Developing and Assessing Integrated Mechanical Engineering Curriculum for Middle School Students

Mausumi N. Syamal and Gary A. Ybarra
Duke University Pratt School of Engineering, Durham, NC

Abstract – *Our society is becoming increasingly dependent on technology. The use of cell phones and mp3 players permeates every age group and socio-economic stratum. The creation of new devices that improve human life quality is the essence of engineering. Yet, the vast majority of the population does not even know what engineering is. In a 1998 Poll 61% of adults claimed that they were "not well informed" about engineering. This statistic is the result of the fact that engineering is generally not introduced in either elementary or secondary education. Exposing elementary and middle school students to engineering concepts will increase awareness of the general population and potentially lead to more children pursuing careers in engineering fields. This project introduces students at Rogers-Herr Middle School in Durham, North Carolina, to mechanical engineering fundamentals throughout the course of a school year. Our goal is to create an integrated curriculum accompanied by hands-on projects and weekly quizzes. Teaching is structured with weekly lectures accompanied by several interactive demonstrations and experiments. Students are given weekly hands-on projects that are evaluated and assessed based on their incorporation of the concepts presented in lecture. In addition, students are given short, individual, weekly quizzes that contain problems that rely on a conceptual understanding of the material presented during the previous week. The topics covered are: heat transfer, fluid dynamics and velocity/acceleration. Projects include mousetrap cars, catapults and Rube-Goldberg machines. This paper presents a detailed description of the program curriculum, the assessment instruments and conclusions regarding program effectiveness.*

INTRODUCTION

For many young students across the nation, the notion of becoming an engineer is foreign and formidable. Yet most of these students are unable to accurately describe what an engineer does, perhaps reinforcing the old saying that "we fear what we do not know". Traditionally, early American schools taught students essential academic and trade skills. Students were instructed on proper methods of maintaining the farm, homemaking and even apprenticeship skills. Yet why are students today, not taught the basics of what is a rapidly growing field in the world? Recently, current programs have been implemented that attempt to bridge secondary education with engineering fundamentals, such as the Techtronics[1] Program at Duke University, and the programs offered by New Jersey Institute of Technology[2], both which partner secondary students with current college students.

Yet a critical question that has yet to be explored is whether it is even possible within secondary curriculum to integrate engineering fundamentals? In an effort to address this question, a model was created. The objective was to determine whether or not it is possible to develop integrative engineering curriculum within the scope of middle school students. Due to its versatile application, the mechanical engineering field was chosen. This model is perhaps a greater extension of a Pre-Engineering Instructional and Outreach Program (PrE-IOP)[3] with a slight difference in its main initiative. While the ultimate outcome may result in a greater proportion of students expressing a desire to continue engineering education, if it is determined that engineering instruction can be well integrated into current middle school curricula, this model may possibly serve as a pilot program that incorporates engineering into basic secondary school science. If students are capable of grasping basic engineering concepts as early as middle school and these concepts can be introduced without requiring drastic changes in current curricula, secondary schooling may be on the brink of change.

STUDENTS

Students were selected from Rogers-Herr Middle School in Durham North Carolina. Rogers-Herr was selected due to its diverse socio-economical and ethnographical make-up. The school was also selected due to its familiarity with engineering integrative programs, such as Techtronics [1].

Primarily, a single grade level was selected in order to reduce the possibility of age and background discrepancies. For this model, two 7th grade science classes were selected. These two classes were also selected from the same science teacher in order to ensure that their science background and teaching thus far was as homogenous as possible. Both classes contained both male and female students

To obtain indicative results, care was also taking in obtaining a wide range of academic ability. If this model were to continue on as a standard in education, it must be effective for a large majority of students, regardless of academic ability. Thus, the first class, S1, selected contained students that were marked as "gifted" or "talented" while the second class chosen, S2, contained students that regularly perform at a level below the average 7th grade class at Rogers-Herr.

With the guidance of the classes' science teacher, Andy Scott, initially twenty-two students from S1 and fifteen students from S2 were to participate in the model. A few students were omitted from the initial S2 due to severe emotional and behavioral problems.

MACROSCOPIC MODEL STRUCTURE

The model seeks to seamlessly integrate mechanical engineering instruction into the standard course of study. For this model, four modules were designed to blend with the North Carolina Standard Course of Study for 7th grade science[4]. Next, four major modules were created, to be evenly distributed throughout the course of a seven-month period. The four modules were created by noting the major sections of the standard science and math curriculum.

