# AC 2011-2282: A SPIRAL LEARNING CURRICULUM FOR SECOND YEAR STUDENTS IN MECHANICAL ENGINEERING

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# A SPIRAL Learning Curriculum for Second Year Students in Mechanical Engineering


## Abstract

In this course development project funded through an NSF CCLI Grant, we are developing, implementing, and evaluating a new required integrated four-course sequence taught in the first two years of our Mechanical Engineering curriculum. The first year focuses on design methodology and computer programming, with an overarching theme of robotic/mechatronic systems. The new second-year courses replace traditional stand-alone courses in Numerical Methods and Thermodynamics, and emphasize sustainability in engineering. Each individual course teaches specific engineering science topics in addition to design practice and methodology, computer-aided engineering skills, and professional engineering skills. Thus, our design-motivated, Student-driven Pedagogy of Integrated, Reinforced, Active Learning (SPIRAL) approach distributes the teaching of basic engineering knowledge and skills through multiple courses in order to enhance student understanding through repetitive exposure at ever-increasing depths.


## Introduction

This paper will focus on the new second-year course sequence, titled Introduction to the Design of Sustainable Energy Systems. The first course of this sequence focuses on Numerical Methods, and builds directly on the programming experience obtained during the previous spring semester (as part of the new integrated first-year course sequence). The sustainable energy focus on wind and water power introduces the students to fluid dynamics through fluids-based examples in lecture and homework assignments. The main engineering science topic of the spring semester course is Thermodynamics. Here, thermal power sources are emphasized as sustainable energy solutions and highlighted in lecture and laboratory experiences.

A team-based design project reflects the sustainable energy theme. During the first teaching of this course sequence we concentrated on energy storage in compressed air, which is used to propel an air-powered train in an end-of-year design competition. The project spirals the design methodology, communication, teamwork, programming, manufacturing and hardware skills acquired during the first year of our new curriculum. For example, students are introduced to the following new manufacturing tools and techniques: CNC mill, CNC lathe, CNC router, vacuum forming and injection molding. The students continue to use Arduino® microcontrollers and are introduced to new sensing and actuation techniques. SolidWorks®, which was a primary focus during fall semester of the first year, is utilized in the design project, with the students learning advanced techniques such as flow modeling and finite element analysis.

## Numerical Methods

Applied mathematics classes such as Numerical Methods are often difficult for students in the absence of motivating problems that relate to engineering. At the end of a classical Numerical Methods class, students have a "toolbox" to draw from, but they have difficulty understanding when and how to apply the various tools. One of the advantages of the sustainable energy theme in our new classes is that it provides a suite of relevant applications that students are motivated to learn about. This pathway allows students to be introduced to fundamental and applied thermal fluids science concepts while learning core numerical methods material. Lectures and homework problems in this class include applications such as: fluid statics, compressed air storage, wave motion, drag force, optimizing flow in piping networks, and contaminant dispersion. In addition to using sustainability to motivate various numerical techniques, we have also used it to introduce the more advanced concept of mathematical modeling of multi-process systems and selection of appropriate numerical methods, which can be very difficult for students to grasp. These more advanced concepts are introduced in the lectures and homework problems and then integrated into an open-ended design project (see below), which requires students to understand when different methods should be applied.

**Thermodynamics**

The second course in the sophomore sequence integrates the theme of sustainability into an introduction to thermodynamics course. This is done by incorporating targeted lectures into the course, by having the students work on their sustainability-related team project, and by introducing new laboratories related to both sustainability and the design project.

**Design Project**

The design project spans two semesters. The first semester concentrates on the conceptual and detailed design, while the second semester involves construction, testing and competing (in teams of four) on our Departmental "Design Day." During the first offering of this new course, the students are designing an air-powered train to compete in a race involving a straight track, two tunnels, mail pickup and drop off (using a servo motor controlled by an Arduino® board), and removing a cow from the tracks. Since the first semester's academic focus is on numerical methods, the concurrent emphasis in the design project is for the students to support their design decisions using modeling and numerical simulations. The semester culminates with a design review, in which each team must present detailed design drawings and defend its design decisions to the course instructors and TAs via an oral presentation and a written report. Major decisions are the size of the compressed air storage cylinder, the type of propulsion system (e.g., nozzle, turbine, piston-cylinder), the shroud design, the mechanism used for mail pick up and drop off, and the "cow catcher" design.

