AC 2007-134: MECHANICAL ENGINEERING FOR MIDDLE SCHOOL STUDENTS: AN OVERVIEW OF THE MECHANICAL ENGINEERING PORTION OF MST AT MSU

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Mechanical Engineering for Middle School Students: An Overview of the Mechanical Engineering Portion of MST at MSU

Abstract

Mathematics, Science, and Technology at Michigan State University (MST at MSU) is a two week long introduction to advanced science and technology for academically-gifted middle school students. Though the program consists of a number of academic courses, a cornerstone of this program, and the focus of the present work, is a short course in mechanical engineering, which is presently in its ninth year of existence. This course is intended to expose the students to the fundamentals of mechanical engineering, as well as a variety of practical engineering problems related to the field. Though portions of this program were previously presented to the ASEE in 2000, the program has undergone a significant evolution since the initial report (completed after the first year of the course). As such, the present work contains a comprehensive overview of the current program's curriculum, organization, and, where instructional, evolution. As a whole, the work is intended to serve as a template for future mechanical engineering pre-college programs.

1 Introduction

Mathematics, Science, and Technology at Michigan State University (MST at MSU) is a two week long residential program with the stated purpose of introducing high-achieving middle school students with technical interests to a variety of scientific and technical disciplines (ranging from astronomy to zoology) and university life in general. Though the program has evolved significantly since its creation, a lasting cornerstone of the program's curriculum has been a short course in mechanical engineering. This course, which is taught by a representative of the mechanical engineering department (a faculty member or doctoral candidate) in conjunction with a local secondary school educator, is intended to introduce the fundamentals of mechanical engineering in an informative, yet approachable, manner.

Structurally, the mechanical engineering course is divided into ten two-hour academic units, each of which includes a brief technical lecture (approximately twenty minutes in length), a variety of hands-on demonstrations, and a competitive group project of a design-build-test nature. The course's curriculum presently consists of three distinct sections: (i) mechanical system sciences, (ii) thermal-fluid sciences, and (iii) design and manufacturing. Modules in the mechanical system section place particular emphasis on the basics of mechanics, namely statics, dynamics, and mechanical vibration, as well as on simple electromechanical systems (e.g. motors and speakers) and feedback control. The thermal-fluid modules stress the basic principles of work/energy, heat transfer, and aerodynamics, and the design modules include discussions of structural design and modern manufacturing. While this curriculum may be akin to that found in many pre-college engineering programs, distinguishing traits include the program's emphasis on hands-on, design-build-test projects and the emphasis the program puts on modern and past global engineering accomplishments (and occasionally instructive failures), as well as on 'cutting-edge' technologies likely to see broad implementation at approximately the same time the students will enter the technical work force. For the 2006 session, these forward-looking topics included MEMS and NEMS (micro- and nano-electromechanical systems, respectively), alternative energy systems (including PEM fuel cells), and so-called ‘space age’ materials (including heat-activated shape memory alloys).

The present work is intended to serve as a general overview of the mechanical engineering portion of the MST at MSU program and, as such, places strong emphasis on both the program's organization and curriculum. Due to its longevity, the work also details, where appropriate, the significant evolution of the program (previously described to the ASEE in 2000[1]) over its eight session history. The work begins in the following section with an overview of each of the ten instructional units that comprise the program. In particular, lesson objectives, presentation summaries, project descriptions, methods of learning assessment (homework assignments, project debriefings, etc.), and unit assessments, completed by the instructors in retrospect, are presented. In Section 3 a summary of student assessment data, which was obtained during the 2005 and 2006 sessions, is presented and the work concludes in Section 4 with a brief review.

2 Lesson Overviews

2.1 Lesson I: *What is Mechanical Engineering?*

Lesson Objectives:

- Present a clear definition of engineering.
- Introduce the students to the various engineering disciplines (chemical, civil, electrical, mechanical, etc.).
- Instill an intuitive understanding of mechanical engineering and the types of problems mechanical engineers typically face.
- Introduce a variety of mechanical engineering problems that the students are likely to encounter when they enter the technical workforce.

Presentation Summary: Traditionally the longest presentation of the course, the first lecture represents a self-contained introduction to engineering and its various disciplines. To facilitate student/instructor interaction and to set an early example of student participation, the course period begins with the development of a student definition of engineering. Once an acceptable definition has been developed (and a sufficient number of students have supplied input), the students are shown a brief movie (created by the instructors in 2004) entitled *An Introduction to Engineering*. This movie begins with a pictorial overview of the various engineering disciplines and then segues into a montage of modern technical disasters, which is used to motivate the need for sound engineering, as well as future class discussions.[2] The multimedia presentation then concludes with a brief summary of the twenty greatest engineering accomplishments of the 20th century, as determined by the National Academy of Engineering.[3] Following the movie, the students are tasked with revisiting their previous definition of engineering and are asked to extend it to the various disciplines. Following this brief discussion, the second part of the presentation begins.