Next a three-step process for each module was developed. These steps were designed to develop and test what Erwin calls "engineering intuition"[5] or an ability to use knowledge acquired in order to make decisions or judgments that demonstrate a fundamental understanding of "core concepts". Thus, the three steps are as follows:

1) **Introduction and Lesson on Core Concepts**—a "lecture" type instruction on topic with numerous visual demonstrations via drawings and quick hands-on examples.
2) **Experimental Activity**—an observational activity following the pseudo-lecture in order to allow students to observe the fundamental principles at work. Often coupled with a timed handout with several "small" concept recollections.

3) **Concept Quiz**—a series of questions often given as a section of a unit test that are designed to test the student's ability to not only recall the concepts but also apply them to a new or unfamiliar situation. Questions are developed after the lecture and activities, in order to prevent quizzing on material that was omitted in class due to time constraints.

Based on a successful completion, of the experimental activity, handouts and quiz, an overall evaluation is made based on the total percentage of students that are able to correctly apply a concept or answer a question. Individual percentages are also calculated for each section in order to observe any trends. The approximate time frame from the initiation and termination of a module is approximately 1.5 weeks. However, a final concept quiz may be implemented upon the termination of all modules.

MODULE DETAILS & DESCRIPTIONS

As stated before, four modules were created. These modules were to encompass the major areas of mechanical engineering, and their depth was not to exceed a mathematical or scientific level above that suggested in the standard course of study. As a result, the modules were designed to contain very little or no mathematical computation. These modules were created and taught by Mausumi Syamal, an undergraduate Mechanical Engineering student in the Pratt School of Engineering at Duke University.

The science curriculum for 7th grade students in North Carolina dictates four major sections; Cell Theory, Genetics/Heredity, Matter, and Motion & Forces. Two of these sections, Cell Theory and Motion & Forces were chosen to incorporate mechanical engineering instruction. Since Cell Theory encompasses all major human body systems, thermal and fluid modules were selected for integration into that section. A Module on Velocity and Acceleration was selected for integration into the Motion & Forces section. The instructional and structural details for each module are outlined below. To date, only two of the four modules have been implemented with results available for only the first.

MODULE 1: Heat Transfer and the Skin

This unit allows students to explore and learn about how the skin serves as primary mode of thermoregulation for the body. Emphasis is placed on reminding students that the goal of thermoregulation and all thermoregulatory processes[6] is to maintain core body temperature. Furthermore, it is important for students to understand that heat "flow" is unidirectional. That is, heat can only flow from warmer areas to colder areas[7]. These concepts are illustrated "pictorially" for students on the board as shown in Figures 1.1 and 1.2.

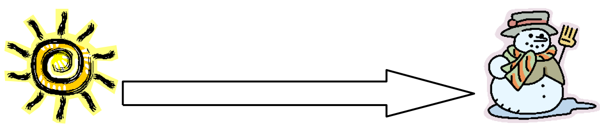


FIGURE 1.1[8]: A drawing illustrating the direction of heat transfer.

Thermoregulatory Processes
Maintaining Core Temperature!!!

Too Cold
(Body must decrease heat loss)

- Shivering: muscle contractions that break up convection currents.
- Piloerection: hairs stand up.
- Vasoconstriction: blood vessels constrict to minimize heat loss by blood flow to extremities.

Too Hot
(Body must increase heat loss)

- Sweating: cooling by convection.
- Vasodilation: blood vessels dilate to increase heat loss by blood flow to extremities.

regulatory Processes

e, students are given three small bowls—one water and one containing room temperature water. ger in the warm and cold bowls for about 3 minutes, ature water. Students observe and record which d" in the room temperature bowl. They are then asked from the lecture. A vocabulary handout that requires the lecture is passed out as homework and as the lecture and activity, students are given a York® reason peppermint feels "cold" on the tongue is dissolution requires heat.

in which the skin plays a vital role in thermoregulation. Students should know that heat transfers from warm areas to cold areas and the three major modes of heat transfer. In addition students should be familiar with the body's various responses to temperature conditions and how they aid in the increase or decrease of heat transfer. Using these goals, seven questions designed to test the students' understanding were developed.

