Int. J. Engng Ed. Vol. 22, No. 2, pp. 247–256, 2006
Printed in Great Britain.
0949-149X/91 $3.00+0.00

Evaluation of an Experiential Engineering Library*

JAMES T. McLESKEY, JR., JOHN E. SPEICH, JUDY S. RICHARDSON, and MOHAMED GAD-el-HAK
Virginia Commonwealth University, Richmond, VA 23284, USA
Email: jtmcleskey@vcu.edu

The VCU Mechanical Engineering Department has developed and tested an NSF-sponsored 'Experiential Engineering Library' that provides an easily accessible environment for hands-on learning experiences beyond the traditional ME curriculum. The library fosters 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 come from state-of-the-art faculty research as well as other sources and are assigned as a complement to, or in lieu of, paper and pencil homework, or utilized independently by students seeking to improve their understanding. The library concept has been described in detail in a previous IJEE paper. The present article describes the implementation and impact of the four library learning modules into the four courses during the year-long pilot program. The library has been found to be effective in improving student understanding as well as motivation.

Keywords: Guided Discovery; Hands-On Learning; Modules; Constructivist Learning Theory

INTRODUCTION

AS DESCRIBED in detail in a previous IJEE paper [1], the Mechanical Engineering Department at Virginia Commonwealth University has developed a novel 'Experiential Engineering Library'. This library is analogous to a traditional library, in that it contains experimental learning modules that are either 'on reserve' or available to be 'checked out' by the students. The experiential library collections allow students to study problems of interest in emerging fields that come from faculty research, senior capstone design course projects, commercially developed educational tools and donations from industrial partners. Hands-on problems can be assigned from the library as a complement to or in lieu of written homework. The modules can also be used independently by students seeking to improve their understanding and/or by students whose learning styles include manipulation and visualization.

The experiential engineering library was piloted in 2003–2004 under a planning grant from the U.S. National Science Foundation. The aim of the grant was to plan, organize and test the library concept of incorporating experiments based on cutting-edge research into the curriculum. The results have been highly encouraging. A set of four different laboratory modules has been developed: force-sensing surgical instrument, rehabilitation robot, Stirling engine, and nanocrystalline solar cell. The collection was housed in the research labs of the principal investigators and the labs were kept open for extended hours and manned by graduate and upper-level undergraduate students. Often the students enjoyed the modules so much that they stayed long after completing the requirements or returned to complete the modules several times. The library was integrated into an Energy Conversion Systems course in the fall of 2003, and into Thermodynamics, Mechanics of Deformables, and Robotics in the spring of 2004. The present paper describes the implementation and impact of the four library learning modules into the four courses during the yearlong pilot program.

BACKGROUND

Laboratory and hands-on activities are a key component of any engineering curriculum. Across the country, a number of programs have been developed with the intent of increasing hands-on learning and improving engineering education [2–4]. While many schools recognize and fulfill the need for hands-on activities at the freshman level, the quantity 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 fifteen during the senior year, while providing only three lab hours during each of the sophomore and junior years. The experiential engineering

* Accepted 4 October 2005.

library bridges the gap between freshman activities and senior laboratories by providing students with opportunities to gain hands-on experience and instructors with a collection of practical experiments for in-class demonstrations and homework assignments.

The library modules 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 then expected to know it and discovery learning, where students are given a few parameters and then 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 [5, 6], which has been shown to increase—as well as engage—learners more effectively than traditional lecture instruction. The constructivist environment encourages collaborative learning and team building as the students perform guided experiments and discover the answers to their questions. A complete description of the background and motivation for the Experiential Engineering Library was given in our earlier paper [1].

IMPLEMENTATION AND EVALUATION OF THE LIBRARY

The experiential engineering library was piloted in 2003–2004, and a set of four different laboratory modules was developed: force-sensing surgical instrument, rehabilitation robot, Stirling engine, and nanocrystalline solar cell. These modules were integrated into four courses: Energy Conversion Systems, Thermodynamics, Mechanics of Deformables, and Robotics. The library was first piloted in the technical elective Energy Conversion Systems course during fall 2003 using the Stirling engine and nanocrystalline solar cell modules. While both experiments are available commercially in kit form, they nonetheless represent the state-of-the-art in energy conversion and both are the subject of ongoing research [8, 9]. During the following semester, spring 2004, the Stirling Engine module was used in a sophomore-level Thermodynamics course. In addition, the force-sensing surgical instrument module was integrated into a sophomore-level Mechanics of Deformables course, and the hand rehabilitation robot module was utilized in a technical elective Robotics course. The impact of these modules on student learning was evaluated using pre- and post- self-assessments. In addition, focus group interviews were conducted to gather qualitative expressions of student satisfaction and perceptions of learning. This section describes the development and implementation of the learning modules and presents the results of the self-tests and focus group interviews.