For the 2006 session the topical areas of alternative energy technology and micro-/nano-systems were chosen to exemplify engineering challenges and opportunities that the students are likely to face should they choose to enter the engineering workforce. With regard to alternative energy, students were first introduced to a variety of apolitical issues regarding both energy consumption and availability. Following this brief presentation, the students were introduced, by means of hands-on demonstration, to a number of promising technologies including semiconductor-based solar cells and PEM fuel cells. With regard to micro-/nano-systems, the students were first given a broad overview of the field's technical successes (technologies such as cochlear implants, pressure sensors, and chem-/bio-detectors) and then given the opportunity to interact with a number of devices and gain an appreciation for scale.

Learning Assessment: To build upon the day's lecture and, ultimately, facilitate a deeper understanding of the mechanical engineering profession and the types of technical problems mechanical engineers typically face, students are assigned a homework activity based upon a descriptive engineering article. These articles, taken from back-issues of *Mechanical Engineering Magazine*, provide a comprehensive (and interesting) description of various mechanical engineering successes, including modern refrigeration, manned flight, and the automobile. After answering a handful of brief questions pertaining to the article, the students are asked to note any 'burning questions' they have which are engineering related. These questions are addressed at the beginning of subsequent classes.

Unit Assessment: Overall, the instructors believe that the lesson has proven extremely effective at meeting its principal objective: to create a clear and concise understanding of the engineering profession. This feeling is strongly reinforced by student feedback and the homework assignment, both of which indicate a deeper and more accurate understanding than that verbalized at the beginning of the class period. At present, the only concern is the duration of the lecture, which despite its interactive nature can be too long for the students. Future alterations may include the introduction of a brief, hands-on group activity, which should help stimulate additional active learning in this introductory lesson.

2.2 Lesson II: *Design: A Creative Problem-Solving Process*

Lesson Objectives:

- Introduce the students to engineering design and the design process.
- Introduce the students to the fundamental tenets of structural design.

Presentation Summary: Given the central role of design in modern engineering, the first technical unit of the course focuses on engineering design and the design process. The lecture begins with the development of a student definition for design and then proceeds with a formal presentation of the design process. To facilitate discussion, a modern engineering success – *Space Ship One* – is considered. To begin, the societal need for private space venture is discussed and the engineering problem (in part specified by the Ansari X-Prize[4]) is defined. The students are then introduced to a variety of 'shuttle' designs created by the various competitors and then finally shown a video of the successful launch of *Space Ship One* by Scaled Composites.

Once the real and complex engineering problem of inexpensive, efficient, and safe space travel has been introduced, the students are presented with a much simpler project to consider: the design and construction of a straw structure. Though few details are presented before the commencement

Figure 1: A representative straw structure being prepared for evaluation.

of the project (described subsequently) to stimulate creativity, the students are briefly introduced, via example, to the basic tenets of structural design and are strongly encouraged to consider the importance of strength, stability, aesthetics, and serviceability.

Project Description: The objective of the project is to build a portable structure capable of statically supporting a bottle of water (approximately 20 oz.) a maximum distance above the structure's base. The students are divided into groups of two and are given the following materials:

- 1 Cardboard Base Plate (approximately 12 in $\times$ 12 in)
- 1 Box of Drinking Straws
- 1 Roll of Masking Tape
- 2 Pairs of Scissors

To begin, the groups are given fifteen minutes to design their structures and devise a construction strategy. During this time the course's instructors move across the room discussing topics such as modular manufacturing and truss design with the various groups, while simultaneously asking questions about each of their designs. Once each group has finalized their design, the students are given fifty minutes to construct their structures. At the end of this period all work is halted and the structures are individually evaluated (see Fig. 1).

Learning Assessment: Given the nature of the project, learning assessment is largely completed in class. Specifically, the students are asked to partake in a group assessment of the various structures and identify which design elements led to success and which to failure. Where appropriate, methods of structural improvement are also discussed. At the class' conclusion, the students are given a brief worksheet and are tasked with noting which structural elements are capable of increasing a given structure's strength and stability.

Unit Assessment: Despite the simplicity of the project and the fact that many students have worked on similar assignments in the past, the project successfully attains its stated objectives. Generally speaking, the lessons learned from this activity are revisited by the students later in the course and various engineering principles discussed in the unit, such as modular manufacturing, can be seen in their later work.

2.3 Lesson III: *Mechanical Motion*

Lesson Objectives:
- Introduce the students to engineering dynamics.
- Present clear definitions for both kinematics and kinetics.
- Discuss Newton's Laws of Motion.