MODULE 2: Fluid Mechanics and Blood Flow

This module applies the basic properties of fluid flow to blood flow and is dependent on integrating several demonstrations throughout the lecture. Lecture is initiated by asking students to list how fluids are involved in the body. While answers vary, students are likely to list blood flow amongst them. Using this connection, the definition of fluids is introduced. Most students, when told that a fluid is a liquid or a gas[9], are skeptical since it stretches the definition they are familiar with. Upon establishing this, the concept of viscosity is introduced. For practical purposes, viscosity was introduced as how “sticky” a fluid is. Introducing balloons (about the size of a baseball) filled with chocolate syrup and water allows students to “feel” the difference in viscosity. By shaking each balloon students will observe that the water balloon “swishes” and moves more freely, while the chocolate syrup balloon does not. By explaining that the more viscous a fluid it the harder it is to flow or deform students can get a feel for the difference in viscosities between the two fluids. Students are then asked to speculate how viscous blood is in comparison to water and chocolate syrup. It is important for students to understand that blood in more viscous than water since it carries cells and nutrients, but less viscous then chocolate syrup since it must flow rather quickly to sustain life.

To help students understand how a fluid flows, the concept of pressure is introduced. Although the students’ textbook[10] contains a brief discussion on pressure and how to compute it, students can once again “see” pressure and forces at work by experimenting with the fluid filled balloons. A salient point in this lecture is for students to realize that a fluid can only flow from an area of higher pressure to an area of lower pressure. At this point, students may also be introduced to two different types of flow: laminar and turbulent. A good analogy for students is that “turbulence” on an airplane is an example of turbulent airflow, hence it is choppy. While laminar flow is smooth.

From a hemodynamic standpoint, students may be encouraged to guess properties of blood. As blood flows from the aorta to the capillaries, there is a pressure drop[11], due to the change in cross sectional area. Although most blood flow is laminar, the aorta is the only place in the body where flow is turbulent[12]. Figure 2.1 serves as a “cartoon” representation of blood flow through the body. Students can be asked to identify which point, from two selected points, has higher pressure (e.g. the arterioles or capillaries). As a closing, various disorders such as Atherosclerosis and hypertension can be briefly discussed.

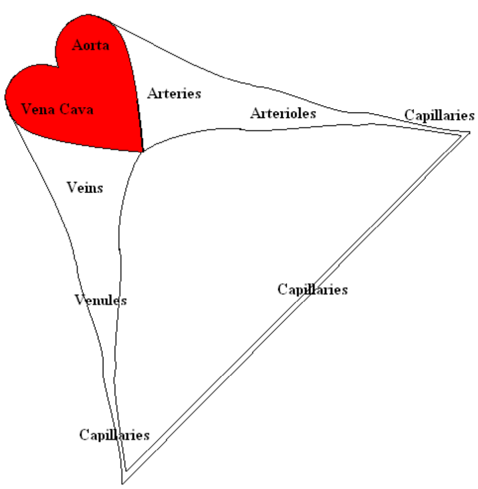


FIGURE 2.1: Cartoon Diagram of Blood Flow

Activities: As an extension of the balloon demonstration in lecture, several unknown fluids may be used to fill balloons to roughly the same size. Students are asked to work in teams to determine as many properties (liquid, gas, viscosity, density, etc) they can about the mystery fluids before a timer runs out. For a fun closing activity students can be given candy with viscous fluids inside such as caramel.

Unit Goals: Students should be able to identify fluids and relative viscosities. Students should know that all fluid flows from higher to lower pressure, and that flow can be either laminar or turbulent. Students should be able to relate these concepts to blood flow as well as other flow systems and be able to identify points to high pressure, low pressure and whether flow is laminar or turbulent. Students should be familiar with the path of blood flow in body and how blockages and certain conditions require the heart to work harder to drive blood flow.

MODULE 3: Velocity and Acceleration

Since force and acceleration are already integrated into the current curriculum for this model, this module may be adapted to best fit each class. For most students, this is their first introduction to these concepts. Accordingly, the emphasis for this module lies in tying each concept to some concrete hands-on observation. As a result, the bulk of this module is centered around activities rather than the lecture.

It is important for students to begin with a basic understanding of motion and the quantities of time and distance. Next, velocity and acceleration are introduced as quantities arrived by multiplying or dividing some combination of mass and changes in time and distance. Students may get a better understanding of the relationships between these quantities by observing a Time-Distance diagram as shown in Figure 3.1.