Stirling Engine module

Energy conversion systems course

The Stirling engine module pictured in Fig. 1 was designed using a kit available from Fisher Scientific [10]. 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. The module was assigned in lieu of one homework problem with no prior introduction in class. All nineteen students in the Energy Conversion Systems course completed the Stirling engine library module over the course of one week. The students were primarily seniors who had already completed several fundamental thermal/fluids courses, and each student worked independently. Immediately prior to beginning the module, the students were given a nine-question, multiple-choice (primarily) pre-test to assess their knowledge of Stirling engines. The students also rated

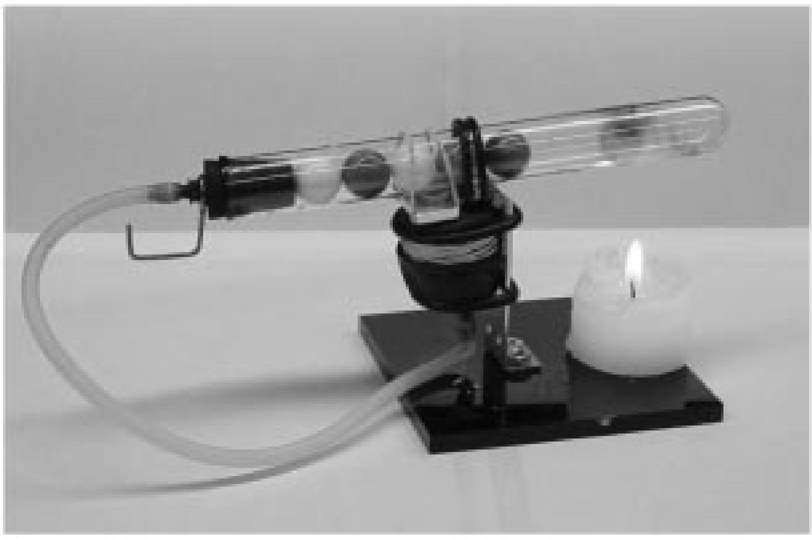

Fig. 1. Stirling engine model.

their existing knowledge of Stirling engines on a scale from 1 (no knowledge) to 10 (expert). After completing the experiment, they were given a post-test that included the same nine questions and self-rating. The students were also asked whether the lab was helpful in increasing their knowledge and whether or not the lab raised 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 (± standard error) are presented graphically in Fig. 2. 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 1 (no knowledge) to 10 (expert) before and after completing the library module. The self-assessment scores are shown in Fig. 3. 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. When asked whether or not the lab was helpful in increasing their understanding of Stirling engines, seventeen of the nineteen students (89%) answered affirmatively. The students clearly believed that they had increased their expertise. Students also found the lab enjoyable and intriguing. Fifteen of the nineteen (79%) said that the lab raised their interest in Stirling engines. This is also supported by the student comments listed in Table 1.

Thermodynamics course

The Stirling engine module was also utilized in the Fundamentals of Thermodynamics course taught during the Spring 2004 semester. As before, the module was assigned in lieu of one homework problem. Based on lessons learned during the Energy Conversion course, changes were made to the format of the pre- and post-tests and how those tests were applied.

The tests took the form of an anticipation guide. Anticipation or prediction guides prepare readers by asking them to react to a series of statements that are related to the content of the material. In reacting, the students anticipate what will happen in the module. Once students have committed themselves to the statements, a purpose for reading and participating has been created and the students' curiosity about their own knowledge then helps maintain their interest [11]. The 78 students in the class were asked open-ended questions and were asked to explain why they answered questions in a certain way. The pre-test was given in class several days before the students completed the module. Although no prior instruction was offered and the use of open-ended questions made it difficult for the students to guess the answers, the questions created great anticipation and curiosity. As shown in Fig. 2, the pre-test average was only 22.8%. Many students asked about the answers to the pre-test questions or looked for the answers in their textbook or on the Internet.

