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The Experiential Engineering Library*

JOHN E. SPEICH, JAMES T. MCLESKEY, JR., JUDY S. RICHARDSON and MOHAMED GAD-EL-HAK
Virginia Commonwealth University, Richmond, VA 23284, USA. E-mail: jespeich@vcu.edu

Virginia Commonwealth University is developing an NSF-sponsored 'Experiential Engineering Library' that will provide an easily accessible environment for hands-on engineering learning experiences beyond the traditional mechanical engineering curriculum. The library will foster critical thinking by encouraging students to apply fundamental mechanical engineering principles to emerging interdisciplinary research in fields including microelectromechanical systems (MEMS), bioengineering, and nanotechnology. The present article describes the library concept, elaborates on its contents and provides some preliminary findings.

INTRODUCTION

IN PREPARATION FOR solving twenty-first century problems, today's engineering students need twenty-first century examples. These students also express a need for hands-on activities to help them understand the theories they learn in class. Satisfying both these needs within the typical mechanical engineering curriculum is becoming an increasingly greater challenge. In order to meet this challenge, the VCU Mechanical Engineering Department is developing a novel 'Experiential Engineering Library' with three broad objectives. First, the library will provide an easily accessible and readily available environment for hands-on engineering learning experiences beyond the traditional mechanical engineering curriculum. It will foster critical thinking by encouraging students to apply fundamental mechanical engineering principles to emerging interdisciplinary fields including microelectro-mechanical systems (MEMS), bioengineering, and nanotechnology. Finally, it will encourage collaborative team-based learning among peers as well as mentoring by more senior undergraduates, graduate students, and faculty.

The experiential library is envisaged to be analogous to a traditional library. It will ultimately contain a large number of experiments and computer simulations either 'on reserve' or available to be 'checked out' by the students. At the instructor's discretion, hands-on problems will be assigned as a complement to or in lieu of paper-and-pencil homework. The equipment can also be used independently by students seeking to improve their understanding through manipulation and visualization. Additional activities will provide enrichment opportunities for both undergraduate and visiting secondary-school students. The flexibility and integration of the experiments in the library make it superior to laboratories used in traditional engineering courses.

The library collections will allow students to study problems of interest in emerging fields that come from a number of sources, including: faculty research, senior capstone design course projects, commercially developed educational tools, and donations from industrial partners. Our faculty includes experts in smart materials and nanomaterials, surgical and rehabilitation robotics, traditional and alternative power generation, acoustics and vibration, flow control and MEMS. These experts will provide examples from their research that excite the students while teaching fundamental principles. For example, students can build nanotechnology-based solar cells from simple materials or measure their grip strength using a robotic device for hand rehabilitation therapy. In the past, senior design course students have built an adaptive video game controller for children with disabilities, a hang glider simulator complete with support sling, and a fully functional, continuously variable transmission. Teams of students will be encouraged to develop projects for the library that demonstrate important engineering concepts.

Utilizing support from the U.S. National Science Foundation, the library is being initiated on a small scale first. During the first year, the project has five specific aims:

1. To develop a collection of hands-on experiments that demonstrate fundamental principles to be piloted in three core mechanical engineering courses (Thermodynamics; Mechanics of Deformables; and Dynamics) and one technical elective (Energy Conversion Systems).
2. To initiate the library by locating the experiments in a central setting readily accessible to all students.
3. To incorporate the experiments into four courses through both mandatory homework assignments and voluntary extracurricular learning activities.

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4. To measure the impact of the library on student interest, performance, and retention.
5. To hold a workshop with all mechanical engineering faculty to formulate a plan to fully develop the library and integrate other courses in subsequent years.

The hands-on experiential learning laboratory will enable students to reinforce their understanding through manipulating and simulating the theoretical and conceptual content of their lecture courses. Incorporating experiments from faculty research and student senior design projects will serve to expand and promote a more holistic curriculum that encourages comprehension. This article presents motivation for including more hands-on learning experiences in the mechanical engineering curriculum, it describes the library concept, elaborates on its contents, and presents some initial findings.

BACKGROUND

As part of its 2003–2004 evaluation criteria, the Accreditation Board for Engineering and Technology (ABET) has defined a set of 11 characteristics that an engineering graduate must possess [1]:

(a) An ability to apply knowledge of mathematics, science, and engineering.
(b) An ability to design and conduct experiments, as well as to analyze and interpret data.
(c) An ability to design a system, component, or process to meet desired needs.
(d) An ability to function on multidisciplinary teams.
(e) An ability to identify, formulate and solve engineering problems.
(f) An understanding of professional and ethical responsibility.
(g) An ability to communicate effectively.
(h) The broad education necessary to understand the impact of engineering solutions in global and societal contexts.
(i) A recognition of the need for, and ability to engage in, lifelong learning.
(j) A knowledge of contemporary issues.
(k) An ability to use the techniques, skills, and modern engineering tools necessary for engineering practice.

These criteria can be met in any number of ways, but laboratory and hands-on activities are a key component.

Across the country, a number of programs have been developed with the intention of increasing hands-on learning and improving engineering education, particularly at the freshman level. For example, Pennsylvania State University offers an Introduction to Engineering Design course for freshmen that involves prototype building and testing [2]. The University of Washington offers an elective freshman-level design course as part of the Engineering Coalition of Schools for Excellence in Education and Leadership (ECSEL) [3]. The objectives of the course are to teach design and teamwork early in the curriculum and increase retention by helping students envisage their role in the engineering profession early in their college education. Projects in the course include building structures using spaghetti and tape and disassembling and reassembling lawnmower engines.