During the second semester, the teams construct their devices (trains), as modified after the first semester design review. Each team manufactures a shroud using a numerically controlled router and vacuum forming, and a "cow catcher" using a numerically controlled milling machine and injection molding; the numerically controlled manufacturing tools require the parts to be modeled in SolidWorks®. In the first offering of this course, the students are learning how to operate manual mills and lathes in the laboratory portion of the course, and will then use these tools to manufacture a common "flatcar" for holding their propulsion system. The students also have Arduino® laboratories in which they develop the programming skills needed to control their servo motor and take pressure and temperature measurements from their air storage tank. These measurements are then compared to the results of modeling efforts based on the material learned in the lecture portion of the course (i.e., thermodynamics).

## Laboratory Experiences

The laboratory portion of this course involves four components, all of which closely support the design project: Arduino®, numerical methods, machine shop, and CAD. During the first semester, most labs include both a numerical methods tutorial and a hands-on Arduino®-based lab experience.

*Arduino®.* In both semesters, the students learn increasingly advanced mechatronics skills using the Arduino® microcontroller platform (they learn the basics during the second semester of the freshman year). For instance, they start with a lab that introduces them to C on the Arduino® in which they write code to compensate for a draining battery (by adjusting the pulse width modulation output) using "ints" and "longs" and floating point math. Other labs explore the basics of analog to digital conversion, how to write functions to interface with serial LCDs, using interrupts in conjunction with encoders for velocity and position tracking of a DC motor, controlling a DC motor with pulse width modulation, and controlling a servo motor. Thermodynamics-related labs involve measuring temperature and pressure with their Arduino® boards and performing thermodynamic experiments related to the design project.

*Numerical Methods.* During the first semester, students individually learn to apply important numerical methods concepts and develop good programming habits using the MATLAB® environment. The assignments are typically based on fluid mechanics and sustainable energy applications. For example, in one lab the students utilize Newton-Raphson's root finding method to achieve specific fluid densities at particular heights in a solar pond. This element of the class allows the students to increase their level of sophistication in programming well beyond that which could be taught in a non-lab based class.

*Machine Shop.* In the second semester, the students learn how to operate manual mills and lathes, and use that knowledge to construct the "flatcar" base that they must use to carry their designs. They also manufacture a few other common components needed for the design project.

*CAD.* During the first semester, the students learn how to perform flow simulations in SolidWorks® for both external and internal flow, and are required to use that knowledge to design a shroud for their train and determine aerodynamic drag forces. In order to spiral their previous SolidWorks® knowledge, they are also required to develop detailed drawings of their proposed designs in the first semester. In the future offerings, we plan to require animation and motion analysis of their proposed mail pick up and drop off systems. In the second semester, the students refine and redo their designs for their final presentations.

## Communication Skills

During the course of the design project, the students are required to communicate their progress via project memos, written reports and oral presentations. At the end of the first semester, they present a final proposed design and explain how major decisions were made (with emphasis on using numerical methods). At the end of the second semester, they will describe how well their design actually performed, how they did in the competition, what they would have done differently, what lessons they learned, and how accurate their modeling and numerical simulation were.

**Conclusion**

In the second year of our new SPIRAL curriculum, we have implemented laboratory experiences, a team design project, and an overarching sustainable energy theme in an effort to motivate and enhance student learning of Numerical Methods and introductory Thermodynamics. The sustainability theme has facilitated the incorporation of fluids-based examples into the Numerical Methods lectures, laboratory tutorials, and homework assignments. These examples are expected to not only increase students' understanding of and appreciation for numerical techniques but also improve comprehension of fluids content in the junior year. The new laboratory experiences equip students for the sustainability-themed design project by teaching CAD skills, manufacturing techniques, and microcontroller-based actuation and sensing. Finally, the design project enables immediate application of the engineering science principles (i.e., Numerical Methods and Thermodynamics) being taught in the new course sequence, where the hands-on component is expected to enhance learning and improve retention in the program.

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