As shown in Fig. 2, the average quiz score increased from 22.8% to 99.0% after the students

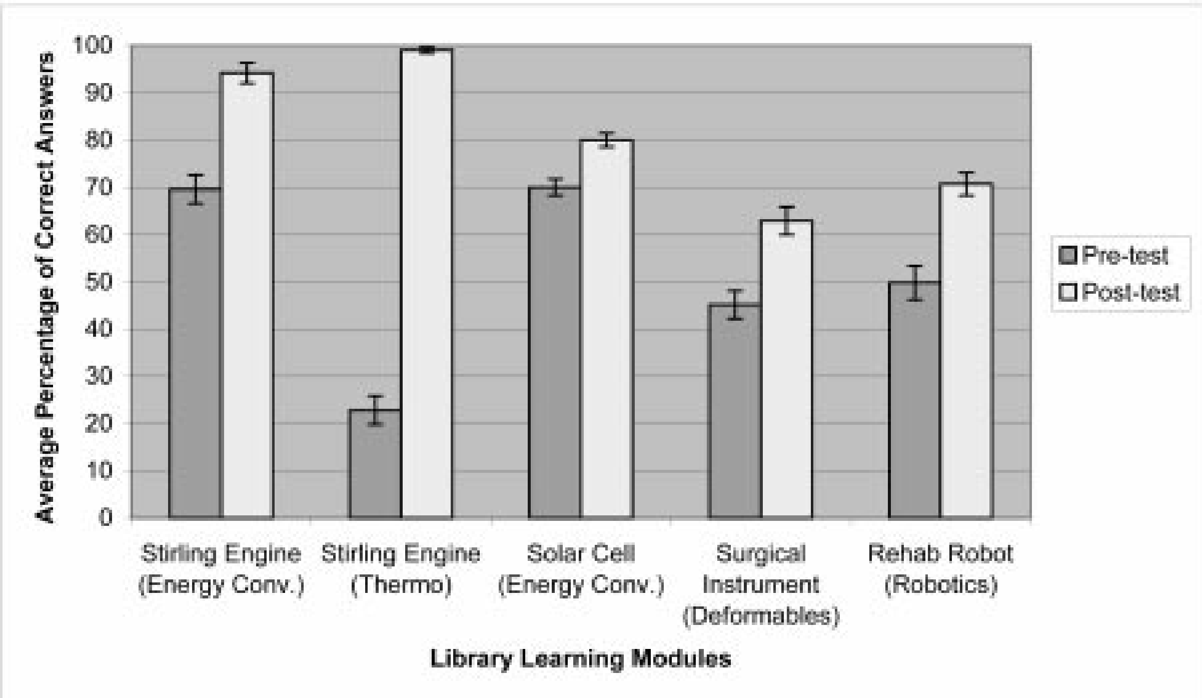

Fig. 2. Comparison of the average percentage (± standard error) of correct answers from the pre- and post-tests for the library learning modules.

