that the liquid is nitroglycerin, and thus are presented with an ethical dilemma, as to whether or not they want to be a part of developing an explosive device that could be detrimental to society and or the environment. At the end of the lesson we discuss the process of: identifying the need, constraints, different systems and how they inter-relate, and the ethical issues.

Throughout all of my teaching I try to show my students how each part of a problem or equation is related to other parts so they realize that there are systems in almost anything they deal with. Students' discover that changing one variable will create change for another.

All of my classes whether engineering or mathematics are based on collaborative learning, where students are grouped into teams, so they can learn the dynamics of team work and can feed off of each other as they work thru a problem or project.

Understanding the Design Process:

As I have progressed through the MASEE program, I have become more and more familiar with the engineering design process. I have found through my research that there are many different outlines of the design process, but they all have the same basic principles but use different language. All design processes begin with identifying a need, for me choosing the direction of my Master's report was just that. I identified that there was a need for more research based engineering design lessons would help students understand experimental design, and design driven by data obtained from those experiments.

Knowledge for and of Engineering Teaching:

The knowledge I have gained through the MASEE has helped me realize that the engineering design process is not an inherent skill that most students have, but that it must be taught in a systematic way. Before becoming involved with the MASEE program I often used problem based lessons in both my general math classes and Engineering Math class and expected my students to naturally follow a design process with little or no instruction. I have discovered that each aspect of the engineering design process must be introduced and systematically taught to students. The UTeach-Engineering Design Process can and should be used in all classrooms, I have now been able to teach the process not only in engineering classes but in mathematics classes and the students have greatly benefited from it. Using all that I have learned through the MASEE program I am able to create more interest in engineering in my students.

Appendix

Unit 1 Outline:

1) **Introduce quakes. Show that they are a real, regular challenge faced by people everywhere.**
   a) Bring out students' knowledge of quakes. Ask: What's an earthquake? Has anyone felt one before? What does it feel like?
   b) Get those students who haven't experienced a quake to understand what quakes look, sound, and feel like, and what they do. Show relevant media: (*sample videos to be provided to the teacher, including:)*
      1. 2004 Parkfield earthquake – video of outdoors, shaking trees (public domain from USGS) ***3.1.5 Video 1_Parkfield Quake 2004.wmv***
      2. 2011 Washington DC quake – video of inside the Washington Monument ***3.1.5 Video 2_Washington Monument 2011.wmv***
      3. 2011 central Virginia earthquake – video of interviews with people who experienced it (public domain from USGS) ***3.1.5 Video 3_Virginia Quake 2011 Interviews***. You may or may not wish to show this, if your students are interested.
   c) Show pictures of the aftermath of quakes.
   d) Show recent earthquake activity through seismicity maps.
      i) Around the world: http://earthquake.usgs.gov/earthquakes/map/ -- If there is an internet connection, actually visit the website. It gives the latest major earthquake activities around the world up to 30 days ago. For example, this image was taken from January 2013:

      ii) Seismicity map for around the USA: http://earthquake.usgs.gov/earthquakes/states/seismicity/.

      iii) If there is an internet connection, visit: http://earthquake.usgs.gov/earthquakes/map/ and click on "US" right above the map, to show earthquakes detected in the last 7-30 days. Example taken from January 2013:

   e) Discussion: Why are quakes so dangerous? Deaths and injuries usually caused by failing structures.
   f) (If the teacher has pre-built a demo building) Shake the model building on the

myQuake. Ask if a building shaking like that is normal, or safe. Tell students that in this unit their job will be do tests like this to help them design an earthquake resistant building.

2) **Introduce the region in the story of this unit.**
   a) Show map(s) of northeast India
      Wikipedia: http://en.wikipedia.org/wiki/Northeast_India
   b) Show where earthquakes usually hit India, and the reasons for this
      http://en.wikipedia.org/wiki/Earthquake_hazard_zoning_of_India

3) **Students read and interpret separate interview statements from four stakeholders.**
   a) Pass out interviews and documents from the stakeholders. *3.1.3 Handout 1_Interview Statements* and *3.1.3 Handout 2_Documents Given*
   b) Engineering firm – gives general information, and requirements/constraints about:
      i) Test system
      ii) material prices
      iii) asks for a technical report as the final product from the team.
      iv) Time constraint
   c) Landowner interview – gives requirements & constraints related to:
      i) building space, size,
      ii) total material cost limit
      iii) Gives a drawing of the actual building design desired design.
   d) Local government interview – gives requirements/constraint about:
      i) Earthquake safety and codes
      ii) Earthquake and city history
   e) Residents – gives requirements/constraints related to:
      i) safety;
      ii) worst-case testing; Their statement should justify testing a "worst-case" situation of having heavy snow on the roof during an earthquake.
      iii) some residents have seen or been in earthquakes; show real but age-appropriate and school-appropriate video of earthquakes to students, so they get an idea of resident fears (especially if students have never felt an earthquake themselves). Example videos are:
         1. http://youtu.be/soxxjPEiBzw – First 30 seconds. Shows aftermath of an earthquake in northeast India near Nepal and Tibet.