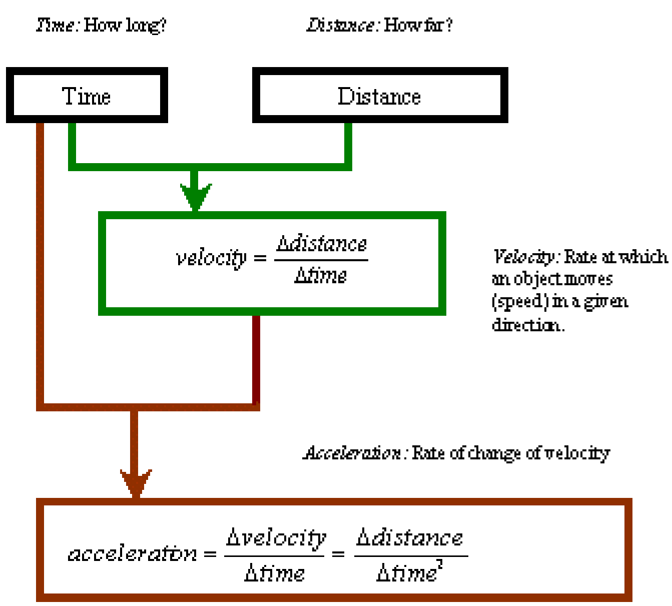


FIGURE 3.1: A Time-Distance Diagram relating Velocity, Acceleration.

As the diagram is discussed, relations are established by using the definitions[16] while discussing everyday relationships, such are riding in a car, roller-skating, or running. Also additional kinematic equations may be introduced depending on the class. Beginning the lesson by introducing velocity as a rate of change of distance per time. Next, it is effective to show that this rate can be applied and compared to running velocities of various animals. Figure 3.2 may be passed out at the beginning of the lecture. It is also important to distinguish between speed and velocity before moving on to acceleration.

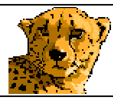
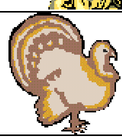
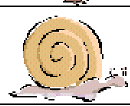
	Animal	Miles per Hour
	Cheetah	70
	Ostrich	43
	Elephant	25
	*Tyrannosaurus Rex*	<25
	Wild turkey	15
	Snail	0.03

FIGURE 3.2: Animal Running Velocity Chart[8,17]

The concept of acceleration can be explained as the time it takes to “speed-up” or “slow down”. Next, providing numbers and guiding students through a series of calculations develops a four-step approach16 to problem solving.

1. **Determine the “Big Picture”:** Is the object moving? If so, how? Is it changing direction, speeding up, slowing down, accelerating, or decelerating?

2. **Determine what equations are needed:** Write down all relevant equations.

3. **Determine what has been given:** Which quantities have been given? Substitute them into the equation(s).

4. **Solve for what is unknown:** Perform the necessary calculations using the given values and the equations selected to arrive at desired quantity.

Activities: A handout with a distance-time plot and the corresponding velocity-time plot is provided. Students work in partners to answer questions and perform calculations about the motion of the object.

Experiment-Students can get an opportunity to measure their own running velocity and acceleration by running set distances. For measuring velocity, students run a set distance of 100m and measure the time required to do so with stopwatches. For acceleration, students run a very short distance of 5m while times. Later, students can be given conversion factor to see how their velocities compare to the animal velocity charts. Students can also to compute the acceleration of various animals on the chart for the given distance assuming the animal starts at rest and final velocity is the running velocity provided on the chart.

Project—As a weeklong project, students will work in groups of three or four to create and race mousetrap cars (Figure 3.3). Sensors may be used to calculate velocities.

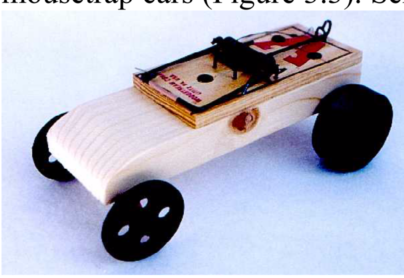


FIGURE 3.3: A Funtrap® Mousetrap Car[18]

Unit Goals: Students should be able to accurately define time, distance, velocity, and acceleration mathematically as well and qualitatively. Students should be able to perform basic computations using the four-step process.

OUTCOMES

As two of the four modules will be implemented in the late winter and spring, and Module 2 is currently in progress, results are available for Module 1 only. Moreover, since this integrative curriculum is in its early experimental stages, future impact has yet to be determined.