The ECSEL coalition was formed to address two primary goals: (1) transforming undergraduate engineering curricula, and (2) increasing the diversity of engineering graduates. It includes Howard University, City College of New York (CCNY), Massachusetts Institute of Technology (MIT), Morgan State University, Penn State University, and the University of Maryland [3]. This program has led to the incorporation of more hands-on activities into a number of courses. The University of Washington also has its own Center for Engineering Learning and Teaching (CELT), which has evolved into the Center for the Advancement of Engineering Education (CAEE) in partnership with the Colorado School of Mines, Howard University, Stanford University and the University of Minnesota [4]. This center is trying to improve engineering education by understanding 'how engineering students think and learn'. The University of Notre Dame has developed the Engineering Learning Center with the mission of fostering hands-on, multidisciplinary activities for students at all levels. The Learning Center is also used 'as a testbed for developing innovative teaching and learning methods' [5]. The chair of the VCU Mechanical Engineering Program, Mohamed Gad-el-Hak, contributed to the Engineering Learning Center while serving on the faculty at Notre Dame.

One of the largest efforts of this type began in 1991 when the College of Engineering at the University of Colorado at Boulder started a college-wide curriculum reform effort with an emphasis on active, team-based learning [6]. This led to the opening of a $17m, 34,000 sqare foot Integrated Teaching and Learning (ITL) laboratory in 1997. The lab features design studios for both freshman and senior projects, several group study rooms, a gallery for interactive art/engineering exhibits, two laboratory plazas, an active learning center for course instruction, a manufacturing center with machine tools and rapid prototyping equipment, an electronics project center, and a computer simulation laboratory.

The ITL lab has several curriculum components including a freshmen design course, hands-on homework components for many theory courses, and an interdisciplinary senior design course. The First-Year Engineering Projects Course has been highly successful. Retention statistics show a 19% seventh-semester retention gain among students who took the Projects course as compared to those who did not [7]. Another recent study found that the students believed that they had developed significant skills as a result of participating in the First-Year Engineering Projects Course [8].

Experimental laboratory modules are one of the key features of the ITL lab [6]. These modules enhance traditional theory courses that cannot accommodate a traditional laboratory component. The modules are designed to be standalone, portable, sequence-independent, suitable for open-ended experimentation, and require minimal supervision. More than 85 modules are in various stages of development, including 30 in the area of mechanical engineering [9]. Modules include electric motor comparison, static force balance, series and parallel pumps, viscosity of fluids, modular heat exchanger, and musical signal analysis labs. These lab modules can be used for in-class demonstrations, scheduled laboratories, and/or homework assignments.

ENGINEERING AT VCU

As in many of the other programs described above, the School of Engineering at Virginia Commonwealth University also provides hands-on learning experiences for freshmen. The mechanical engineering curriculum at VCU includes an Introduction to Engineering course that is taken by all freshmen in the School of Engineering. This course is based on the Introduction to Electrical and Computer Engineering course at Carnegie Mellon University [10]. The course is centered around the assembly and testing of a small programmable robot (Graymark 603A), which gives the students practical experience.

While many schools recognize and fulfill the need for hands-on activities at the freshman level, the level of hands-on activity often decreases during the sophomore and junior years while students study core material. There is often a significant gap between the freshman experience and additional hands-on experience in junior and senior level laboratory courses. For example, the mechanical engineering curriculum at VCU provides nine lab hours during the freshman year and 15 during the senior year, while providing only three lab hours during each of the sophomore and junior years, as is clearly shown in Table 1.

The mechanical engineering curriculum at VCU has seven 'core' courses that are taken during the sophomore and junior years. These seven courses are required for a minor in mechanical engineering. Only two of these courses have specific laboratory components, Fluid Mechanics and Heat Transfer, and this laboratory content is minimal. The other five core courses, Engineering Statics, Dynamics and Kinematics, Mechanics of Deformables, Mechanical Systems Design, and Thermodynamics, do not have specific laboratory components, although some instructors include a few hands-on activities. In the area of mechanical systems, students take a series of five courses (Engineering Statics, Dynamics and Kinematics, Mechanics of Deformables, Material Science for Engineers, and Mechanical Systems Design) before they receive significant hands-on experience in the Engineering Synthesis Laboratory course. The experiential engineering library will help bridge the gap between freshman activities and junior and senior laboratories by providing students with opportunities to gain hands-on experience and provide instructors with a collection of practical experiments for in-class demonstrations and homework assignments.

While building on the accomplishments of the other universities, the VCU library will have a particular focus on giving students knowledge of contemporary issues and experience with modern engineering techniques. In this way, the library will make significant contributions in the development of the ABET characteristics, especially (a), (b), (e), (j) and (k). Helping students develop these characteristics while meeting their desire for hands-on

Table 1. Lab content in engineering courses in the VCU mechanical engineering curriculum

Year	Lab Hours	Engineering Courses With Labs	Engineering Courses Without Labs
Freshman	9	ENGR 101 Introduction to Engineering (3) ENGR 115 Computer Methods in Engineering (3) ENGR 215 Engineering Visualization (3)	
Sophomore	3	EGRE 206 Electric Circuits (3)	ENGR 102 Engineering Statics EGRM 201 Dynamics and Kinematics EGRM 202 Mechanics of Deformables EGRM 204 Thermodynamics
Junior	3	ENGR 301 Fluid Mechanics (1) ENGR 302 Heat Transfer (1) ENGR 305 Sensors/Measurements (1)	EGRM 300 Mechanical Systems Design EGRM 309 Material Science for Engineers EGRM 303 Thermal Systems Design EGRM 420 CAE Design ENGR 315 Process and Systems Dynamics EGRM 421 CAE Analysis
Senior	15	EGRM 410 Engineering Synthesis Laboratory (3) ENGR 402 Senior Design Studio I (6) ENGR 403 Senior Design Studio II (6)	ENGR 410 Review of Internship

activities through twenty-first century examples has inspired the development of the Experiential Engineering Library at VCU.