4) **They start a "Know & Need to Know" list,** which can be updated and reviewed after they have discussed all the interview statements. *Example list given in 3.1.4 Reference 2_Example Know Need-to-Know List*

5) **They create a single general customer needs statement from these interviews.** *Example given in 3.1.4 Reference 1_Example Needs, Requirements, Constraints.*

6) **They piece together the general requirements and constraints for the design.** *Example given in 3.1.4 Reference 1_Example Needs, Requirements, Constraints.*
   a) Point out and emphasize the two constraints related to costs and timeline (coming from the landowner and engineering firm interviews), in case they have not already done so. They cannot build whatever they want whenever they want. They should use materials judiciously. This sets the stage for planning out designs and tests carefully instead of just building whatever is desired and testing without a plan.
   b) They begin creating a list of constraints and requirements (specifications) in their engineering notebooks through these first lessons of Identifying and Describing the Need.
   c) Maintain a class list of Requirements & Constraints on easel paper. Treat it as a living document that students can see and update as a class throughout the next lessons.

7) Students discuss the design process and plan what comes next.
   a) They should have identified the problem by now, and described it somewhat. They will have to determine how safe the existing building is, how safe the desired taller building is, and then design a new building as necessary.
   b) Before they can start to answer the initial customer questions, they must learn more about what the customers really need. Some relevant questions to answer first on their Know/Need-to-Know list are:
      i) How do you simulate an earthquake?
      ii) What is an earthquake?
      iii) What kind of earthquake do we simulate?
      iv) How do we analyze the quake and building?
   c) Once they know this, they can address the customers' initial concerns. They will characterize the system by analyzing and evaluating the existing structure and the desired taller structure, with and without a worst-case roof load. They will do this on a small-scale test system.

d) They will set benchmarks and identify opportunities for improvement. This is the first discussion of benchmarking in the curriculum.
e) Then they will come up with design solutions that improve on the baseline; they will select, test, and refine a concept; and finally they will report on it.

Unit 2 Outline:

1) **Review the Engineering Design Process (EDP).** *(Graphic provided)*
   a) The immediate next step is to describe the need more.
   b) Refer to their "Know/Need-to-Know List". Before they can answer the initial questions of the customer by testing, they should know:
      i) what an earthquake is, and
      ii) how to use the earthquake simulator.

2) **Students learn background science and technology relevant to understanding the customer needs statements.** *(Teacher references provided as noted below)*
   a) They review earthquakes, geology *(See 3.2.5 Reference 1_Background on Earthquake Science)*
      i) What do the students already know about earthquakes? → Some interactive activity so that this lesson isn't just all lecture?
      ii) Effects of earthquakes on people, in terms of lives and money.
      iii) What causes earthquakes? Plate tectonics and faults → different types of quakes (*Relevant animations provided in: 3.2.5 Video 1_Plate Tectonics USGS.wmv)*
      iv) Different types of waves → Surface waves can be felt and measured by everyday people; seismologists call the surface waves that shake back and forth Love waves (after AEH Love) and cause the most destruction; they shake perpendicular to the direction of the wave travel. (demonstration with Slinky? Video?)
      v) Higher amplitude and higher frequency = more energy released to possible cause destruction.
      vi) Typical frequency of shaking in a quake < 20 Hz
         (1) Ask: What is frequency? Where else do you think about it? Music (pitch and rhythm), car motor RPMs, light…
         (2) Show a video demonstrating this frequency visibly, if possible. For example: Shaking starts at 50 seconds: http://youtu.be/zE_TBgYad6c
            (a) Try to count the cycles per second of the shaking just visually; it may

end up falling between 0.5-2Hz. Ask: What are the chances of a quake like this, with this same frequency, happening in the city in India that we are looking at? Students should refer back to the interview statement from the government to answer this.

b) Refine the list of Requirements & Constraints.
   i) At this point, students should understand the government interview statement better. They should confirm that the list of requirements and constraints includes: "The building must be safe during a 0.5-2 Hz quake." As the lessons continue, this list should become more quantitative.

c) (If students haven't already asked) Ask the class: "What does it mean for a building to be *safe* during a quake?"
   i) Building doesn't collapse, buckle, or fail
   ii) Minimize forces on building
   iii) Minimize forces on people
   iv) Ask: How do you know what forces the building and people inside it experience? Use sensors.
   v) You also could use a sensor to check the frequency of shaking during a quake.

3) Students learn about characterizing earthquakes with sensors.

a) Students know what type of quakes must be simulated. Now they have to learn how to measure these quakes.

b) Accelerometer sensors can let you estimate frequency and amplitude of quake shaking. *(See 3.2.5 Reference 2_Background on Accelerometers)*
   i) Accelerometers will let you measure acceleration wherever you place it (m/s2).
   ii) Ask: Where else do we use accelerometers? Smartphone, new game controllers, new cars... technologies where changes in motion are important.
   iii) Ask: Why measure acceleration during a quake?
      (1) It helps us evaluate safety. Ask: Do we want larger or smaller accelerations in a building during a quake? Smaller. $F = ma$. Higher accelerations mean higher forces on both the building parts and the people inside it.
      (2) Confirm that the list of requirements and constraints includes: "Minimize peak accelerations in the building during shaking"
      (3) The acceleration pattern matches the shaking. You can measure frequency based on the pattern in acceleration.
      (4) (If they know calculus) You can estimate velocities and displacements.