Presentation Summary: The third lesson of the course focuses on engineering dynamics and, in particular, Newton's Second Law of Motion. As part of a comparatively short presentation, simple definitions for both kinematics and kinetics are first presented. Following this, an intuitive understanding of position, velocity, and acceleration is developed and the fundamentals of kinetics are introduced through a brief review of Newton's Laws of Motion – a topic which a majority of the students are quite familiar with. To ensure a sound foundation for the class project, kinetic and potential energies are also briefly discussed.

Project Description: The objective of this project is to build a ground-level slingshot or catapult, mounted to a rigid base plate, capable of launching a table tennis ball a maximum distance. To accomplish this students are divided into groups of two and given the following materials for construction purposes:
- 1 Plywood Base Plate (approximately 8 in $\times$ 12 in)
- 50 Wooden Popsicle Sticks
- 1 Roll of Masking Tape
- An Assortment of Rubber Bands
- 1 Pair of Tin Snips (for cutting the popsicle sticks)
- 1 Table Tennis Ball

As with most projects in the short course, each group is given approximately fifteen minutes to design their device. During this time the instructors meet with each group not only reminding them of the lessons learned in the previous instructional unit (relating to structures), but also urging them to consider the various mechanisms through which energy can be needlessly lost in their design. At the conclusion of the design period each student group is given 45 minutes to construct their device and conduct initial testing. Each device is constructively critiqued by the instructors during this period and the students are encouraged to make design alterations as they see fit. Once construction has concluded, each group is given the opportunity to 'fire' their device twice and the group with the greatest distance (in either attempt) is declared the winner.

Learning Assessment: In order to reduce the course's overall work load, a homework assignment does not accompany this project. However, a group discussion at the conclusion of the class period is used to evaluate the various device designs. Generally speaking, the instructors allow this discussion to be student driven, as the devices used in the *Mechanical Motion* project are also used to convey the basics of open-loop control in a subsequent unit (described in Section 2.5).

Unit Assessment: Overall, the presentation portion of the class appears to do an acceptable job of meeting the unit's stated objectives, however, there is room for improvement with regard to the project. Though well liked by students, the project tends to emphasize the efficient transfer of energy rather than the dynamics principles it was originally designed to convey. In previous years, simple projectile motion analyses have been included in the lecture portion of the lesson to help unify the project and lecture, but the absence of aerodynamic force contributions in these analyses ultimately limits their applicability. For 2007, the use of a simple worksheet designed to examine the relationship between the launch angle and the distance the table tennis ball travels may be incorporated to re-emphasize basic dynamics during the project portion of the lesson.

2.4 Lesson IV: *Why Things Float and Fly: Buoyancy and Aerodynamics*

Lesson Objectives:
- Introduce the students to the fundamentals of aerodynamics.
- Introduce the students to the fundamentals of buoyancy.

Presentation Summary: The fourth unit of the course is intended to serve as a broad introduction to the fundamentals of aerodynamics and buoyancy. The lecture begins with a general overview of the role of fluids in engineering systems, and then turns to the basic principles of aerodynamics. Using a commercial jet liner for illustrative purposes, the concepts of lift and drag are described. Following this brief overview of the physics of flight, the presentation continues with an investigation of buoyancy and Archimedes' Principle. Here, for the first time in the course, the students are given a set of simple equations and asked to derive a practical engineering result – the physical conditions under which a given object will sink or float. In an attempt to discern those students using only intuition and those using sound technical judgement, the students are asked to use the results of their preliminary analysis and determine whether a 95,000 ton metal object could possibly float. Though the student's answers vary, they quickly realize the validity of their predictions when shown the USS Dwight D. Eisenhower – a modern aircraft carrier.

Project Description: Prior to the 2006 session, the project accompanying this lesson utilized the fabrication and testing of small clay boats to reinforce the basic principles of buoyancy.[1] Though this project was largely successful in meeting the stated learning objectives, an alternative project was introduced in 2006. The objective of the present project is for each student to design and fabricate two paper airplanes capable of achieving two distinct tasks: flying the longest possible distance and staying aloft for the longest duration of time. To achieve these tasks, each student is given the following materials:
- A Supply of Assorted Paper (including white multi-purpose paper, construction paper, and poster board)
- A Supply of Assorted Tapes (clear, masking, etc.)
- A Supply of Assorted Weights (paperclips, coins, etc.)

Once the materials have been distributed, the students are given approximately thirty minutes to design, build, and test their planes. Following this, the students are taken outside and allowed one attempt on each of two courses: one prepared to measure the total distance traveled by a paper airplane and another with a timing system to measure flight duration.

Learning Assessment: Following the class competition, the students are asked to reconvene and discuss the various design elements that led to successful outcomes in each of the unit's events. In addition to this discussion and in an attempt to extend the aerodynamic concepts discussed in class, the students are also instructed to take each of their planes home overnight and investigate the impact that flaps have on their plane's performance. Specifically, the students are asked to investigate and note which flap configurations cause their plane to turn and which lead to nominally straight flight. The results of this study are discussed at the beginning of the following unit.