THE EXPERIENTIAL ENGINEERING LIBRARY

Many of the examples currently used in engineering curricula seem better suited to the 'Greatest Generation' than to the students in school today. While some of these examples are still educationally sound, twenty-first century students need twenty-first century examples. Our experiments are intended to promote learning through guided inquiry. There is a constant battle in educational circles between traditional explicit instruction, where students are told what they need to know and are then expected to know it, and discovery learning, where students are given a few parameters and then are given the chance to 'play' and figure out the way things work. The former seems more efficient and most engineering faculty seem more comfortable with this method. It is relatively easy to grade objectively (right or wrong) and is well-suited for preparing students for standardized tests. The latter reflects constructivist learning theory [11, 12], which has been shown to engage learners more effectively than traditional lecture instruction. Components of a constructivist environment include: shared knowledge; authentic, real-world tasks; scaffolding; cognitive apprenticeship; learner control; and non-linear instruction [13]. It therefore encourages collaborative learning and team-building. The aim of the library is for the students to perform guided experiments and discover the answers to their questions.

The library collection will be taken from faculty research, senior capstone design course projects, commercially developed educational tools, and donations from industrial partners. The mechanical engineering faculty at VCU are conducting cutting-edge research in fields such as smart materials and nanomaterials, surgical and rehabilitation robotics, photovoltaics, acoustics and vibration, flow control and MEMS. These areas are not only of interest to the national and international scientific communities, they also spark interest among students. Examples from this research will be incorporated into experiments that can be performed by students in the library.

All undergraduates in mechanical engineering at VCU must complete a senior design project in teams of two to four students. These projects provide an excellent source of experiments for the library. The topics covered in the core courses and the associated areas of difficulty are fresh in the minds of these seniors and they have unique insights into ways of presenting the material to enhance understanding. This effort can lead to mentoring by upper-classmen and collaboration between upper- and under-classmen. It also provides a sort of teacher training for preparing the faculty of tomorrow.

Every engineering student at VCU is required to complete a summer internship before graduating and the VCU School of Engineering has developed strong relationships with many local businesses. These industrial partners can provide assistance to the library in the form of both state-of-the-art equipment and mentoring by experts working in the field. This will further strengthen the library's relevance to modern engineering issues.

In order for the library to be used by the students, it must be in a convenient location and open for a sufficient number of hours. At this stage, the library is being located in two laboratories belonging to the principle investigators. These laboratories are both located in the School of Engineering building at VCU where nearly all of the engineering classes are taught. The library will be kept open approximately 20 hours per week by undergraduate librarians. These librarians will be trained to monitor and maintain the experiments and assist students that visit the library. Specific instructions will be included with each experiment and also posted on the web. These instructions will be written in a way that will encourage self-guided learning.

The courses earmarked for inclusion in the first stage of the library development are Thermodynamics, Mechanics of Deformables, Dynamics, and Energy Conversion Systems. The experiments will be incorporated into these courses in a number of ways. While traditional in-class demonstrations can be instructive, the intention of the library is to involve the students more directly. Instead of restricting activities to pencil-and-paper homework, assignments will be made that require use of the library. Certainly traditional homework problems will continue to be assigned, but some of these will be replaced or supplemented with experiments in the library.

Another area where the library will be useful is in the development of 'reserve' materials. Much like the reserve reading materials that are often included on a syllabus, these extracurricular assignments would give all students a way to enhance their understanding, especially those whose learning styles include kinesthetic and manipulation techniques. We recognize that the traditional reserve readings are under-utilized. It is our hope and belief that hands-on experiments designed around state-of-the-art research (solar cells, robots, MEMS, smart materials, etc.) will stimulate more interaction and interest in learning among students.

Other types of assignments may be developed as well. Team projects can be developed for both users and suppliers of the library. For users, theoretical calculations done in class can be checked in the lab. Criteria can be added to senior design requirements that encourage the design teams to design projects that can be used in the library following completion.

The experiential library will be comparable to a traditional library, in that it will contain materials either 'on reserve' or available to be 'checked out' by the students. Of course, the collection will be comprised of experiments and computer simulations rather than books. As an initial step in creating the library, a set of experiments is being collected.

THE LIBRARY COLLECTION

Examples of some specific experiments currently being developed for the library include force sensing in robotic surgery using smart materials, the dynamics of rehabilitation robots, and the thermodynamics of nano-crystalline solar cells. These experiments are described in detail in this section.

Experiment # 1: Using Force-Sensing Surgical Instruments to Illustrate Fundamental Principles in the Mechanics of Deformables Course

Background

A surgeon's ability to control the forces he or she is applying to a patient during a surgical procedure is critical to the success of any surgery. Research is currently being conducted at VCU to develop force sensors that will enable direct measurement of the instrument tip forces during minimally invasive surgery. Feedback from these instruments will reduce the number of errors during surgical procedures and allow quantitative assessment of surgical skills during both conventional and robot-assisted surgery. These surgical instruments can also be used to demonstrate several basic engineering mechanics concepts taught in Mechanics of Deformables courses.

State-of-the-art smart materials are being used to develop the force-sensing surgical tools. Preliminary experiments were conducted to test the feasibility of using PZT material as a sensor on a laparoscopic surgical grasping tool. A PZT layer was cut to the size of the gripping surface and taped on one side of the gripper as shown in Fig. 1. In addition, a strip of PZT material embedded in a strip of stainless steel was taped onto the tool's handle as shown in Fig. 1. Both sensors were then connected directly to an oscilloscope that could capture the voltage response signal when triggered by a change in the signal. The surgical instrument was used to push on a piece of synthetic tissue that was used to simulate human tissue. The responses from the PZT materials are shown in Fig. 2. No special filtration circuitry is used on these measurements, so the signals are noisy. Nevertheless, a clear signal response was captured from both pieces of PZT. The applied force was also measured using an ATI Nano17 force sensor (ATI Industrial Automation, Inc.) placed under a piece of synthetic tissue. The force magnitude is also shown in Fig. 2. Notice that the responses of both pieces of PZT clearly correlate with the magnitude of the applied force. In additional experiments, different levels of force were applied to the tissue using the surgical tool and the responses of both pieces of PZT material were related to the magnitude of the applied force in approximately linear relationships. These simple experiments show the feasibility of using PZT as a force sensor for surgical instruments.