Calculus lets you also measure any one of these and get pretty good estimates of the other.

iv) How does the accelerometer work? Give a brief, 1 or 2-slide intro to how it works.

(1) This is a transducer – it changes one energy domain into another (mechanical to electrical). Bigger accelerations in mean bigger voltage signals coming out.

(2) It senses forces with tiny devices inside the circuit. F = ma, so if you know force on it, you can get the acceleration on it, too. This data can be read by a computer.

4) **Students learn about earthquake simulators.** (*See 3.2.4 Reference 3_Background on Earthquake Simulators)*

a) Students know what type of quakes must be simulated and can measure these quakes. Now they have to learn how to simulate them, before they can start initial baseline tests.

b) Show a video demonstrating the large-scale testing that engineers normally do. Some example videos are:

i) 3.2.5 Video 2_Earthquake Simulation Simpson.wmv

ii) http://youtu.be/3z4YLUqOysI – concrete frame test; building fails.

iii) http://youtu.be/9X-js9gXSME – wooden frame test; building survives. Skip to 4:40 for just the test;

c) Point out that students are testing on a much smaller scale than you would normally test a building, for the sake of safety, cost, and learning.

d) Demo the myQuake system and software. (*See 3.2.5 Reference 4_Demonstrating the Test Setup)*

i) Show how when you wave the *accelerometer*, the *signal* changes.

ii) Have students look at the motor-cam mechanism. Ask: What's going on? How did we create this back-and-forth motion?

iii) Explain that the computer controls the electrical power going into *DC motor*. The DC motor spins a *cam*. The cam converts the *rotary* motion into a *reciprocating linear* motion.

iv) Show how you can control the speed of the DC motor.

5) **Plan to model the baseline buildings to spec.** Now students know what they're simulating and how to do it. Next they'll think about how to model the baseline buildings for testing. Before building, they should plan construction.

a) Ask: Why plan it out?
   i) There's a limited amount of balsa wood (see Unit Overview for recommended amounts to be provided per team or per class.) We don't want to waste wood.
   ii) There's a limited amount of time, so we should make sure we do the building and testing efficiently. Think through the plan now, so you don't have to change it too much later.

6) **Plan a Design of Experiments (DOE).** Ask the class to plan out the build process to answer the customers' initial questions and get baseline data. The baseline data is useful if we end up designing a different building altogether and need to compare it to something. Point them to a design of experiments involving model height and roof load.
   a) Ask: What should we build first?
      i) Scaled-down models, not life-size models.
      ii) Existing building
      iii) Desired tall building
      iv) What about the "worst case" or extreme testing? Often when we design something, especially if it affects people's safety, we should consider the worst case that might happen. What did the residents say really worried them? A quake when the building has a lot of snow on top. How can we simulate that? We need to make something to hold extra weight at the top of our model. We'll call that the "roof load" simulator for our tests.
   b) Introduce the term *Design of Experiments* (DOE) (if you haven't previously).
      i) So we are changing two things: height and absence/presence of a roof load.
      ii) Draw out an experimental matrix (4x2 table). This table is one way to organize the tests that will be done later. If you had more variables, this table would get much bigger.

Case	**Height**	**Roof load**	**Safety**
1	shorter	absent	?
2	shorter	present	?
3	taller	absent	?
4	taller	present	?

iii) We've just designed an experiment to help us answer the customer's questions. There are two variables, or two *factors*, in this experiment: building height, and the roof load. Each factor has two *levels* in this case. Short vs tall, and absence vs. presence of roof load.

c) Important to plan all this out now, since the customer is asking about all of this.

Now we know what to build.

7) **Scale the drawings down.** Record the scaled drawings in the engineering notebook. (~5-10 min; include time for a team to demonstrate briefly how they did this)
   a) Start with the shorter existing building, so you check their work. Dimensions should be 125x smaller than the actual building dimensions. They also should convert units from meters to centimeters.
   b) They sketch what the two scaled-down physical models of the existing short building and the desired tall building should look like in their notebooks. *(See 3.2.5 Reference 5_Example Drawings of Scaled Down Buildings.)* They should include:
      i) Dimensions
      ii) Beam size callouts (they can refer to the initial customer needs interviews to be reminded what sizes are available for the model)
   c) Confirm everyone has the same dimensions.
      i) The model base area is 6 x 6 cm.
      ii) The height of the model for the existing building is 48 cm. The height of the model for the taller desired building is 72 cm.
      iii) Remind them of the test constraints. Use 1/4"balsa to simulate "wide" beams. (Later they'll use 1/8" balsa for "medium" beams, and 1/16" balsa for "thin" beams.)
      iv) Use 1/16" thick balsa sheet (6 x 6 cm squares) to simulate the horizontal levels joining the beams.
   d) Optional homework is to make these sketches in CAD, if desired, for either bonus points or an extension activity.

8) **Plan out the construction process; divide and conquer.**
   a) We want to be efficient; we've got all these student teams, so split up the work. Half the teams will build the short building, and half will build the tall.
   b) They will test their buildings later, with and without the roof load.

c) After testing and data analysis, the teams will swap buildings, so that all teams will have tested both the short and the tall buildings. (This will save class time and class costs.)
d) At the same time, we will still get repeated tests on each case (also called replicates). Note that they'll talk more about replicates later.