Unit Assessment: Despite some minor complications with the new project, many of which can be attributed to fact that the project had not been previously attempted with an MST class, the unit did an excellent job of meeting its stated objectives. The modified presentation, which had a greater emphasis on aerodynamics and engineering mathematics than that used in previous years, was well accepted by the students and, generally speaking, the project received very positive verbal feedback. Based on the success of this initial trial run, the revised unit will likely be used in subsequent MST sessions.

2.5 Lesson V: *Out of Control: The Need for Engineering Control Systems*

Lesson Objectives:

- Develop a low-level, intuitive understanding of engineering control systems.
- Delineate the difference between open-loop and closed-loop control systems.
- Introduce the students, through hands-on demonstration, to a variety of closed-loop control systems.

Presentation Summary: The first week of the mechanical engineering portion of MST at MSU concludes with a presentation on engineering control systems. Given the relative complexity of this subject area, the lecture associated with this unit traditionally begins with a brief definition of control and the introduction of a number of representative systems (i.e. automobile speed controls, rocket guidance systems, thermostats, etc.). Once the students have exhibited an acceptable level of understanding, the difference between open-loop and closed-loop control systems is examined. Rather than belaboring the theory behind the topic, the students are asked to participate in an interactive demonstration based on a simple inverted pendulum. A number of students from the course are selected at random and asked to balance a standard yardstick in the palms of their hands. Generally speaking, one student in the course proves particularly adept at balancing the yardstick and that particular student is subsequently asked to balance a small ruler. Once this task has been shown to be futile, the students are introduced to an inverted pendulum demonstration unit, which utilizes a simple closed-loop controller to stabilize the pendulum's unstable equilibrium. After the students have had an opportunity to interact with the system and test its disturbance rejection capabilities, a single student is asked to attempt to balance a double pendulum (two rulers joined by a single hinge joint). After a handful of unsuccessful attempts, the class is shown videos of control-system-stabilized double and triple pendula.

Following the completion of the hands-on, inverted pendulum demonstration detailed above, the students typically have a rudimentary understanding of the capabilities of closed-loop controllers and thus more complex systems can be considered. For illustrative purposes a set of autonomous robots, utilizing touch, sound, and infrared sensors, are used to demonstrate a number of advanced controller capabilities.

Project Description: Given the students' lack of experience with practical engineering control systems, as well as strict budgetary constraints, the project associated with the control system unit emphasizes open-loop control. Specifically, the students are asked to revisit the design of their slingshots and catapults created in Lesson 3 (see Section 2.3 for further details) and determine how they can be calibrated to hit two targets placed at arbitrary locations within a given distance range. As this examination of open-loop control is essentially a scientific study of calibration, each group is given a ruler and protractor to integrate into their device, as well as any materials necessary to mend device damage incurred during Lesson 3. Following approximately thirty minutes of calibration and testing, the students reconvene and attempt one shot at each of two targets spaced an indeterminant distance between five and fifteen feet. The group with the smallest composite target error is declared the competition's winner.

Learning Assessment: Given the nature of the project and the duration of the interactive presentation, a group discussion on the results of this project is typically omitted. Likewise, as the students' weekend is filled with other planned activities, homework is not assigned.

Unit Assessment: Despite the fact that the control systems unit is the most technical unit in the mechanical engineering curriculum, the lesson proves quite effective at meeting its stated goals. In the latter parts of the course, the students can not only identify the difference between an open-loop and closed-loop control system, but can also determine which type of controller is likely employed in a given application. A lasting concern with this unit is the project. Though generally well liked by students, the project, as previously noted, is essentially an exercise in calibration. A number of projects based on closed-loop systems have been considered by the instructors, but the technical and budgetary overhead needed to implement such projects has proven problematic.

2.6 Lesson VI: *Manufacturing Madness: An Overview of Modern Manufacturing and the Assembly Line*

Lesson Objectives:

- Introduce the students to a variety of common manufacturing processes.
- Describe the modern assembly line.
- Describe the difference between parallel and series manufacturing.

Presentation Summary: Prior to 2006, the manufacturing portion of MST at MSU consisted of two instructional units. In the first, students were introduced to the fundamentals of modern manufacturing and the assembly line, and in the second, they toured a local manufacturing facility. Though this approach (previously detailed in 2002[5]) proved quite successful, local factory closures and changes in safety regulations have prevented its continuance. As such, the manufacturing section of the course was restructured in 2006 and condensed into a single lesson.

