2006-1554: MULTIPLE MODELS OF A FRESHMAN ENGINEERING EXPERIMENT

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Multiple Models of a Freshman Engineering Experiment

Introduction

The College of Engineering (COE) at Virginia Tech is the sixth largest US engineering program in terms of bachelor's degrees awarded[1]. All first-year engineering students are required to complete a common General Engineering (GE) curriculum with the introduction to engineering course taught by the faculty in the Department of Engineering Education (EngE). Students transfer from ENGE to eleven degree-granting departments as sophomores. The yearly enrollment in GE has been about 1300 for the past decade. The department has been emphasizing a hands-on approach to instruction with design as the central theme since about the year 2000.[2]

Providing meaningful hands-on experiences to a large number of engineering students is a challenge. Faculty, lab space, and money are always a consideration. Even the mechanics of adding lab time to the students' already tight schedules creates an immense hurdle. The department has been fortunate to receive significant funding support for student projects through the generosity of Virginia Tech's Student Engineers Council (SEC). The SEC has provided the freshman engineering program approximately $10,000 per year for the last six years in direct support of EngE's hands-on instruction. From 1998 to present, they have given a total of nearly $200,000 to the college in support of undergraduate engineering instruction.[3]

In 2004, the EngE faculty, in collaboration with faculty from other engineering departments and the School of Education, were successful in getting a major engineering education project funded by the National Science Foundation (NSF) through its departmental level reform (DLR) program.[4] The goal of the DLR project is to reformulate the freshman engineering (i.e., GE program) within EngE and the bioprocess engineering option within the Biological Systems Engineering (BSE) program using a theme based spiral curriculum approach. The twentieth century psychologist, Jerome Bruner, proposed the concept of the spiral curriculum. Bruner advocates that a curriculum as it develops should revisit the basic ideas repeatedly, building upon them until the student has grasped the full formal apparatus that goes with them.[5] In the proposed reformulation, a theme of sustainability has been selected to provide a contextual framework. The supporting principles of design, ethics, and a systems approach and cross-cutting skills of communication, teamwork, life-long learning, research experience, and lab experience will be woven throughout the curricula.

In the spring of 2005 the department piloted a new model for student instruction in one of the freshman year engineering courses called "Engineering Exploration EngE1024" in order to provide avenues for educational research, provide teaching opportunities for graduate students, and reduce faculty teaching loads for pursuing scholarly activities. This model was fully implemented in the fall of 2005. Traditionally, EngE faculty members taught the two credit hour introduction to engineering classes similar to EngE1024 twice a week for fifty minutes each in a traditional classroom of about thirty seats. With the new model, the course had eight large weekly lecture sessions with 150-170 students in each section and taught by a faculty member for fifty minutes. These lecture sessions were then split into 41 weekly workshop sessions of 30-32 students each taught by a graduate student in a standard 32-seat classroom. Each workshop met for one and one half hours per week. These workshops were used to practice what was taught in the large lecture and conduct experiments in support of the lecture material. For the lecture session, three large classrooms were required, and for the workshop sessions five classrooms were needed. All first semester General Engineering students participated in the study. A companion paper in this conference presents the details on the fall 2005 implementation of various activities in EngE1024 course.[6]

The Models

A simple water tower experiment was developed by a sub-set of DLR investigators for use in the fall of 2005. The goals of the experiment were to provide a hands-on experience of data collection and analysis, demonstrate the concept of systems modeling in engineering, and have the students solve the same problem in a number of different ways. These goals were in direct support of the NSF/DLR grant objective of introducing topics in the freshman year that would be expanded upon in upper level courses. A falling head experiment was chosen as the vehicle to accomplish the goals. The problem was to consider an inverted and truncated cone (conical frustum) water reservoir with an orifice at the bottom. Analysis was made of the decreasing height of water surface with an open valve as is summarized in Table 1.

Table 1: Water Tower Activities, Fall 2005

Activity Week	Description of activity
Week 2 Homework	Compute conical water tower volume and flow problems by hand.
Week 5 Workshop	Conduct water tower experiment and collect data related to water head and time of drainage
Week 5 Homework	Fit an empirical function using data collected in the week 5 workshop
Week 7 Lecture	Demonstrate a systems model of the water tower experiment and show the effects of changing parameters like orifice diameter on rate of water drainage
Week 12 Lecture	Compute the volume of a conic frustum using an object oriented program
Week 13 Lecture	Further modify the object oriented programs and add behaviors as defined in an object oriented approach to the Cone class

For example, in the second week of the semester the following problem was assigned as homework and was to be completed by hand.

> *A pump is pumping water into a conical tank at a constant rate of 1.15 gal/min. The tank dimensions are: top inner circumference = 2.87 ft, bottom inner circumference = 2.60 ft, and inner tank length along the slanting surface = 1.47 ft. If the tank was initially empty, how long (in s) will it take to fill 80% (by volume) of the tank?*

The purpose of assigning this problem was to have students refresh their geometry, trigonometry skills, and unit conversion skills. They were expected to apply these skills later in the semester for doing various problem solving and programming work.