Fundamental principles demonstrated

Several fundamental concepts taught in Mechanics of Deformables courses can be illustrated using the feasibility experiments for the force-sensing surgical instruments described above. The shaft of the laparoscopic grasping instrument is essentially a long slender hollow cylinder, which is a geometric shape commonly used in examples in the course. The instrument can be used to demonstrate several different loading conditions discussed in the course. Pushing or pulling axially on the instrument creates an axial load, twisting the instrument creates a torsional load, and pushing laterally on the instrument creates a bending load. Combined loadings, such as combined axial and torsional loading, can also be demonstrated. The strain in the material caused by these loading conditions varies with the type, magnitude, and point of application of the load. The strain also varies with position throughout the instrument. The relationships between strain, location, and loading conditions can be illustrated by using smart materials to measure the strain (or generate a voltage proportional to the strain) at selected locations on the instrument.

Student activities for the experiential engineering library

A 'Force Sensing Surgical Instrument Experiment' is being created for the Experiential

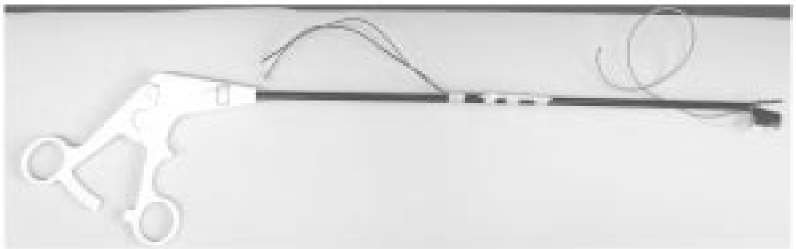

Fig. 1. A surgical grasping instrument with PZT sensors attached to the shaft and grippers.

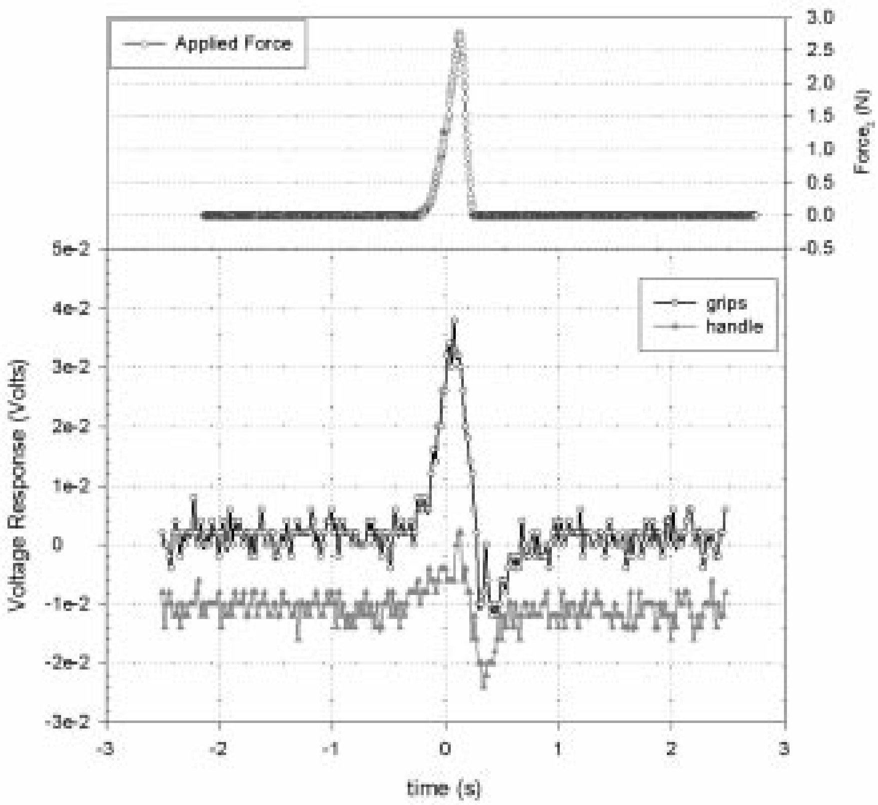

Fig. 2. Voltage responses for PZT sensors on the handle and grippers of a surgical instrument when a force is applied to the instrument tip.

Engineering Library. The experiment will include several surgical instruments with PZT strain sensors placed at a couple of different locations on each instrument. The data acquisition equipment will consist of an oscilloscope and computer for collecting data from the smart material sensors, and an ATI multi-axis force/torque sensor for measuring the external loading conditions.

Students will use surgical instruments to apply forces to the force/torque sensor while collecting strain data from the smart material sensors. They will apply fundamental concepts being learned in the Mechanics of Deformables course to examine the relationships between the strain magnitude, strain location, load type, load magnitude and load location. This information will be used to calibrate the instruments. Once calibrated, the students will be able to use the instruments to perform suturing tasks on samples of synthetic skin and compare measurements from the smart material sensors to measurements from the force/torque sensor as they record the forces applied to the skin.

These experiments will also be used as an in-class demonstration during the first week of the Mechanics of Deformables class to emphasize the importance and practicality of the concepts to be learned in the course. Homework assignments will be assigned to teams of students to perform specific activities with the experiments. In addition, students will have access to the experiments throughout the semester, so they can learn through independent activities.