Currently, the manufacturing presentation serves as a multimedia introduction to the basics of modern manufacturing. The lecture begins with a brief overview of common manufacturing processes, such as casting and forging. Following two to three brief instructional videos, distributed by the Alliance for Innovative Manufacturing (AIM) at Stanford University,[6] the presentation transitions to a discussion of the modern assembly line. Here, the students are introduced to the concepts of series and parallel manufacturing and are urged to consider the benefits and tradeoffs of each approach. To reinforce these concepts, and to further expose the students to manufacturing processes, the presentation concludes with two brief videos detailing the manufacturing and assembly processes used at the Harley-Davidson Motor Company.[6]

Project Description: Unlike other projects, which utilize individual or small group effort, the manufacturing unit's project is a large group effort used to create a deeper understanding of manufacturing and the assembly line. Specifically, the students are divided into groups of approximately eight and are tasked with designing, implementing, and efficiently operating an assembly line capable of producing a specified number of 'beanie fish' (see Fig. 2).[5] To achieve this task, each group is given the following materials:

- 2 Beanie Fish Templates
- 2 Pieces of Cloth (approximately 15 in x 15 in)
- 2 Pairs of Scissors
- 2 Heavy-Duty Office Staplers
- 2 Felt Markers
- An Assortment of Wiggle Eyes
- 2 Bags of Dried Beans
- 1 Plastic Spoon
- 2 Sheets of Multipurpose Paper
- 1 Styrofoam Cup

At the beginning of the project, each group is asked to design their respective assembly lines. Specifically, the students are required to construct a manufacturing and assembly flowchart detailing (i) the steps required to construct the beanie fish, (ii) in what order the steps will occur, (iii) whether the steps will be done in parallel or series, and (iv) which group member is assigned to each particular task. Once the flow chart has been approved by a course instructor, the group is allowed to make a single test run to create one fish. At the conclusion of this test run the students are encouraged to redesign as they see fit and to note any changes on their flowcharts. After each student group has completed their test run, the groups are instructed to begin the construction of approximately eight fish. As the ultimate goal of the competition is to create these fish in the shortest possible time, speed and efficiency are key. Since speed often leads to poor workmanship, however, one instructor serves as a quality control inspector rejecting inferior products. The group that produces eight quality fish in the shortest amount of time is declared the competition's winner.

Learning Assessment: As the manufacturing lesson consumes the most class time of any unit, the project debriefing is generally quite short. However, to tie the project back into the presentation, the winning group's flowchart is analyzed with the class. There are typically no homework assign-

Figure 2: A beanie fish assembly line in operation.

ments given with this unit.

Unit Assessment: Generally speaking, the project portion of the unit, largely unchanged since its introduction in 2000,[5] does an excellent job of introducing students to the assembly line and the concepts of series and parallel manufacturing. It is worth noting, however, that exit surveys have revealed that the project is not quite as popular with the students as it once was. As this is believed to be reflective of the product being assembled by the students, rather than the unit concept itself, product changes are being considered for future sessions. With regard to the lecture portion of the unit, the instructors are still concerned that the students are being introduced to modern manufacturing via multimedia sources rather than industrial tours. While this approach does free up an additional day for an alternative topic (such as electromechanical systems), it comes at the expense of a 'real world' engineering experience. If local factory tours were to become accessible again, the instructors would strongly consider resuming the old manufacturing curriculum.[5]

2.7 Lesson VII: *Energy and Work: Sources and Conversion*

Lesson Objectives:

- Present clear definitions for energy and work.
- Introduce the students to the fundamental modes of heat transfer.

Presentation Summary: One of the shorter lessons in the course, the energy and work unit places particular emphasis on energy conversion and heat transfer. The lesson begins with the development of student definitions for both energy and work. Following this brief group discussion, the presentation transitions to an examination of various energy conversion and transfer mechanisms. Given the breadth of this subject area and the nature of the accompanying project, particular emphasis is placed on the various modes of heat transfer. Specifically, the instructors work with the students to develop an intuitive understanding of conduction, convection, and radiation by examining a variety of common examples. To ensure student understanding, the lecture concludes with a brief class quiz wherein the students, as a group, are asked to identify the heat transfer mechanisms active during the operation of a number of household objects.

Project Description: Prior to the 2006 session, the birthday candle boiler project, detailed by the authors in a previous ASEE publication,[1] was used in conjunction with the energy and work unit. However, with growing safety concerns and a continuing decline in the students' overall laboratory experience, this experiment was retired. In its stead, a new project, previously utilized as part of a senior-level heat transfer laboratory, has been implemented. The objective of this new project is to develop a 'solar-powered' hot dog cooker capable of realizing the greatest possible temperature change in a fixed amount of time. To complete this project the students are divided into groups of two and given access to the following materials:

- Assorted Cardboard Boxes
- Assorted Poster Board
- Assorted Metal Foils (aluminum foil, etc.)
- Assorted Tapes (masking, duct, etc.)
- Saran Wrap
- 1 Hot Dog
- Assorted Wire
- Scissors
- Wire Cutters

After the groups have been formed, the students are given approximately fifteen minutes to design their devices and devise a construction strategy. During this time the instructors meet with each group to further discuss the fundamentals of radiation heat transfer (the role of reflecting and absorbing surfaces, etc.). Once each group has developed an acceptable design and it has been approved by the instructors, the groups are given approximately forty minutes to construct their devices.