9) **Half the teams build the shorter model; the other half builds the taller one.** Each team also has to build something to hold the load on the roof.
   a) Students review construction instructions and tips. *(See 3.2.4 Handout 2_Construction Tips and Instructions)*
      i) Constraints for building the model, in addition to the dimensional requirements:
         (1) Glue will simulate joints (hot glue).
         (2) Wood and glue materials are limited. Every group can only have a certain amount for the whole unit (as listed in "Materials" section at the beginning of this document)
      ii) Tips for working with balsa
      iii) How to build the base of the small-scale model
      iv) How to build the roof-weight holder.
   b) They build the models. They attach it to a foam core base.
   c) They build a foam core holder for the roof load.
   d) Pause construction when everyone finishes building the 1st model of the short building; move on to the next lesson about testing the physical model and analyzing the data.
   e) If student groups finish constructing the first building earlier than others, have them they can immediately start building the second, taller building, and have them pause when ready to move on to the next lesson.

Unit 3 Outline:

1) **Students review the design process.**
   a) The initial goal is to evaluate the safety of the current building and the new proposed taller building. They also should consider cost. They have built the models of the two buildings according to the building owner's specifications, so that they can test them.

2) **Ask: How should we test this first building?**
   a) Put it on the simulator.
   b) Add weights to simulate loads, according to what the engineering firm said.
   c) Shake it, get acceleration data from the roof

i) Real tests engineers would take data in multiple places, but here we just have two sensors, so it makes sense to measure the input acceleration at the base and the last output acceleration at the roof.

d) If students will share test systems among multiple teams, warn them ahead of time. The teacher should prepare for explaining how to use software more than once, or to have teams who already know how to use the software to explain it to other teams.

3) **Give the students the rules for simulating the loads.** (*See 3.3.3 Handout 1_Testing Instructions.)*

a) The model must hold 33g per 6cm in height (2 washers [steel, 1-3/8"OD, 1/2"ID, 5/64" thick] and one binder clip approximate 33g).

i) Note that these numbers are somewhat arbitrary, to facilitate teaching, just like using balsa wood for the model. For real seismic testing, real building materials would be used, along with loads that are more proportional to the material strengths. However, real testing should still distribute loads realistically, and in extreme cases, as in this unit.

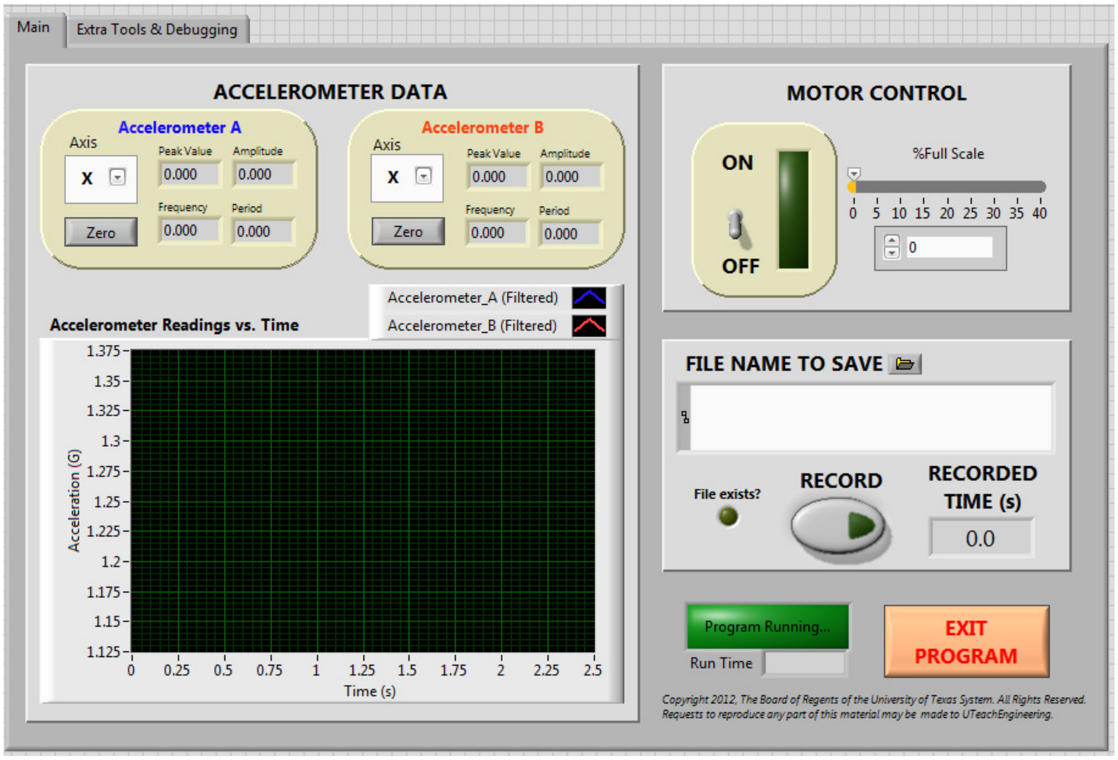
b) The building will be tested with and without the roof load (normal case vs. worst expected case). The roof load is 280g. Fill the "roof load holder" with weights or washers up to this mass.