Impacts on student learning

A typical demonstration in a Mechanics of Deformables class might include the use of conventional strain gages to measure the strain in an object without a specific application. In contrast, the proposed activities demonstrate fundamental principles using state-of-the-art smart materials in an interesting real-world biomedical application. These activities will be especially interesting for Biomedical Engineering students that are required to take this Mechanical Engineering course. These experiments will also encourage undergraduates to participate in research activities in this area.

Experiment # 2: Using a Rehabilitation Robot to Illustrate Fundamental Principles in the Dynamics and Kinematics Course

Introduction

A robotic device for delivering rehabilitation therapy to the hand and fingers is currently under development at VCU. This device can measure the position and orientation of the fingers in a plane perpendicular to the palm of the hand and control the forces acting on fingertips using a planar five-bar mechanism. The photographs in Fig. 3 show side and top views of this mechanism without the actuators. The photographs in Fig. 4

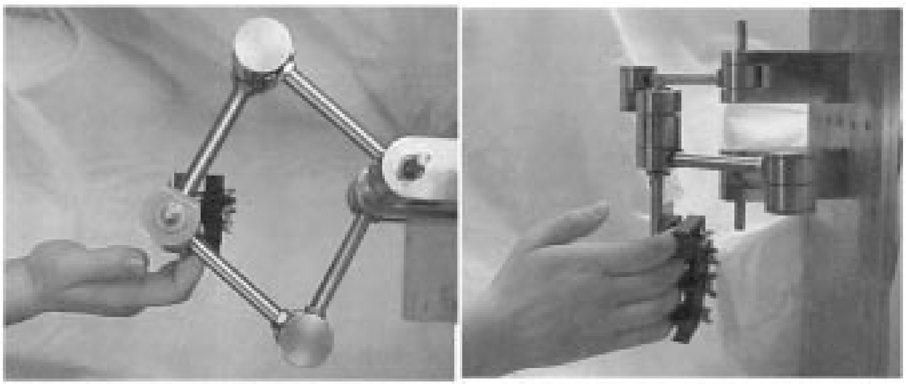

Fig. 3. A robotic device for delivering hand and finger rehabilitation therapy shown without the actuators.

demonstrate the range of motion of the prototype. In addition to delivering rehabilitation therapy and characterizing the function of the hand and fingers, this robotic device will serve as an excellent hands-on tool for teaching undergraduates the basic principles of kinematics and kinetics of mechanisms.

Fundamental principles demonstrated

Several fundamental concepts taught in Dynamics and Kinematics courses can be illustrated using the robotic rehabilitation device described above. The device consists of a five-bar linkage with two rotary motors that control the position of the fingertips in a plane perpendicular to the palm of the hand. The device is equipped with potentiometers to measure the rotary motion of the motors and force sensors to measure the interaction forces between the mechanism and the fingers. The forward kinematic relationships for the five-bar linkage are used to determine the position of the fingers when the orientations of the motors are known (i.e. when the motors turn, where do the fingertips move?). The inverse kinematic equations for the device are used to determine the orientation of the motors when the position of the fingertips is known (i.e. if the goal is to move the fingertips to a specific position, how much do the motors need to turn?). The relationship between the speed of the fingers and the speeds of the motors, as well as the dynamic relationship between the motor torques and the forces applied to the fingers, can also be demonstrated using this device.

Student activities

The rehabilitation robot is a unique and expensive piece of research equipment; therefore, a duplicate robot will not be fabricated for the Experiential Engineering Library. Instead, the robotic equipment located in the VCU Robotics Laboratory will be available ‘on reserve’ for students in the Dynamics and Kinematics course during the weeks when the topic of mechanism kinematics is being discussed. This will be easily coordinated, since John Speich is both the director of the VCU Robotics Laboratory and one of the instructors for the Dynamics and Kinematics course.

The ‘Rehabilitation Robot Dynamics and Kinematics Experiment’ will include a series of interactive activities using the robotic device. Students will be able use the robot to visualize the kinematics of the mechanism by moving the end-effector of the robot and observing the motion of the linkage and motors, or vice versa. The computer that controls the robot will be programmed to display both the angular positions of the motors and the corresponding location of the fingertips. The students will develop forward and inverse kinematic equations for the mechanism and compare the results obtained from these equations with the actual kinematics of the robot displayed by the computer. The students will also be able to study the relationship between the motor torques and the forces applied by the robot to the fingers. This will be achieved by programming the robot to simulate a virtual spring with which the student’s fingers can interact. As students push on the virtual spring, they will be able to see the magnitude of the force they are applying and corresponding motor torques displayed by the computer. These values can be recorded for comparison with values calculated by the student.

The rehabilitation robot will also be used for an in-class demonstration during the first week of the Dynamics and Kinematics class to emphasize the importance and practicality of the concepts to be learned in the course. Homework will be assigned to teams of students to perform specific activities with the experiments.

Impacts on student learning

A typical demonstration in a Dynamics and Kinematics class might include a simple mechanism similar to the prototype of the rehabilitation device shown in Fig. 4. This mechanism was made from a toy modeling kit and is not equipped with sensors or actuators. In contrast, the proposed activities demonstrate fundamental principles using an interesting, state-of-the-art rehabilitation robot equipped with actuators and both motion and force sensors. These activities will be especially interesting for Biomedical Engineering students