In the fifth week of the semester, the students completed a workshop where they used the water tower shown in Figure 1 to measure time and the height of water in the tank as water flowed out of the orifice.

Figure 1. Workshop Water Tower Experiment

Figure 2. Data Collection

This hands-on workshop gave the students (see Figure 2) the opportunity to tactilely experience mathematical models that they would create later. They also collected data that they would then curve fit in order to determine the mathematical relationship between height of water and discharge (Torricelli's equation: velocity of discharge is equal to the square root of two times the height of water times the acceleration due to gravity). Knowing the velocity, discharge can then be calculated using the continuity equation (rate of flow equals velocity times the area of the orifice). In earlier semesters, students used data from book problems to fit empirical functions.

In the seventh week's lecture a demonstration of a systems model of the water tower experiment was made using the Berkeley Madonna™ software environment. In this demonstration, emphasis was placed on the height of water/velocity/discharge relationships as shown in Figures 3 and 4. A simulation example was run with exactly the same set of parameters that were used in the week 5 water tower experiment and the plot between water height and time, just like what students did as part of week 5 homework assignment, was created using the Berkeley Madonna™ model. In figure 4, an "o" indicates a response in the opposite direction and an "s" a response in the same direction (e.g., as discharge increases height decreases). Due to the logistics involved in installation of the software and licensing requirements, the students were not provided with an opportunity to use the Berkeley Madonna™ software directly, but future plans include a more active involvement of the students in the exercise.