4) **They test the model for baseline data (benchmarks).**

a) First they load the structure evenly on all the levels and test it. Then they load everything including the roof load and test it. This shows the effect of mass or static loads on the building response.

b) After students load their weights and set up the hardware, have them follow along as you show how to use the software. If teams are sharing a system, have one team use the system, while the other team watches. Each team will take turns gathering their data. If several teams are waiting, they can work on building the tall building.

c) Introduce data acquisition software (LabVIEW) shown below. *(A side reference is provided for teachers to understand the software, so they can explain how to use it directly.)*



i) Show how to start, run, and stop the program.

ii) Show how to configure the accelerometers whenever you start the program, and how to set motor power.

iii) Show what the indicators mean (acceleration in G-forces, motor %full scale, estimates of frequency). Some examples G-forces so students have a sense of what G's feel like.

(1) 1 G is the acceleration of gravity, if you were falling

(2) 2 G's is like moving in a car at 44 mph, then suddenly hitting the brakes, so you decelerate to 0 mph in 1 second.

(3) 0.5 G's is like being in a car that decelerates from 11 mph to 0 mph in 1 second.

(4) People start to get lightheaded and pass out around 4-5 G's, depending on the direction of acceleration.

iv) Show how to save data. They should save enough data points to understand how the building responds to various frequencies from 0.5-2Hz. They'll have to decide this as they go on.

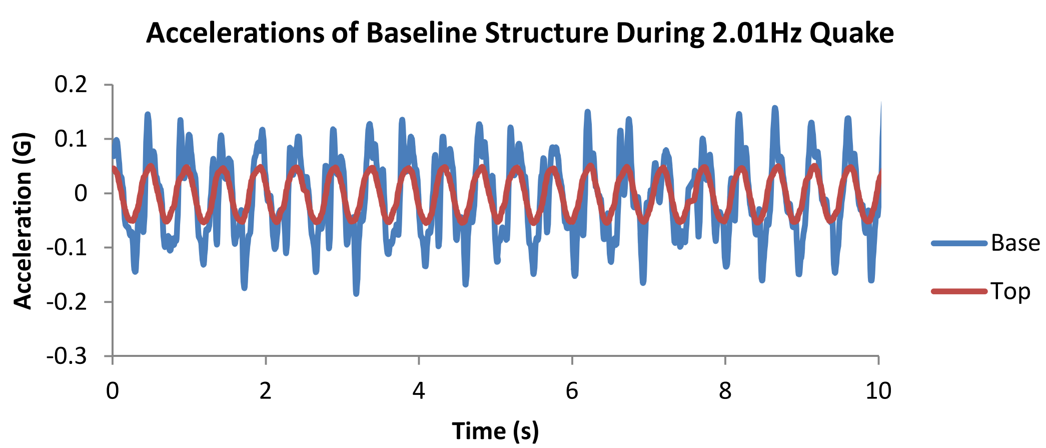
d) Introduce periodic signals: Offset, frequency, period, amplitude

i) Be sure to explain to students how to choose the right axes and zero the accelerometer data properly. Note that there's a time delay between what's happening and what they see. All equipment requires some preparation, and this is part of the preparation process.

e) The groups test their models of the existing building for quakes of approximately 0.5-2Hz.
   i) The buildings should not really resonate at this point, without the roof load.
   ii) They should save at least 3 data points here, but they may need around 8 or more if there is resonance, which they will see later.
   iii) If any buildings collapse at this point, construction probably wasn't good enough.

5) **Discuss: What did you see?**
   a) Did the shaking change with frequency?
   b) Yes, the amplitude seemed to increase as frequency increased.
   c) How can we confirm this pattern? Graph it out.

6) **Show students how to graph a seismic spectrum for their first model.**
   a) Use spreadsheet software to analyze saved data. Sample output data from the system will look as follows. Students will cull frequency, period, and amplitude measurements from the software. They really only have to look at the "roof" or top-level data. The base data is shown here just for comparison.



   b) Students learn about graphing their data as a response spectrum (or optionally as a frequency response) to quantify resonance. *(3.3.4 Reference 2_Creating a Seismic Spectrum in Excel)*

i) Plot acceleration vs. frequency, for seismic response spectrum. (Earthquake engineers will often plot it versus period, as well; other engineers may also plot gain, or the ratio of output/input amplitudes.)

ii) If needed, explain how to format data, set axes and titles, use legends, and clean up graph.

iii) Compare student's graphs. They all should show the increase in acceleration as frequency increases.