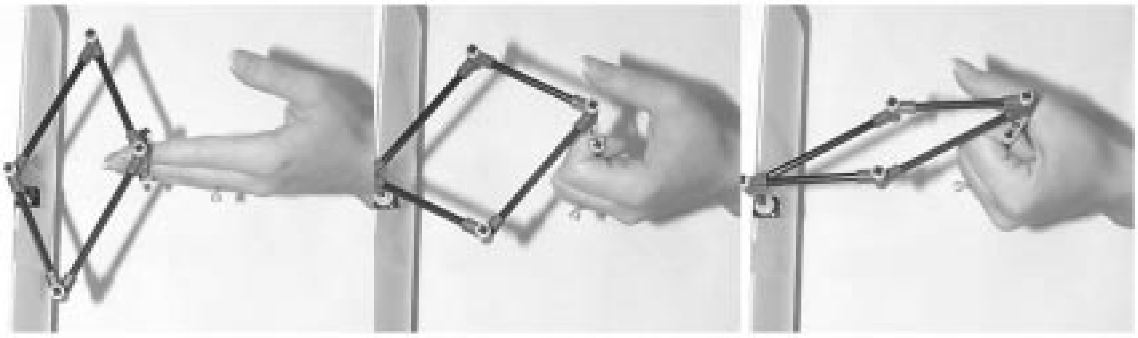

Fig. 4. Prototype of the hand rehabilitation robot demonstrating the range of motion of the five-bar mechanism.

that choose to enroll in this Mechanical Engineering course. These experiments will also encourage undergraduates to participate in research activities in this area.

Experiment # 3: Thermodynamics of Nano-crystalline Solar Cells

Background

The first and second laws of thermodynamics learned in an introductory course are often taught using examples first developed in the nineteenth century to help engineers design steam engines for locomotives. While these examples still bear relevance to the design of steam turbines and internal combustion engines, the engineers of the twenty-first century need experience in applying the laws of thermodynamics to twenty-first century technology. Photovoltaic cells are such a technology.

In recent years, numerous authors have applied the principles of thermodynamics to solar cells [14–19]. In general, the principles can be applied to solar cells made from any material (crystalline silicon, amorphous silicon, cadmium telluride, etc.). The nano-crystalline dye-sensitized titanium dioxide solar cell (or Graetzel cell) has the advantage that the student can construct the cell from common materials prior to performing the experiments.

Student activities and fundamental principles demonstrated

Using the Nano-crystalline Solar Cell Kit from the Institute for Chemical Education [20], students can build their own solar cells in a lab using simple materials, including titanium dioxide and blackberry juice. The resulting solar cells can then be tested for important values, including voltage and current (and thus power). For a known solar flux, the energy conversion efficiency of the solar cell can be calculated.

The nano-crystalline solar cell shown in Fig. 5 can be used to help teach the concepts covered in any number of mechanical engineering courses. The first and second laws of thermodynamics and energy conversion efficiency [14–18] can all be demonstrated for a course in Thermodynamics. Unique calorimetry measurements can be made to identify loss mechanisms in the solar cell [19] and thus teach the concepts of conductive and radiative Heat Transfer. For a course in Energy Conversion Systems, the relationship between different forms of energy can be demonstrated by storing the output from the cell in a capacitor and later using that energy to power a motor or an LED. The challenge of producing large quantities of energy at low cost can also be presented.

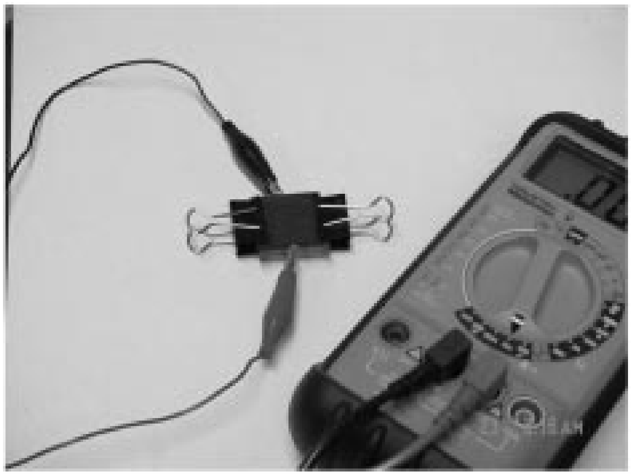

Fig. 5. Dye-sensitized nano-crystalline solar cell.

Impacts on student learning

The promise of 'free energy' offered by photovoltaic solar energy conversion is very enticing to students. This experiment offers them the opportunity to build a nano-crystalline solar cell while learning about the limits imposed by the first and second laws of thermodynamics. It also illustrates the interrelationships between the various disciplines of science and engineering and could be used in teaching Thermodynamics, Heat Transfer, and Energy Conversion Systems. This gives the students the opportunity to revisit the same experiment as they learn new concepts, thus helping to build continuity.

These three experiments will form the foundation for the library collection. Students will utilize the experiments in four separate courses and the impact of the library on student learning will be evaluated.

ASSESSMENT OF THE LIBRARY

Measuring the effectiveness of the library will be a challenge [21]. One important task during the initial development of the library will be identifying the best methods for assessing the impact of the library on student learning. Ways of measuring the influence of the library on student knowledge (cognitive thinking), thought processes (attitudinal thinking) and skills (behavioral thinking) will be explored during the full implementation phase. As a best first effort at evaluating the concept during the first year, a number of assessment techniques, both qualitative and quantitative, will be employed to measure success.

One critical qualitative measuring stick is student perceptions [21]. These perceptions can affect both subsequent learning as well as retention rates and will be measured using student self-assessments. Students will demonstrate their perceptions of learning by completing a pre and post self-assessment of important terms encountered during the module study. Students will also rate, before and after completion, their learning via modules according to objectives for learning to be gained from the module. Focus group interviews with students who experienced only the traditional lecture method and those who experienced the library will be conducted to gather qualitative expressions of satisfaction and perception of learning. A more quantitative measure of student interest in the hands-on activities will be measured by comparing the number of completed traditional homework assignments vs. the number of completed hands-on assignments to see if students are more or less likely to do the hands-on assignments.