Though dubbed 'solar-powered' cookers by the instructors, time constraints require that the oven designs be evaluated using heat lamps. Accordingly, each finished device is placed beneath two 250 W lamps, each stationed approximately 18 in above the highest point on the device, loaded with a hot dog, and then monitored with thermocouples to detect changes in temperature. The device which achieves the maximum temperature change at the center of the hot dog over a twenty minute period is declared the competition's winner.

Learning Assessment: To reinforce the fundamentals of energy conversion and heat transfer discussed in the lecture portion of the unit, the students are asked to complete a short worksheet. Though this worksheet asks a number of brief questions (requiring qualitative answers) about each student's oven, the focus of the worksheet is a simple efficiency calculation. Specifically, the students are asked to determine the efficiency of their device using the initial electrical energy going into the heat lamps and the change in temperature realized in their hot dogs. As this computation is slightly more complex than many they have seen to date, a number of helpful hints are provided.

Unit Assessment: Though never utilized in an MST course prior to the 2006 session, the 'solar-powered' cooker project proved quite effective. It received extremely positive student reviews and did not sacrifice the learning opportunities associated with the birthday candle boiler project. Due to the project's success, it is slated for inclusion in the 2007 session.

2.8 Lesson VIII: *Propulsion and the MST Regatta*

Lesson Objectives:

- Introduce the students to a variety of propulsion systems.
- Examine a chemical reaction representative of one used in a conventional propulsion system.

Presentation Summary: Though not a core topic in a standard mechanical engineering curriculum, the eighth lesson of the mechanical engineering portion of MST focuses on propulsion. The presentation begins with a general overview of the field and then briefly examines a handful of representative engineering systems, including internal combustion engines, steam engines, nuclear propulsion systems, and rocket engines. Given the relative complexity of each of these devices, schematics and videos taken from a variety of engineering databases are used to illustrate each system's fundamental mode of operation. The lecture concludes with an in-depth examination of the chemical reaction that takes place when vinegar and baking soda are mixed – a necessary precursor to the unit's project.

Project Description: First introduced in 2004, the project associated with the propulsion unit is the design, fabrication, and testing of a CO_2 powered boat. Specifically, the students are tasked with building a boat, which utilizes baking soda and vinegar as fuel, capable of traversing a 12 ft water track (a household rain gutter) in the shortest amount of time. For construction purposes, the students are divided into groups of two and given the following materials:

- 1 20 oz. Water Bottle with Cap (empty)
- 5 Standard Drinking Straws
- An Assortment of Tape
- An Assortment of Weights (e.g. coins)
- An Assortment of Waxed Cardboard
- 2 Balloons
- A Reservoir of Vinegar
- A Bin of Baking Soda
- 1 Funnel
- 1 Plastic Spoon
- 1 Graduated Cylinder
- 1 Knife (not distributed, but available for supervised use)
- 1 Electric Drill Motor (not distributed, but available for supervised use)

After all construction materials have been distributed, the students are given approximately ten minutes to design their boats. Once the instructors have had an opportunity to evaluate each group's design and discuss some of the pros and cons of their approach, the students are allowed approximately 45 minutes to build and test their device. Despite the relative simplicity of most designs, success typically requires a number of trial runs utilizing different volumes and volume fractions of baking soda and vinegar (Fig. 3 depicts one such trial run). At the conclusion of the build/test period, construction is halted and the boats are evaluated individually. The boat which traverses

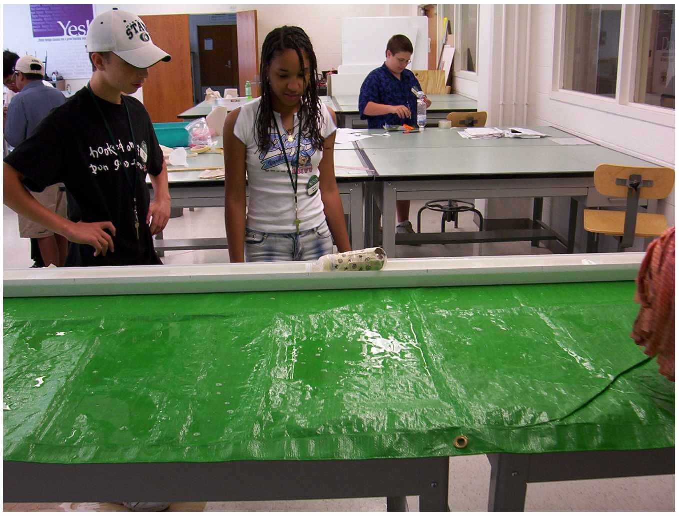

Figure 3: A representative CO_2 powered boat in the midst of a trial run.

the track in the shortest amount of time is declared the competition's winner.