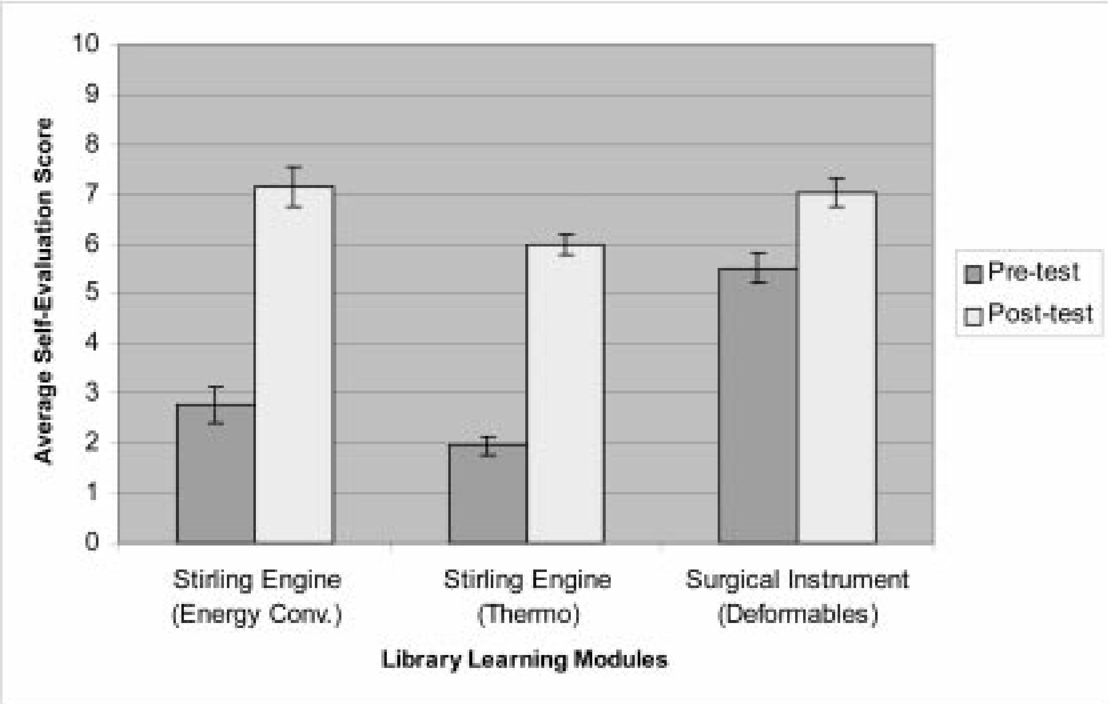

Fig. 3. Average self-evaluation scores from the pre- and post-tests for selected learning modules.

Table 1. Students' written comments about the Stirling engine module

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

completed the modules. The students learned the answers to some test questions by completing the module and others by reading the background material that accompanied the instructions. The interest sparked by the hands-on experience clearly also provided the students with the motivation to read.

As before, each student rated his/her knowledge of Stirling engines on a scale from one (no knowledge) to ten (expert) before and after completing the library module. However, unlike the relatively experienced students in the Energy Conversion Systems course, the Thermodynamics students were sophomores taking their first thermal sciences course. Therefore, as might be expected, the students initial self-assessment scores were quite low, averaging 1.9 out of 10, as shown in Fig. 3. After completing the module, the average self-assessment rating rose to 6 out of 10.

Perhaps more important than the effectiveness of the modules in increasing student learning is the clear success they had at increasing student interest. All of the students said that the modules were effective in helping them understand Stirling engines and 90% said the module raised their interest in the subject.

Nanocrystalline solar cell module

Energy Conversion Systems course

The nanocrystalline solar cell module was based on a model available in kit form from the Institute for Chemical Education at the University of Wisconsin [12]. In this module, the students built their own solar cells in a lab using simple materials including titanium dioxide and blackberry juice. The resulting cells were then tested for key values including voltage and current (and thus power). For a known solar flux, the energy conversion efficiency of the solar cell could then be calculated.

The misconceived promise of 'free energy' offered by photovoltaic solar energy conversion is very enticing to students. This module offered them the opportunity to build a nanocrystalline solar cell while learning about the limits imposed by the first and second laws of thermodynamics. It also illustrated the interrelationships between the various disciplines of science and engineering and could be used in teaching Thermodynamics, Heat

Table 2. Students' written comments about the nanocrystalline solar cell module

Circuit didn't work properly.
Had a lot of problems with lab.
My solar cell is not powerful.
This cell was hard to make properly.
Interesting lab to actually see how simple the cells are and how they work.
We didn't get a very good graph and didn't understand how it got to 0.2 V.
I got part of the I–V curve that looks like ideal curve.
I think that my solar cell has not enough berry juice or I put too much water in the juice.
Our output voltage/current was not very good—maybe something was wrong with the cell.

Transfer, and Energy Conversion Systems. Students can revisit modules as they learn new concepts, thus helping to build continuity.

The module was assigned in lieu of one homework problem. Unlike the Stirling engine module, the students had some prior knowledge because the solar cell module was assigned at the end of a unit on solar energy and photovoltaics. Prior to attempting the experiment, the students were given a five-question anticipation guide to test their knowledge of nanocrystalline solar cells. The students were required to answer each question either 'Agree' or 'Disagree' and give a rationale for each answer. After completing the experiment, they were given the same anticipation guide as a post-test to see if they had improved their ability to answer the questions. At the end, the students were given the opportunity to make written comments.

The solar cell library module was completed by all nineteen students in the Energy Conversion Systems course; however only sixteen students submitted both the pre-test and post-test. The average percentage of correct responses was 70% on the pre-test and 80% on the post-test as shown in Fig. 2.

While there was some improvement in the students' performance on the evaluation after completing the module, the results are not as dramatic as with the Stirling engine module. In part, this is probably because the solar cell module was done after the topic was discussed in class. In addition, the student comments given in Table 2 show that the students had some difficulty obtaining the expected results. While all of the students measured some electrical output from the solar cell, many experienced difficulty in getting the cell to reach its design specifications. This may indicate that the details of the fabrication and testing procedures need to be adjusted.