The preliminary stage covers only four courses taught during consecutive semesters. This makes obtaining reliable statistics on the impact of the library on grades, standardized test scores and retention rates during one semester challenging. Some comparisons, however, can be made with students who have taken the class during a previous semester. An assignment will be identified that can be given in both the traditional classroom and with those who use the library; the assignments will be compared for difference in cognitive thinking, behavioral thinking, and attitudinal thinking. Students will create concept maps to demonstrate their learning; these maps will be compared. Grades on projects between the two groups of students will be compared. In addition, by monitoring library usage, it will be possible to compare the number of hours spent in the library against the semester grade and determine any correlation.

In the first year, monitoring long-term student retention rates is not possible. As the project moves into a full implementation stage, the retention rate of students in the mechanical engineering program can be analyzed to determine if student interest and persistence have been altered through implementation of the library.

The School of Engineering has teamed with the VCU School of Education for this program. Judy Richardson, a professor from the School of Education, is responsible for advising the Mechanical Engineering Program on methods of assessment and evaluation and assisting with the interpretation of results. She will also provide insight and historical perspective on the effectiveness of various teaching models.

PRELIMINARY RESULTS

The Experiential Engineering Library was first piloted in the curriculum during the fall 2003 semester in a senior technical elective course: Energy Conversion Systems. The results of the first module, in which the students built a simple Stirling engine, are presented below. This module was a homework assignment with no prior introduction in class. Although the experiment is available commercially in kit form, it nonetheless represents the state-of-the-art in Energy Conversion Systems and is the subject of ongoing research [22]. An evaluation of the impact of the module on student learning was conducted using pre and post self-assessments and the results of these self-tests are presented.

The Stirling engine module (see Fig. 6) was based on a model available in kit form from Fisher Scientific [23]. The model uses a test tube and marbles as the transfer cylinder and piston and a rubber stopper and balloon as the power cylinder and piston. All 19 students in the Energy Conversion Systems course completed the Stirling engine library module over the course of one week. Each student worked independently. The students were given a nine-question pre-test to assess their knowledge of Stirling engines. They were also asked to rate their existing knowledge of Stirling engines on a scale from one (no knowledge) to ten (expert). After completing the experiment, they were given a

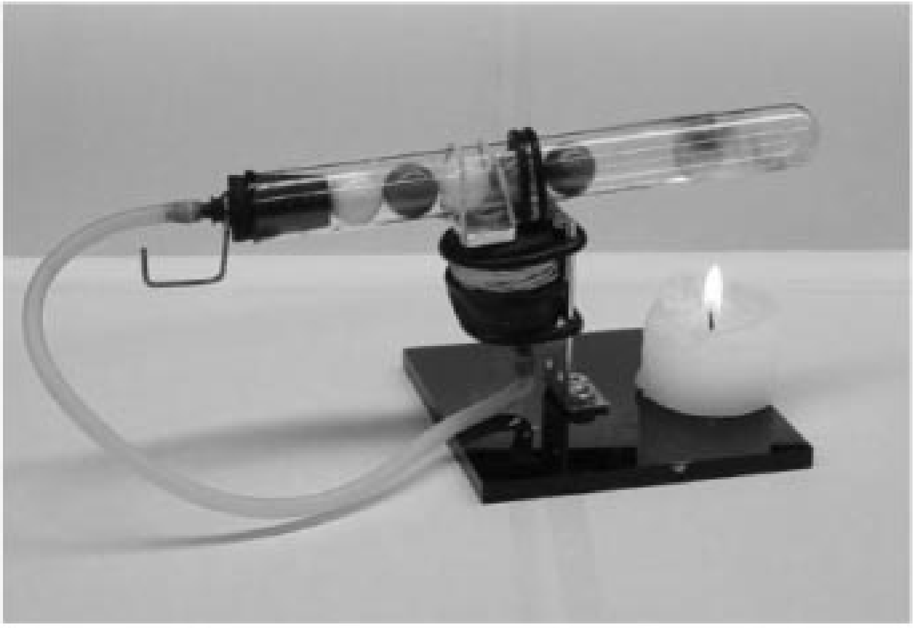

Fig. 6. Stirling engine model [23] used in the Experiential Engineering Library.

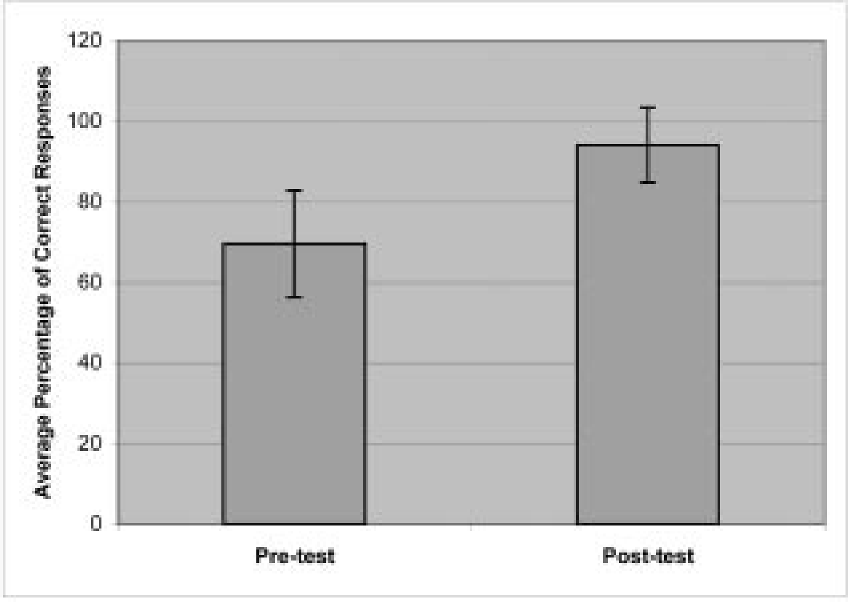

Fig. 7. Average percentage of correct responses for the Stirling engine pre-test and post-test. The error bars show ±1 standard deviation.