Learning Assessment: At the conclusion of the course period the students are asked to reconvene and examine the various design elements that led to success. Amongst the topics discussed are the importance of discharging exhaust into the water versus air, the relationship between exhaust velocity and exit port size, and the value of simple device designs. A homework assignment does not traditionally accompany this unit.

Unit Assessment: Prior to 2004, the class project associated with this unit utilized the chemical reaction between baking soda and vinegar to examine the pressure induced by a simple, student-made 'rocket' engine with a balloon attached to its exhaust port.[1] Though this proved successful in meeting the lesson's stated objectives, it lacked the popularity of some of the course's other units. Following the transition to the current project in 2004, the unit became both a student and instructor favorite. Presently, the unit not only meets its stated objective, but does so in a way the students find highly enjoyable. It is worth noting, that a lasting concern with this project is the mess it can create.

2.9 Lesson IX: *Electromechanical Systems*

Lesson Objectives:

- Provide a brief overview of basic electrical theory.
- Introduce the students to the fundamentals of electromagnetism.
- Introduce the students to a number of common electromechanical systems.

Presentation Summary: The ninth unit of the course – a brief look at electromechanical systems – is also the course's newest (it was conceived well after the other new projects). This lesson, introduced in 2006 following the removal of one of the manufacturing lessons, is designed to introduce the students to the fundamental science behind electromechanical systems in a largely qualitative way. Due to the organization of middle school curriculum in the state of Michigan, few, if any, students have been introduced to the basics of electricity. As such, the lesson begins with an introduction to simple electrical theory, which explores concepts like voltage, current, resistance, and Ohm's Law. Following this brief introduction, the students are shown a simple circuit, which is examined qualitatively. After an acceptable level of understanding has been achieved, the lecture continues with a brief overview of magnetism and electromagnetism. Given the students limited familiarity with these concepts, hands-on demonstration utilizing household speakers, electric motors, and generators are used during instruction.

Project Description: The objective of the electromechanical system project is to construct a simple electric motor capable of achieving a maximum angular velocity. Though a number of design alternatives exist, the students are strongly encouraged to build motors akin to that originally described in an episode of *Beakman's World* – a syndicated educational television program for children. As these motors are relatively small, each students is asked to construct their own device. However, to add a design element to the project, the students are divided into a number of small groups, each of which is tasked with fabricating a variety of motor designs with different coil geometries. For construction purposes each student is supplied the following materials:

- 1 D-Cell Battery
- 1 Rectangular Ceramic Magnet (approximately 0.75 in $\times$ 2 in $\times$ 0.25 in)
- 3 ft of Magnet Wire
- 2 Large Paper Clips
- 1 Large Rubber Band
- 1 Roll of Electrical Tape (supplied to the group)
- 1 Sheet of Sandpaper (supplied to the group)
- 1 Pair of Diagonal Wire Cutters (supplied to the group)

After all of the necessary materials have been distributed, each of the students are asked to confer with their groups and select a coil configuration. Once the instructors have verified unique configurations for each group member, the students are given approximately 45 minutes to construct their motors. At any point during this period students can ask to have their motor's angular velocity measured (using a strobe light) and recorded. At the conclusion of the period, the student group that contains the student with the highest angular velocity is declared the winner.

Learning Assessment: Once each motor has been evaluated, the students are asked to not only determine which coil configurations led to the greatest angular velocity, but also to decide whether coil configuration was the largest contributing factor in the winner's design. As a homework assignment, the students are asked to compute their motor's efficiency using the electrical power input and angular velocity output. As their coil's moment of inertia can be quite difficult to experimentally determine, the students are asked to use geometric approximations in their estimates.

Unit Assessment: Though the instructors expected that the students would have little experience with electromechanical systems, the students' level of understanding of basic electricity was lower than expected. As such, the descriptions of basic electrical theory, magnetism, and electromagnetism had to be simplified 'on-the-fly'. Providing that these changes to the lecture are made permanent in subsequent years, the instructors feel this lesson will prove quite successful at meeting its stated objectives. It is worth noting that apart from the lecture, which, as detailed above, slightly overwhelmed the students, the lesson was well received, with many students providing positive feedback about the unit's hands-on demonstrations and project.

2.10 Lesson X: *What's Shaking?: An Introduction to Mechanical Vibrations*

Lesson Objectives:

- Introduce the students to the fundamentals of mechanical vibration.
- Introduce the students to the fundamentals of resonance.
- Review the fundamentals of mechanical engineering described throughout the course.