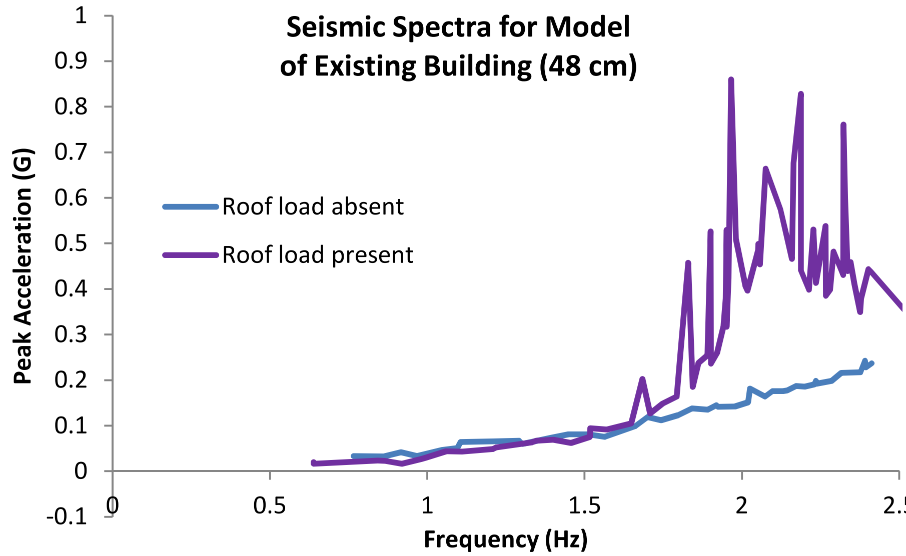
iv) Compile all the groups' measurements of the maximum accelerations in the 0.5-2Hz window. Take the average and standard deviation. This average is a benchmark for maximum acceleration, since we know the existing building safely survived one quake.

(1) Ask: If a different building has lower accelerations than this, is that good or bad? Good. What about if a new building has greater accelerations? Possible bad. We want to avoid that. It's the "number to beat" for any new building.

7) **Have students test the next case: their same building WITH the roof load.** They test, collect data, analyze data, and plot data on their own. This may take a half period.

a) The buildings should still avoid collapsing, according to tests by UTeach; however, there are definitely higher forces on the building in this case and in the next cases, so an occasional collapse in the remaining DOE cases is not impossible, though uncommon.

b) Example data from testing the short building are given below, with and without the roof load. The peak acceleration in the 0.5-2Hz window increases two-fold. There is a resonant period around 2Hz (but resonance is intended to be discussed in the next lesson, after all the data is collected). Notice that there is lots of noise in the data, which is okay; student data may look like this, or smoother.



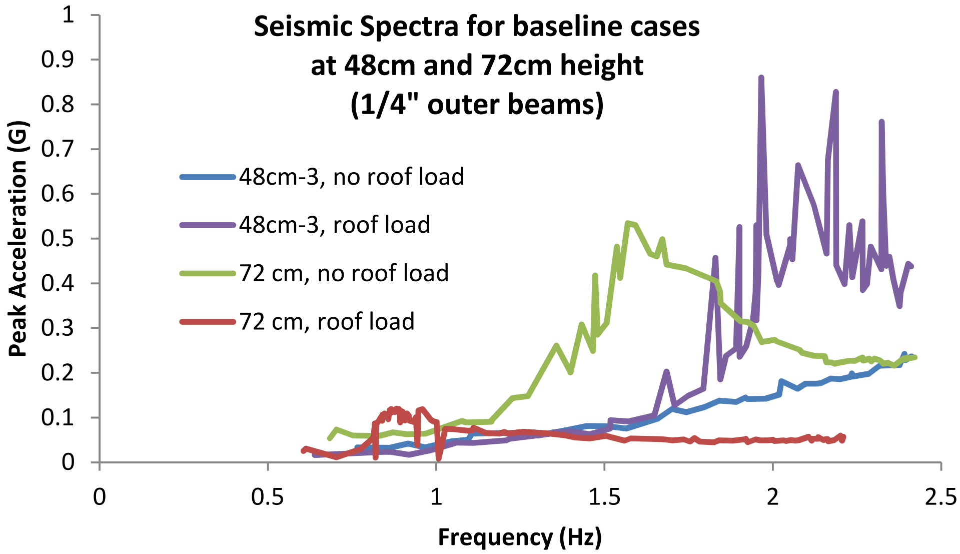
i)

8) **Discuss: Is this building safe with a roof load?** In the case above, no – it visibly shakes wildly. What is quantitative evidence? What is the peak acceleration now? The peak accelerations are much greater within the 0.5-2Hz shaking frequency that we expect for the area. These higher accelerations could be bad.

9) **Discuss the data collection strategy, when they see a pattern with a peak acceleration.**
   a) Ask: How many data points should you collect in the given frequency window? Collect more around the peaks in the seismic spectrum, to make sure you're getting the right shape of the curve. This will help account for noise and variability.
   b) Teams record their data collection plans in their notebook.

10) **They now swap buildings and test the second building without and with the roof load systematically, as in the previous tests.** Each team should plot the 4 seismic spectra on one graph. Compare student graphs. Have students report peak accelerations within the 0.5-2Hz window. (See *3.3.4 Reference 3_Expected Experimental Results* for full details)
   a) Before students make their "final" plot in Excel, show a few slides giving examples of graphs with various formatting or style problems, and comparing them with graphs that might appear in a scientific journal. This should give students an idea of how to properly create graphs.

b) Resulting expected seismic spectra for a single group look like the following:



c)
d) These graphs are expected to be fairly repeatable between different teams, if they build them according to plans.
e) Students reflect on the purpose of the testing they've just done.

Experimental Design Pre-Test

Unit 3 Pre Test

A group of engineering students is designing a rocket; they have determined from research that the number of fins on most existing rockets to be: three, four or six located near the bottom. They have also found that secondary fins are often used part way up the rocket, and there are two basic shapes of fins.