Based on the unit goals for Module 1, seven quiz questions were developed and inserted as part of a unit test on the skin and bones. The questions were as follows:

1. Heat Travels from
    a. Cold to cold
    b. Hot to cold
    c. Hot to hot
    d. Cold to hot

2. Which of the following is NOT a mode of heat transfer?
    a. Conduction
    b. Convection
    c. Connection
    d. Radiation

3. Which of the following is NOT a response that your body would perform on a hot August afternoon?
    a. Sweat
    b. Vasodilate
    c. Radiate
    d. Piloerection

4. If I place my finger in hot water and then place it in room temperature water, heat will flow…
    a. From the room temperature water to my finger
    b. From my finger to the room temperature water

5. Heat Transfer due to "invisible" waves of heat energy is Radiation.

6. What is the GOAL of thermoregulation? Maintain core temperature.

7. How does the skin help regulate body temperature when you have been exercising and feel hot? Helps you lose heat, e.g. sweating, radiating, etc.

Figures 5.1 and 5.2 show the percent of students that answered the seven questions correctly.

Question	S1 (22 students)	S2 (15)	Total (37)
1	18 82%	12 80%	30 81%
2	18 82%	13 87%	31 84%
3	18 82%	11 73%	29 78%
4	15 68%	9 60%	24 65%
5	14 64%	5 33%	19 51%
6	16 73%	9 60%	25 68%
7	18 82%	12 80%	30 81%

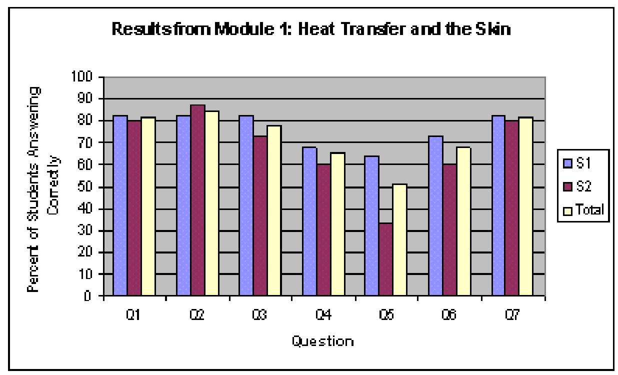


FIGURE 5.1: Number and % of Students Answering Questions Correctly

Based on the results, students appear to be able to understand the majority of the concepts discussed in Module 1. Both classes appear to perform about the same despite their ability levels determined by the school. However Question 5 on radiation yielded a rather low percentage of correct answers from both sections but particularly S2. Perhaps this is due to the nature of radiation itself, most of the other concepts, could be illustrated within the classroom in ways that the students could "see" it. Radiation however was more abstract, and therefore possibly more difficult for students to grasp.

Upon completion of the first module, students responded with a positive outlook on the possibility of other modules. The structure of the lecture and activity appears to hold the students interest. While most students appear to have an increased interest in engineering, S1 students are showing the most enthusiasm towards lessons and activities. S2 students, appear to enjoy the lessons only after one outspoken student displays interest. While this behavior is typical of students in the select age group, both classes are demonstrating a similar level of understanding of the material thus far.

For module two, students were given a crossword puzzle where the clues were given to words within a word bank. Sixteen students from section one and eight students from section two completed and returned the crossword. All twenty-four students were able to complete the crossword correctly.

1. A condition where fatty deposits clog up arteries making it difficult for blood to flow. Atherosclerosis
2. Another name for having high blood pressure. Hypertension
3. The fluid in the body that is pumped by the heart. Blood
4. A substance that deforms easily; a liquid or gas. Fluid
5. Force per unit Area; drives blood flow!!! Pressure
6. Flow that is choppy. Turbulent Flow
7. Connected to the Vena Cava of the heart; carries waste rich blood. Veins
8. When arteries become smaller. Arterioconstriction
9. Describes how sticky a fluid is. Viscosity
10. Flow that is smooth. Laminar Flow
11. Connected to the Aorta of the heart; carries fresh blood. Arteries

While the distribution of a formal quiz was omitted due to time constraints, results from module three are still pending as the module has not been introduced to the classroom yet.

CONCLUSION

This paper has outlined an integrative model curriculum that incorporates basic fundamentals of mechanical engineering into the Standard Course of Study for students at Rogers-Herr Middle School in North Carolina. This model attempts to take topics already present in the science curriculum and extend them to show students the ways in which engineering affects their daily lives through four modules each with hands-on activities and projects. Innovation and critical thinking is encouraged as well as teamwork, experimental and problem-solving skills. The challenge lies in seamlessly integrating the modules with little or no disruption to the current course of study and time frames. Although the model is currently in progress, results and feedback based on quizzes and participation indicate a strong proclivity towards the success of this model and curriculum development.