Force-sensing surgical instrument module

Mechanics of deformables course

Research is underway 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 allow quantitative assessment of surgical skills during both conventional and robot-assisted surgery. During the 2003–2004 academic year, a group of four seniors developed a library module based on this research. The surgical instrument is shown in Fig. 4.

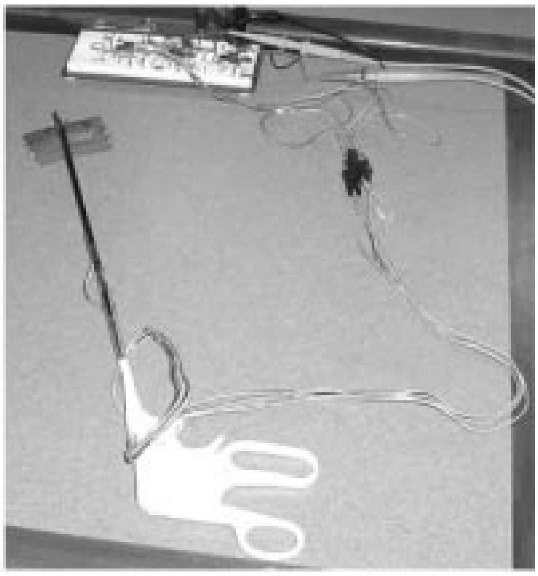

Fig. 4. A force-sensing surgical instrument.

These students implemented a set of surgical tools with sensors that quantify the forces applied to each device tip by measuring strain in the shaft of the tool. Both traditional strain gages and state-of-the art PZT materials were utilized for comparison. The force-sensing surgical instrument module was designed to illustrate the fundamental concepts of stress and strain taught in the sophomore-level Mechanics of Deformables course.

During the spring 2004 semester, 30 out of 31 mechanical and biomedical engineering students in one section of the Mechanics of Deformables course utilized the force-sensing surgical instrument module, along with one student from a different section of the course. Teams of three students completed the module as an extra credit opportunity near the end of the semester, after the concepts of stress and strain had been taught in class. They used the surgical instrument to push on a piece of synthetic tissue used to simulate human tissue, as shown Fig. 5. The responses from the strain gages and PZT materials were used to estimate the forces being applied to the tissue along each axis of a Cartesian coordinate system. The applied forces were also measured using a force multi-axis sensor (ATI Nano17 from ATI Industrial Automation, Inc.) placed under a piece

Fig. 5. Students using the force-sensing surgical instrument.

of synthetic tissue. Measurements from both the instruments and the tissue sensor were displayed graphically to allow the students to visualize the relationships between the strain magnitude, load type (bending, axial. . .), load location and the forces generated during various loading combinations.

Prior to completing the learning module, the students were given a ten-question anticipation guide to test their knowledge of stress and strain, as well as their perception of their own knowledge of the topic. After completing the module, they answered the same set of questions, plus additional questions about their learning experience. When asked how well they could explain the difference between stress and strain on a scale of 1 to 10 with 10 being a complete explanation, the average response was 5.5 on the pre-assessment and 7 on the post-assessment. The students were also asked how well they could identify the types of stress that would be generated at different locations on the surgical instrument on a scale of 1 to 10 with 10 being expert ability. In that case, the average response was 6.3 on the pre-assessment and 7.3 on the post-assessment. In both cases, the students' perception of their knowledge increased after completing the library module.

The pre- and post-assessments included eight questions to measure the students' knowledge of the concepts illustrated by the force-sensing surgical instrument module. The average score on the pre-test was 43%, while the average score on the post-test was 63% as shown in Fig. 2. The assessment was designed to measure which concepts were successfully learned from interaction with the library module and which were not.

One goal of this module was to show the students how the theories that they were learning in class could be applied to an interesting biomedical problem. When asked if the learning module was helpful in increasing their understanding of how the concepts of stress and strain could be applied, 30 out of 31 students responded affirmatively, and all 31 said they would like to see additional learning modules added to the course. The students also communicated the experience with friends who were not in the class. Based on these discussions, a student from a section taught by a different instructor asked permission to complete the module. Another student not associated with the course came to the library to watch a friend complete the module.

Rehabilitation robot module

Introduction to Robotics course

A robotic device for delivering rehabilitation therapy to the hand and fingers is currently under development at VCU. This device can measure and control the position and orientation of the fingers in a plane perpendicular to the palm of the hand and control the forces acting on the fingertips using a planar five-bar mechanism as shown in Fig. 6. In addition to delivering rehabilitation therapy and characterizing the function of the hand and fingers, the device can serve as an excellent hands-on tool for teaching undergraduates the basic principles of mechanism kinematics and dynamics. Therefore, a rehabilitation robot learning module was developed for the library.