1. What parameters should they consider when designing their experiment for testing?
   a. Number of bottom fins
   b. Number of secondary fins
   c. Use of secondary fins
   d. Position on fuselage of secondary fins
   e. A and B
   f. A and C
   g. A, B, and D
   h. A – D
2. After further research and interviews with engineers the students decide to test: 3, 4 or 6 fins at the bottom; 2 or 3 fins located in two different positions. How many different combinations should the group test?
   a. 3
   b. 12
   c. 7
   d. 18
3. You work in a product design company and are creating a new alarm clock for children. You want to find the best sound for the alarm clock that wakes children up the fastest. The plan is to design a multi-factorial experiment to test different sounds on sleeping children. Your team has identified three variables of interest to test, with two levels for each variable. The variables are:

- alarm intensity (quiet vs. loud)
- pitch (low vs. high), and
- sound type (musical vs. buzzer).

a) What is the minimum number of experimental tests you should do, and why?

b) Your teammate suggests that you repeat each test on three different children. Do you agree to do this, and why or why not?

c) What might be sources of noise or variability in your data?

d) What procedures could you follow to control or reduce the noise in your data?

4. An engineering team is going to redesign a wind turbine. The team is going to consider the number of blades and pitch of the blades. Theoretically the pitch could range from 1^0 to 89^0, and the number of blades could range from 2 to 12. The region that the turbine will be used in has winds that vary from 1 mph to 30 mph. Create and describe in detail an experimental design that you would use to determine the best blade configuration for the region. Be sure to include what you would measure, how you would take measurements, how you would present the data.

Experimental Design Post-Test

Unit 3 Post Test   Name_________________

A group of engineering students are designing a rocket; they have determined from research that the number of fins on most existing rockets to be: three, four or six located near the bottom. They have also found that secondary fins are often used part way up the rocket, and there are two basic shapes of fins.

1. Circle the parameter(s) they should consider when designing their experiment for testing?
    a. Number of bottom fins
    b. Number of secondary fins
    c. Use of secondary fins
    d. Position on fuselage of secondary fins
    e. Shape of fins
2. After further research and interviews with engineers, the students decide to test: 3, 4 or 6 fins at the bottom; 2 or 3 fins located in two different positions; two shapes of fins. How many different combinations should the group test?
    a. 4
    b. 12
    c. 9
    d. 24
3. You work in a product design company and are creating a new alarm clock for children. You want to find the best sound for the alarm clock that wakes children up the fastest. The plan is to design a multi-factorial experiment to test different sounds on sleeping children.   Your team has identified three variables of interest to test, with two levels for each variable. The variables are:

- alarm intensity (quiet vs. loud)
- pitch (low vs. high), and
- sound type (musical vs. buzzer).

a) What is the minimum number of experimental tests you should do, and why?

b) Your teammate suggests that you repeat each test three times on ten different children. Do you agree to do this, and why or why not?

c) What might be sources of variability in your data?

d) What procedures could you follow to control or reduce the variability in your data?

An engineering team is going to redesign a wind turbine. The team is going to consider the number of blades and pitch of the blades. Theoretically the pitch could range from 1^0 to 89^0, and the number of blades could range from 2 to 12. The region that the turbine will be used in has winds that vary from 1 mph to 30 mph.

4. Describe **in detail** an experimental design that you would use, to determine the best blade configuration for the region. Be sure to include:
    a. What you would measure.
    b. How you would take measurements.
    c. How you would present the data.

Data Driven Design Pre-Test

Three groups of students (Group A, Group B, and Group C) collected data from three identically set up wind turbine systems. Each group tested three blade configurations (3, 4, and 6); each with five different blade pitches (5^0, 10^0, 15^0, 20^0, and 25^0) at three wind speeds. The data collected is shown in the table below. You and your team will duplicate the testing procedure to collect data to help you design the best configuration to pump the maximum amount of water. Using the data below you will predict what your results will be.

Pitch	3 blades A (ml/sec)	3 blades B (ml/sec)	3 blades C (ml/sec)	4 blades A (ml/sec)	4 blades B (ml/sec)	4 blades C (ml/sec)	6 blades A (ml/sec)	6 blades B (ml/sec)	6 blades C (ml/sec)	Wind speed
5.0	0.0	0.0	0.0	3.2	0.0	0.0	6.0	8.2	5.8	Moderate
10.0	3.4	0.0	5.2	9.8	9.8	9.4	10.5	11.0	10.2	Moderate
15.0	7.8	5.6	6.3	11.2	10.8	11.0	12.0	11.4	10.5	Moderate
20.0	7.8	6.1	6.6	11.7	10.4	10.0	11.8	10.4	7.0	Moderate
25.0	6.6	0.0	3.3	8.7	7.8	9.0	9.7	3.7	7.2	Moderate
5.0	0.0	0.0	0.0	0.0	0.0	0.0	0.0	0.0	0.0	Low
10.0	0.0	0.0	0.0	0.0	0.0	0.0	3.3	0.0	0.0	Low
15.0	0.0	0.0	0.0	4.2	0.0	0.0	5.7	0.0	3.2	Low
20.0	0.0	0.0	0.0	4.8	0.0	0.0	6.1	0.0	0.0	Low
25.0	0.0	0.0	0.0	1.8	0.0	0.0	4.1	0.0	0.0	Low
5.0	0.0	0.0	6.0	9.3	12.6	9.2	9.6	12.2	5.7	High
10.0	11.0	12.4	12.6	14.0	14.0	15.0	14.0	15.2	15.0	High
15.0	13.6	13.8	13.0	16.0	15.8	15.0	15.0	16.0	16.0	High
20.0	13.0	11.9	12.0	14.6	14.6	14.8	14.6	14.4	15.0	High
25.0	11.0	10.3	9.6	12.7	12.4	13.0	13.0	5.8	12.0	High

Your goal is to design a blade configuration that will pump the maximum amount of water in a location that has equal amounts of Low, Moderate and High wind conditions. Using the data in the table.