REFRENCES

[1] Klenk, P., Barcus, K., Ybarra, G.A., "Techtronics: Hands-on Exploration of Technology in Everyday Life". *Proceedings of the 32nd ASEE/IEEE Frontiers in Education Conference, November 6-9, 2002, Boston, MA.*

[2] Kimmel, H., Cano, R., "K-12 and Beyond: The Extended Engineering Pipeline". *Proceedings of the 31st ASEE/IEEE Frontiers in Education Conference, October 10-13, 2001, Reno, NV..*

[3] Kimmel, H., Rockland, R., "Incorporation of Pre-Engineering Lessons into Secondary Science Classrooms". *Proceedings of the 32nd ASEE/IEEE Frontiers in Education Conference, November 6-9, 2002, Boston, MA.*

[4] North Carolina Standard Course of Study, North Carolina Department of Public Instruction publication, 2001

Online: http://www.ncpublicschools.org/curriculum/

[5] Erwin, B., "K-12 Education and Systems Engineering: A New Perspective." Tufts University Center for Engineering Educational Outreach. Session 1280

[6] Hedge, A., "Thermal Sensation and Thermoregulation. Class Notes DEA 350- Human Factors: Ambient Environment. Cornell University 2002

[7] Incropera, F.P., DeWitt, D.P., *Fundamentals of Heat and Mass Transfer*. 5th ed. John Wiley & Sons:New York. 2002.

[8] Clip art for Figures 1.1 and 3.2 from Microsoft® Clip Art Files for Windows XP 2002.

[9] Munson et al. *Fundamentals of Fluid Mechanics*. John Wiley & Sons:New York. 1999.

[10] Biggs et. al.., *Science Voyages:Exploring the Life, Earth and Physical Sciences*. Glencoe:New York. North Carolina Edition 2000.

[11] Koehler, K.R. , *The Human Cardiovascular System*. Physics Online Hypertextbook. University of Cincinnati. 1996.
Online: http://www.rwc.uc.edu/koehler/biophys/3a.html

[12] Nave, C. R., *HyperPhysics Software*. Department of Physics and Astronomy. Georgia State University. 2002.
Online: http://hyperphysics.phy-astr.gsu.edu/hbase/hph.html#ahph

[13] Nova Online. *Cut to the Heart: Amazing Heart Facts.* PBS. 1997.
Online: http://www.pbs.org/wgbh/nova/eheart/facts.html

[14] ECHO in Profile. *Forward Blood Flow Profiles: Ejection Rate Indices and Ventricular Function*. Duke University Medical Center. 2000.
Online: http://www.echoincontext.com/doppler03/doppler03_03.asp

[15] Lyons MF, Cadden SW, Baxendale RH, Yemm R. *Twitch interpolation in the assessment of the maximum force-generating capacity of the jaw-closing muscles in man.* Archives of Oral Biology 1996 Dec. pgs 1161-1168.
Online: http://www.gla.ac.uk/schools/dental/research/oralbiology/abstracts/21.html

[16] Maton, A., et al. *Motion, Forces, and Energy*. Prentice Hall: New Jersey. 1997. (all figure definitions)

[17] The World Almanac for Kids Online. 2001-2003.
Online: http://www.worldalmanacforkids.com/explore/animals2.html

[18] Photo from Funtraps.
Online: http://www.funtraps.com/web01/page_common/book_tbimc.asp

MAUSUMI SYAMAL is an undergraduate teaching fellow at Rogers Herr Middle School in Durham, NC where she teaches mechanical engineering concepts. She develops and teaches computer programming labs for first-year engineering students at Duke University and has been teaching gymnastics for over 8 years. She will receive her bachelor of science in mechanical engineering degree in May 2003 and plans to pursue her Masters in Mechanical Engineering at the University of Michigan.

GARY A. YBARRA, Ph.D. is an Associate Professor and Director of Undergraduate Studies in the Department of Electrical and Computer Engineering at Duke University. He is the Principal Investigator for the MUSCLE program and has been leading K-12 Engineering outreach programs since 1988. He received a Ph.D. in Electrical and Computer Engineering from North Carolina State University in 1992 and has been on the ECE faculty at Duke University since 1993.