The rehabilitation robot learning module was piloted in the Introduction to Robotics technical elective course taken by 39 mechanical and electrical engineering students during the spring 2004 semester. Although the rehabilitation robot is a unique and expensive piece of research equipment, it was made available 'on reserve' for students in the Robotics course during one week of the

Fig. 6. Photographs of the hand rehabilitation prototype.

semester. The students worked in teams of three or four and used 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 vise versa. The computer that controls the robot was programmed to display both the angular positions and velocities of the motors and the corresponding position and velocity of the fingertips. The students solved the forward and inverse kinematic equations for the mechanism and compared their results with the actual kinematics of the robot displayed by the computer. The students were given specific instructions; however, they were also encouraged to explore the kinematics of the mechanism independently.

As with the other learning modules, the students completed pre- and post- assessments to measure their knowledge of kinematics and assess their perception of the knowledge they gained in this area. When asked to rate their knowledge of robot kinematics on a scale of 1 to 10 with 10 being expert, the average was 6.3 on the pre-assessment and 7.7 on the post-assessment. The assessments included seven questions to measure the students' knowledge of the concepts illustrated by the rehabilitation robot module. The types of questions included 'fill in the blank,' 'circle all that apply,' and 'agree/disagree and why' questions. The average percentage of correct or partially correct responses increased from 50% on the pre-test to 71% on the post-test. All 39 students asserted that the learning module was helpful in increasing their understanding of robot kinematics. In addition, they all responded that they would like to see additional modules added to this course.

FOCUS GROUP INTERVIEWS

Following the conclusion of the fall 2003 and the spring 2004 semesters, Dr. Judy S. Richardson from the VCU School of Education conducted focus group interviews with several students who had completed the modules of the experiential library. The first interview was conducted in December 2003 with four students from the Energy Conversion Systems class. Two more interviews were conducted following the spring 2004 semester. The interviews included ten students on April 30, 2004 and four students on May 5, 2004. None of the students had met Dr. Richardson prior to the interview, and the course instructors (Dr. McLeskey and Dr. Speich) were not present. Because an education professor conducted the focus group and had had no contact with these students previously, her presence was considered to be non-threatening.

Each focus group met for approximately 70 minutes. The sessions were videotaped as well as audiotaped for transcription purposes. To maintain student confidentiality, a student assistant transcribed the audiotapes. The videotapes were used only to assign comments to the correct student when it was impossible to use the audiotape for this purpose. This occurred when comments were extremely brief or when two students spoke simultaneously. No engineering faculty member listened to or watched any of the tapes. Their involvement in the analysis process took place only after the transcriptions were complete. The tapes were erased following the final audit. The transcripts of the focus groups were analyzed using qualitative analysis. The transcripts underwent a line-by-line content analysis [13]. The data corpus was repeatedly reviewed to test the validity of the assertions [14].

The focus groups were led via a series of prompts that were designed to encourage thoughtful comment about the student experiences with the experiential library. These prompts probed for: ease of use, increased class performance, deepened understanding of content and concepts, the 'hands-on' aspect (constructivism), interest, and overall impressions of the library. From the written responses to the prompts and the taped discussions, several themes emerged. The findings are organized around the themes, with direct quotations to support the findings.

Theme 1: The experiential library creates a real and practical application of content and provides context for learning.

Numerous experts in the field of reading and study skills instruction [11] have indicated that learning must include practical experiences and a context for learning. Students were enthusiastic in their discussion of how the experiential library provided them with another way to learn engineering material. They appreciated the opportunity to manipulate objects and discover by doing. They indicated that the library experiments enabled them to see how something presented in the textbook or lecture could actually work out in real situations.

The students were very excited to have an opportunity to 'do' as well as to listen and read. They appreciated seeing and manipulating so that they could really understand how the theory works. Often, they wanted to see if they could keep the Stirling engine going past the task assigned. 'I liked that Dr. McLeskey is going for this hands-on stuff.' 'I'm the kind of person that has to see and feel something to understand it.'

The students expressed much enthusiasm for the activities. It made the subject more interesting for them, especially because they were planning to be mechanical engineers and these experiments helped them to grasp electrical engineering better. They volunteered that the experiential library provided excellent opportunities for application; in fact, they suggested that the pre- and post-tests should better reflect the applicative nature of the tasks, and not dwell on the facts so much as the application of the facts.