1. How many blades would you choose for your design? Explain the basis of your decision.
   a. 3
   b. 4
   c. 6

b. What pitch would you use for the situation in problem number one? Explain the basis of your decision.
   a. 5^0
   b. 10^o
   c. 15^0

   d. 20^0
   e. 25^0

c. If you are using a three blade system in a location that has only moderate wind conditions; what pitch would you use to guarantee a flow of 6ml/sec? Explain the basis of your decision.
   a. 5^0
   b. 10^o
   c. 15^0
   d. 20^0
   e. 25^0

d. Would your design change if you where designing for a village with limited finances? Explain, be specific.

Data Driven Design Post-Test

Unit 3 Post Test

Name___________________

Three groups of students (Group A, Group B, and Group C) collected data from three identically set up wind turbine systems. Each group tested three blade configurations (3, 4, and 6 blades on the turbine); each with five different blade pitches (5^0, 10^0, 15^0, 20^0, and 25^0) at three wind speeds. The data collected is shown in the table below. You will design the configuration to pump the maximum amount of water using these data.

Pitch	3 blades A (ml/sec)	3 blades B (ml/sec)	3 blades C (ml/sec)	4 blades A (ml/sec)	4 blades B (ml/sec)	4 blades C (ml/sec)	6 blades A (ml/sec)	6 blades B (ml/sec)	6 blades C (ml/sec)	Wind speed
5.0	0.0	0.0	0.0	3.2	0.0	0.0	6.0	8.2	5.8	Moderate
10.0	3.4	0.0	5.2	9.8	9.8	9.4	10.5	11.0	10.2	Moderate
15.0	7.8	6.1	Pitch	11.2	10.8	11.0	12.0	11.4	10.5	Moderate
20.0	7.8	5.9	7.0	11.7	10.4	10.0	11.8	10.4	7.0	Moderate
25.0	6.6	0.0	3.3	8.7	7.8	9.0	9.7	3.7	7.2	Moderate
5.0	0.0	0.0	0.0	0.0	0.0	0.0	0.0	0.0	0.0	Low
10.0	0.0	0.0	0.0	0.0	0.0	0.0	3.3	0.0	0.0	Low
15.0	0.0	0.0	0.0	4.2	0.0	0.0	5.7	0.0	3.2	Low
20.0	0.0	0.0	0.0	4.8	0.0	0.0	6.1	0.0	0.0	Low
25.0	0.0	0.0	0.0	1.8	0.0	0.0	4.1	0.0	0.0	Low
5.0	0.0	0.0	6.0	9.3	12.6	9.2	9.6	12.2	5.7	High
10.0	11.0	12.4	12.6	14.0	14.0	15.0	14.0	15.2	15.0	High
15.0	13.6	13.8	13.0	16.0	15.8	15.0	15.0	16.0	16.0	High
20.0	14.0	11.9	12.0	14.6	14.6	14.8	14.6	14.4	15.0	High
25.0	11.0	10.3	9.6	12.7	12.4	13.0	13.0	5.8	12.0	High

Your goal is to design a blade configuration that will pump the maximum amount of water in a location that has equal amounts of time of Low, Moderate and High wind conditions. Using the data in the table.

1. How many blades would you choose for your design? Explain the basis of your decision.
   a) 3
   b) 4
   c) 6
2. What pitch would you use for the for the blade configuration you chose above? Explain the basis of your decision.
   a) 5^0
   b) 10^o
   c) 15^0
   d) 20^0
   e) 25^0

3. If you are using a three blade system in a location that has only high wind conditions; what pitch would you use to guarantee a flow of 12ml/sec? Explain the basis of your decision.

a) 5^0
b) 10^o
c) 15^0
d) 20^0
e) 25^0

4. Would your design change if you where designing for a village with limited finances to use for the initial start-up costs? Explain, be specific.

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Vita

Patrick Fallin was born in 1958 in Farmington, New Mexico to parents Bill and Dorothy. Patrick grew up in San Angelo, Texas and graduated from San Angelo Central High School. He received a Bachelors of Science in Physical Education from the University of Texas at Austin in 1981; he then received a Master's of Science in Biomechanics from Brigham Young University in 1986. After coaching gymnastics for fifteen years, Patrick became a math teacher in 1992; teaching at the Saegert Middle School in Seguin for ten years and then Crockett High School in Austin Texas for five years and the past six years at Canyon Lake High School in Fischer Texas. He has taught: Pre- AP Algebra 2, Engineering Math, Engineering Design and Problem Solving, Algebra 1, Pre-AP Physics and AP Physics.

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