Presentation Summary: The final unit of the mechanical engineering portion of MST at MSU consists of a 45 minute presentation on mechanical vibrations and a 75 minute review session. The technical portion of lesson begins with a brief introduction to mechanical vibration motivated by the Tacoma Narrows Bridge disaster and a handful of early airplane crashes attributed to flutter-induced wing failures. Once a fundamental understanding has been established, phenomena such as resonance, rotating imbalance, and vibration absorbtion are examined through the use of various hands-on demonstrations.

The review portion of the lesson primarily consists of an hour-long trivia game presented in a *Jeopardy*-like format. Specifically, the instructors ask a series of question based on the course's content. While some of these questions require simple recall, others require the active extension of the various topics discussed in class. For the sake of competition, the students are divided into groups of three and are allowed to sequentially select questions. Each group is allowed to answer every question and the instructor reward points to each group that gives a correct answer. The group with the most points at the game's conclusion is declared the winner.

Learning Assessment: Given that this is the final unit of the course, all learning assessment takes place within the lesson itself, namely, in the review game.

Unit Assessment: Overall, the trivia game serves as an effective review mechanism and the competitive nature of the activity ensures active participation. While the hands-on activities included in the mechanical vibration portion of the lecture are generally well liked, the presentation portions have questionable impact, as the students are often looking ahead to the trivia game and the program's conclusion.

3 Student Course Evaluations

In order to evaluate the effectiveness of the MST at MSU program and its constituent classes, the administrative staff conducts student exit surveys, annually, at the program's conclusion. The pertinent results of these surveys are summarized below. Note that, due to structural changes during the 2005 academic year, a reduced amount of information was available following the conclusion of the 2006 session. Accordingly, data acquired during both the 2005 and 2006 sessions is included.

Table 1: Raw data obtained from the 2005 MST Mechanical Engineering Course Evaluations.

Score	Number of Responses	Percentage of Total Responses
0	0	0.00%
1	0	0.00%
2	0	0.00%
3	0	0.00%
4	0	0.00%
5	0	0.00%
6	1	2.78%
7	3	8.33%
8	5	13.89%
9	12	33.33%
10	15	41.67%

Following the 2005 session, students in the mechanical engineering course were asked to rate the class on a 1 - 10 scale, with 1 indicating a very negative experience and 10 a very positive experience. The mean student rating recovered for the course was 9.03. (Raw assessment data, recovered from 36 students can be found in Table 1.) This was a close second to the highest rated course, physiology, which received a 9.17, and significantly higher than the program mean (computed without data from the mechanical engineering course) of 8.08. The program itself, which incorporates not only the various academic classes, but also educational clinics, group activities, and camp-like events received a rating of 8.74. In 2006, course specific data was not recovered, but the composite program data shows similar trends. Specifically, the overall academic course rating was determined to be 7.91 and the overall program rating 8.77. As in 2005, qualitative student responses indicate a probable higher-than-average rating for the mechanical engineering course.

Though not recovered on a course-by-course basis in 2006, the 2005 exit survey also asked the students to briefly comment on what they liked the most about their academic courses and to note any suggestions for improvement. With regard to the first question, virtually every student surveyed indicated that the hands-on demonstrations and class projects were highly enjoyable, and many noted that they liked the competitive nature of the projects, as it provided additional motivation. The most common response to the latter question was ‘none’ (a majority of respondents), with others requesting ‘more time for projects’, and to a lesser extent noting that the projects were ‘too hard’ or ‘too easy’ (in nearly equal proportion).

Unfortunately, the students were not specifically asked in either 2005 or 2006 to indicate how much they learned throughout the course. As such, interested readers are encouraged to examine data recovered in 2000, which indicated that 53% of students ‘learned a lot’, 47% of students ‘learned some new information’, and 0% of students ‘learned very little’.[1] This question will likely be added to the 2007 exit survey.

4 Conclusion

As it enters its ninth year of existence, the mechanical engineering portion of MST at MSU continues to evolve and grow. Despite this constant state of change, the program remains committed to its stated purpose of introducing high-achieving middle school students to this exciting technical field. It should be noted that the program described in the preceding sections is implemented with a yearly budget of $400. Even with this relatively tight financial constraint, the instructors feel that the course's consistently high student ratings are a positive indication of its success. It is hoped that the curriculum and organizational topics presented herein will serve as an effective template for other mechanical engineering pre-college programs.

Additional Information

Those interested in obtaining additional information relating to the structure and organization of the Mathematics, Science, and Technology at Michigan State University (MST at MSU) program are encouraged to visit http://www.msu.edu/~gifted/mst/mst.htm. Additional information relating specifically to the mechanical engineering course and its curriculum will be posted, as time permits, at http://www.egr.msu.edu/~rhoadsje.

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