Student comments supporting Theme 1:

- We would have learned conceptually pretty much the same thing, but we wouldn't actually have seen how the stuff that we're learning actually is there in the real world.
- It was more interesting and I learn better when I am interested.

Theme 2: The experiential library promotes application and critical thinking, which then facilitated retention of content, which in turn facilitated ease of study, test taking, and confidence with future exams for the profession.

While the students commented that the experiential library helped them to perform better in class, they valued more so that the lab would help them remember and apply information in their future careers. 'If somebody were to mention this 10 years later, I think I would remember this.' 'It would help us down the road explaining it to somebody in a simpler way.' Students consistently commented that learning was more than memorization and that they felt the experiential library enriched their learning. Their comments reflect the constructivist viewpoint: constructivism is a term used to explain what happens as a learner processes information [15].

Student comments supporting Theme 2:

- The library allowed me to understand and think critically.
- It generated more ideas for me.
- It gave me a mental picture.
- I was wondering how many applications this could be used for, and whether I can use it in my own life.

Theme 3: Text and lecture are insufficient learning tools for engineering students in today's complex world.

Applefield et al. [16] have stated: 'The field of education has undergone a significant shift in thinking about the nature of human learning and the conditions that best promote the varied dimensions of human learning. As in psychology, there has been a paradigm shift in designed instruction; from behaviorism to cognitivism and now to constructivism.' The student comments in the present study support this view.

The students pointed out that they preferred more control of their own learning process. They occasionally want an environment where there is no pressure and where the manipulative aspects of learning are featured just as the intellectual–academic learning process is used in classrooms.

The students were very impressed with their deepened sense of content and concepts after having completed the experiential library tasks. 'Now I see how it works. Sitting in lecture, you know how it works on paper and from the book but actually doing it you can see what goes on.' 'When you actually see it, you understand it.' 'Putting things in context adds a lot more gravity to it.' Their comments echoed Weaver [17], who explains that knowledge is transmitted to learners who are building information with help from many sources .

Student comments supporting Theme 3:

- I went back three times in three days, just to understand it all better.
- I feel like learning more. It let me learn about a different topic and have physical applications.
- Well, I could learn the detail and the math from a lecture, but I needed to do it to get the right balance.
- The experiential library provides me [with] the mechanism that makes me remember the information. Traditional lectures give me mathematical reasons and derivations that satisfy curiosity and the more complicated problems.
- The more and unique ways to learn help us remember, understand and soak in the information.
- Participating helped me a lot more than class time.
- I am a visual learner, so I need this.

Theme 4: Learning needs to be accessible on just-in-time for today's students.

Students today are attuned to a multi-media society. They have grown up using electronic media and expecting immediate access to the information they seek. The students want this to be part of their academic experiences as well. The experiential library was 'pretty easy' to access and use. The students felt that they could stop by 'whenever it was convenient for us'. Furthermore, they often experimented much longer than the actual task required: 'You could sit there and play with it after you built it'. The students expressed the need for learning to be not only individual but also social because 'by articulating ideas and experience through writing, speaking, and/or visually representing, students deepen their thinking and construct and organize their understanding of new material' [18].

Overall, the VCU students were very impressed with the experiential library. Their appreciation for the constructivist nature of the library was apparent. As one student said, 'You develop a relationship with the idea'. The focus group students are some of the students of the twenty-first century and their comments reflect their needs for and appreciation of the experiential library as a way of meeting those needs.

Student comments supporting Theme 4:

- Accessibility is important to me.
- I could practice as much as I needed to.
- Hands-on experience helps many people of my age gain a much better understanding.
- The openness and personal touch rather than cut-and-dry is important.

Theme 5: The age and year of the student did not change the positive impressions of the experiential library.

Students in the present interviews spanned freshman to senior level. Some were earning higher grades than others. These circumstances did not alter their enthusiasm for the opportunity of using the experiential library. When asked to discuss whether the library should be reserved for older students or started during freshman level, agreement was unanimous that it should be available throughout the four years. To explain their reasoning, they offered comments similar to those shared within the other themes. Some even indicated that they had had a 'rough' start and that, had it been available earlier, the experiential library would have helped them to persevere. The students speculated that others who had dropped out might have persevered if an experiential library had been available.

When asked to think about the similarities and differences between the experiential library and traditional lab assignments, they felt that the library was more 'laid back' and enhanced more efficient learning. With labs, they felt that they were meeting the instructor's criteria more than actually experimenting and learning something in a personal way.