Table 2. Students' written comments about the Stirling engine module

Great interactive learning experience.
Lab helped me understand how the Stirling engine worked.
I am going to build one at home.
Cool lab. Stirling eng's are very interesting.
More detailed diagrams w/ instructions would help.
Fine-tuning the engine to work properly is difficult.
I kinda got it to work.
I have never seen a Stirling engine before and never thought that it was so simple.
Fun lab. Finiky engine.

post-test. The post-test included the same nine questions and self-rating. In addition, the students were asked whether the lab was helpful in increasing their knowledge of Stirling engines and whether or not the lab peaked their interest in Stirling engines. Finally, the students were given the opportunity to make written comments. The average percentage of correct responses was 69.6% on the pre-test and 94.1% on the post-test, with standard deviations of 13.3% and 9.3% respectively. The averages are presented graphically in Fig. 7 with error bars that show ±1 standard

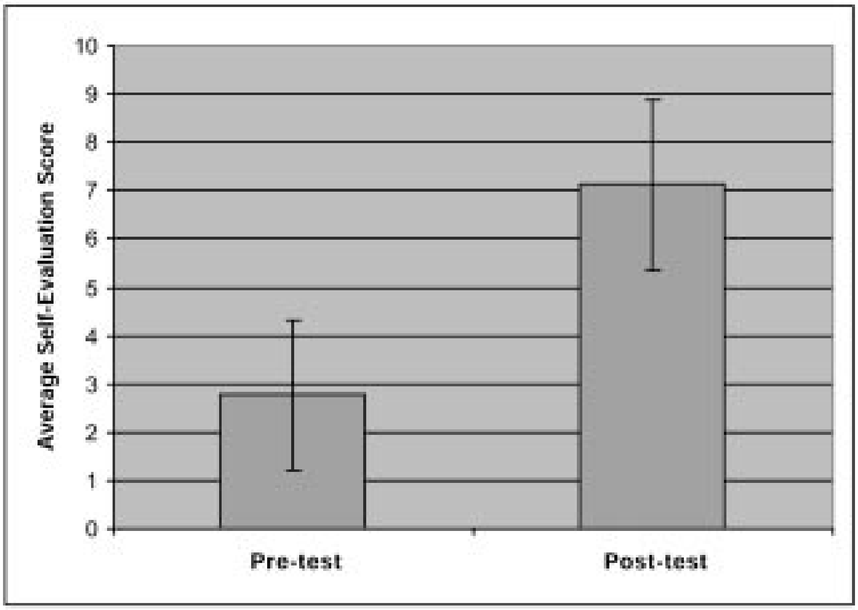

Fig. 8. Average self-evaluation scores in which students rated their knowledge of Stirling engines on a scale from one (no knowledge) to ten (expert) before and after completion of the Stirling engine library module. The error bars show ±1 standard deviation.

deviation. Clearly, reading the instructions and completing the module improved the students' abilities to answer the questions correctly.

As stated above, each student rated his/her existing knowledge of Stirling engines on a scale from one (no knowledge) to ten (expert) before and after completing the library module. The average rating was 2.8 on the pre-test and 7.1 on the post-test, with standard deviations of 1.6 and 1.8 respectively. The averages are presented graphically in Fig. 8 with error bars that show ±1 standard deviation. When asked whether or not the lab was helpful in increasing their understanding of Stirling engines, seventeen out of nineteen (89%) answered affirmatively. The students clearly believed that they had increased their expertise. It should be noted, however, that one of the two students who rated their knowledge as 10 on the self-evaluation did not answer 100% of the post-test questions correctly, but a student who rated his/her post-lab knowledge as two did answer 100% of the questions correctly. Students also found the lab enjoyable and intriguing. Fifteen out of nineteen (79%) said the lab peaked their interest in Stirling engines. This is also supported by the student comments listed in Table 2.

CONCLUSIONS

Virginia Commonwealth University is developing the Experiential Engineering Library to provide an easily accessible environment for hands-on engineering learning experiences beyond the traditional mechanical engineering curriculum. The library will foster critical thinking by encouraging students to apply fundamental mechanical engineering principles to emerging interdisciplinary research in fields including microelectromechanical systems (MEMS), bioengineering, and nanotechnology. Experiments will come from state-of-the-art faculty research as well as other sources and can be assigned as a complement to or in lieu of paper-and-pencil homework or utilized independently by students seeking to improve their understanding of particular concepts. Used initially in four courses, the library will be evaluated for effectiveness and then implemented across the curriculum.

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John Speich is an Assistant Professor of Mechanical Engineering at Virginia Commonwealth University. He received his B.S. in Mechanical Engineering from the Tennessee Technological University and his M.Sc. and Ph.D. in Mechanical Engineering from Vanderbilt University.

James McLeskey is an Assistant Professor of Mechanical Engineering at Virginia Commonwealth University. He received his B.Sc. in Physics from The College of William and Mary, his M.Sc. in Mechanical Engineering from the University of Illinois at Urbana-Champaign, and his Ph.D. in Mechanical Engineering from the University of Virginia. Dr. McLeskey is certified by the State of Virginia to teach high-school Physics and Chemistry.

Judy Richardson is a Professor in the School of Education at Virginia Commonwealth University. She received her B.A. in English from the University of North Carolina, Greensboro, and her M.Ed. and Ph.D. in Education from the University of North Carolina, Chapel Hill.

Mohamed Gad-el-Hak is the Caudill Eminent Professor and Chair of Mechanical Engineering at Virginia Commonwealth University. He received his B.Sc. in Mechanical Engineering from Ain Shams University and his Ph.D. in Fluid Mechanics from Johns Hopkins University. Dr. Gad-el-Hak is a fellow of the American Academy of Mechanics, the American Physical Society, and the American Society of Mechanical Engineers.