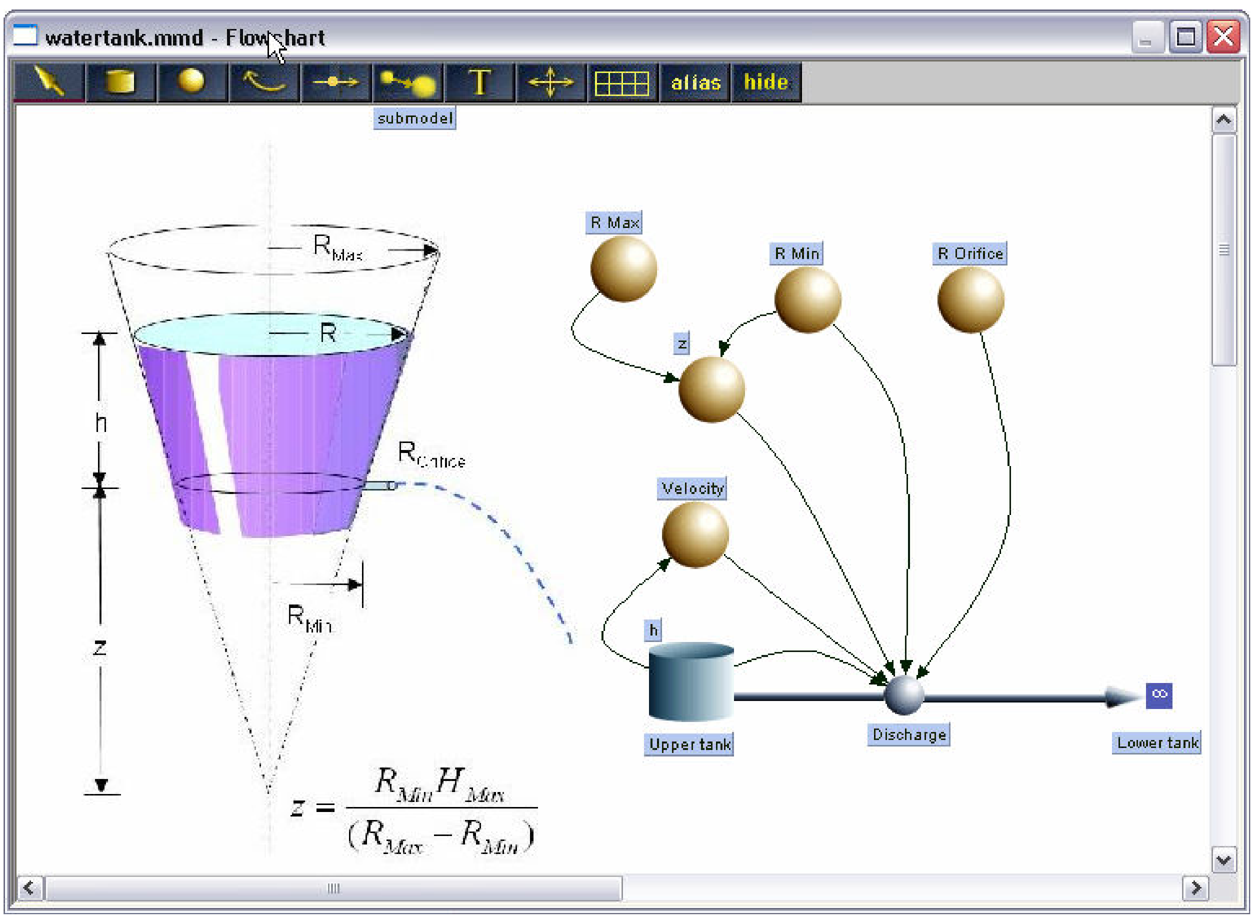

Figure 3. Systems Model of the Water Tower

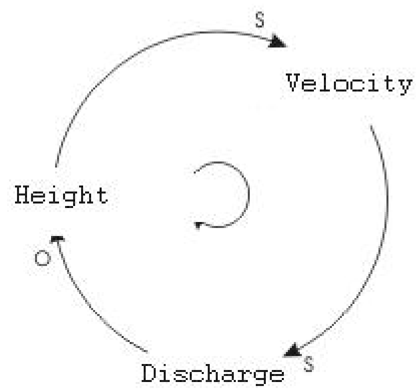

Figure 4. Systems View of Height/Velocity/Discharge Relationship

Lastly, the students were introduced to problem solving techniques using object oriented algorithms. For this purpose an object-oriented programming language called Alice (www.alice.org) was used as the introductory programming language of choice. The Alice system, which is provided free of charge as a public service by Carnegie Mellon University (CMU), provides a completely new approach to learning programming concepts. Alice uses a 3-D Interactive Graphics Programming Environment to teach the fundamental concepts of object-oriented programming. One of the major advantages of using Alice is the mitigation of syntax issues in lieu of teaching programming concepts. The Alice environment includes built-in classes. A program, called a virtual world in Alice lingo, can be developed using objects of built-in classes that are relevant to the scope of the programming problem. One of the built-in classes called "Shapes" includes all commonly known geometric objects like cylinder, sphere, cone, etc. The class Cone was, therefore, used to do in and out-of-class programming problems that began in week 12 of the semester. For example, the same variables used in the other models were used during in-class Alice instruction and students were led by the instructor in a hands-on exercise that involved developing an Alice program using an object of class Cone for computing the height and the volume of the truncated cone. Also, Cone class was modified by adding volume computing functionality. The fact that students had already done problem solving exercises related to a conical section in earlier weeks helped students in concentrating on the programming aspects of the problem.

Assessment Activities

At the end of the spring and fall 2005 semesters, an exit survey was conducted to obtain students' feedback on the course. A major objective of the course is to improve the problem solving and logical thinking skills of the students. The fact that the same cone problem was revisited several times in different contexts probably helped students in developing a deeper understanding of the associated concepts. Revisiting a theme in different contexts situated at a varying level of complexity is the main idea behind the spiral curriculum approach[5]. In order to assess the impacts of this new approach, students' responses to an exit survey question that has to do with improving problem solving and logical thinking skills are compared between spring 2005 and fall 2005 semesters (see table 2). It may be noted that there were not major differences between the content of spring 2005 and fall 2005 versions of the EngE1024 course. The multiple model of a same problem was probably a major difference as it wasn't implemented in spring 2005. As can be seen in Table 2, student perception of their skills increased markedly between the two semesters, an indication of the effectiveness of this multiple models experiment. It can be seen that about 71% students reported improvement in their problem solving and logical thinking skills in fall 2005 while in spring 2005 it was only about 58%.

While these data do support an increase in problem solving and logical thinking skills after the introduction of the project, the evidence is indirect and a measure of student perception. The data will be more rigorously analyzed and focus group assessment will be performed in coming semesters.

Table 2

Exit survey question: Have your problem solving and logical thinking skills improved as a result of ENGE 1024?		
Answer choices	Spring 2005, % (n = 190)	Fall 2005, % (n = 900+)
Yes, definitely	15.5	20.5
Yes, probably	42.0	50.0
Not sure	18.0	15.0
Not, probably not	18.5	10.0
Not, definitely not	5.0	4.5

Summary

Presenting freshman students with a single problem to investigate it from a number of different perspectives and with a number of different tools provides them with a broad perspective of problem solving and an exposure to different tools and their appropriate use. Asking the students to take measurements that are then used to develop a theoretical equation gives the students an appreciation of the concept of precision. When students grind through a hand worked problem and then solve the same problem with a programming tool they appreciate the power of that tool and the need to understand the underlying physics of the problem in order to create the program. Providing students an opportunity to watch and conduct an experiment (e.g., the physical draining of a tank) gives them insight into the general nature of the equation/theory that controls that discharge. A simple introduction to the concept of systems in engineering design prepares the students for future classes in which the concept is used in greater depth. Overall, the water tower problem and its differing models gave the students preliminary insight into many of the methods, concepts, and tools that they will be more formally exposed to in upper level courses. The authors are continuing efforts to refine the project and plan to use it in future semesters.

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