Student comments supporting Theme 5:

- The experiential library is something that benefits everyone.

Student suggestions

Students did offer some suggestions for a future experiential library. They commented that the room was sometimes in disarray, especially at the end of the day; some materials could have been better organized. The students consistently commented that what they were offered was not enough—they really need 'MORE hands-on activities to help learn engineering topics.' They suggested that the experiential library would have been more effective if provided at the beginning of the semester. They were halfway through the semester when they had their first encounter with the library.

CONCLUSIONS

The 'Experiential Engineering Library' has been found to be effective in improving student understanding as well as motivation. In each case where a learning module was piloted, students showed improvement on the respective pre-tests and post-tests of anywhere from 10% (solar cell module) to 76% (Stirling engine module). The students perceived this increase in understanding as measured by their self-evaluation rating.

The students overwhelmingly endorsed the opportunity to participate in the experiential library. Their reflections are consistent with previous studies and literature in the field of reading and study skills research. These studies emphasize the learner's role in actively constructing meaning by relating new material to the known using reasoning and developing concepts. One student's comment provides a good final conclusion: 'This definitely enhanced my learning. I would love to participate in further experiments.'

ACKNOWLEDGMENT

The authors would like to acknowledge the National Science Foundation for its support of this project under the Grants for the Department-Level Reform of Undergraduate Engineering Education Program, NSF Grant number 0342865.

REFERENCES

1. J. Speich, , J. McLeskey, Jr., J. Richardson and M. Gad-el-Hak, The experiential engineering library, *International Journal of Engineering Education*, **20**(6) 2004.
2. Pennsylvania State University, Introduction to engineering design course description, <http://www.ecsel.psu.edu/edg100/course.html>, accessed 2003.
3. University of Washington, Engineering coalition of schools for excellence in education and leadership, <http://depts.washington.edu/mscience/>, accessed 2003.
4. University of Notre Dame, College of engineering learning center web site, <http://www.nd.edu/~englearn/>, accessed 2003.
5. L Vygotsky, *Thought and Language*, MIT Press, Cambridge, MA, 1962.
6. L. Vygotsky, Interaction between learning and development, in, M. Cole, V. John-Steiner, S. Scribner, and E. Souberman (eds), *Mind in Society: The Development of Higher Psychological Process*, Cambridge, MA: Havard University Press (1978), pp. 79–91.
7. S. Norman, Epss: A constructivist learning environment, <http://scholar.coe.uwf.edu/students/snorman/webpages/paperpresentation/sld001.htm>, accessed 1998.
8. P. C. T. de Boer, Maximum attainable performance of stirling engines and refrigrerators, *Journal of Heat Transfer*, **125**(5) (2003), pp. 911–915.
9. M. Gratzel, Photoelectrochemical cells, *Nature*, 414(338) (2001), pp. 338–344.
10. Fisher Scientific, Stirling engine model, <www.fishersci.com>, accessed 2003.
11. J. S. Richardson and R. F. Morgan, *Reading to Learn in the Content Areas*, Wadsworth, Belmont, CA (2003).

12. G. Smestad, *Nanocrystalline Solar Cell Kit: Recreating Photosynthesis*, The Institute for Chemical Education, Madison, WI (1998).
13. R. C. Bogdan, and S. K. Biklen, *Qualitative Research for Education*, Allyn and Bacon, Boston (1982).
14. F. Erickson, Qualitative methods in research on teaching, in M. Wittrock (ed.) *Handbook of Research on Teaching*, 3rd edn, New York: Macmillan (1986), pp. 119–161.
15. P. D. Pearson, and D. Stephens, Learning about literacy: A 30-year journey, in, R. Ruddell, M. Ruddell, and H. Singer (eds), *Theoretical Models and Processes of Reading*, Newark, DE: International Reading Association (1994), pp. 22–43.
16. J. M. Applefield, R. L. Huber and M. Moallem, Contructivism in theory and practice: Toward a better understanding, *High School Journal*, **84**(2) (2000).
17. C. Weaver, *Reading Processes and Practice*, Heinemann, Portsmouth, NH, (1994).
18. S. Gill, and K. Dupre, Constructivism in reading education, *The Reading Professor*, **21**(1) (1998), pp. 91–108.

James McLeskey is an Assistant Professor of Mechanical Engineering at Virginia Commonwealth University. He earned his B.S. in Physics from The College of William and Mary, his M.S. 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.

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

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