AC 2008-2281: LIVING WITH THE LAB: A CURRICULUM TO PREPARE FRESHMAN STUDENTS TO MEET THE ATTRIBUTES OF "THE ENGINEER OF 2020"

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Living with the Lab: A Curriculum to Prepare Freshman Students to Meet the Attributes of "The Engineer of 2020"

Abstract

A project-based, freshman engineering course sequence has been developed and implemented for all new freshman engineering students with support from an NSF CCLI grant. The mission of the curriculum is to systematically instill the ten attributes of engineers outlined in the National Academy of Engineering report "The Engineer of 2020: Visions of Engineering in the New Century."

The curriculum objectives are divided into seven threads that run concurrently throughout the freshman year: systems, electromechanical devices, fabrication and acquisition, software, fundamental engineering concepts, communication, and broadening activities. We have worked to structure the content timing and delivery so that the knowledge, skills and attitudes associated with each thread are built progressively. Curriculum objectives are directly tied to the ten attributes of "The Engineer of 2020."

Instead of a textbook, students purchase a Parallax Boe-Bot kit that serves as a platform for laboratory and design projects, allowing students to quickly develop skills in programming and circuit prototyping. Students also purchase a set of tools for completing electromechanical projects and several software programs for facilitating engineering analysis and 3D modeling. A Freshman Projects Classroom was designed to promote team-based learning.

The faculty and students are challenged by the new curriculum and are now more motivated and engaged in learning than with the prior curriculum. Assessments from this academic year suggest that the curriculum does accomplish our primary goal of preparing students to meet the attributes of "The Engineer of 2020."

Introduction

Engineering faculty who are committed to educational reform have long since realized that passive lecture-based instruction should be replaced by active, integrative, project-based learning[1]. In the United States, the movement toward project-based freshman engineering curricula began in the 1990s due in large part to the National Science Foundation Engineering Education Coalitions[2-5]. This movement towards hands-on freshman engineering programs with a significant design component continues today at universities across the United States[6-8]. A vast body of literature on the subject clearly shows the benefits of incorporating project-based instruction with design *early* and *often*.

Throwing a healthy dose of robotics into the mix provides a "magical" element that brings the instruction to life. Engineering educators are using robots to motivate student learning and to stimulate interest in engineering and science[9-15]. During the past five years, the College of Engineering and Science at Louisiana Tech University has taught a robotics-centered sequence of engineering courses to groups of freshman engineering students. The goal of this course sequence is to provide the knowledge, skills and tools essential for boosting the confidence and creativity of these students while introducing them to the engineering disciplines. The robotics content provides the perfect match for the project-based educational approach – the robotics greatly expands the types and complexity of projects that can be undertaken.

The Freshman Engineering Curriculum

In 1998 the College of Engineering and Science moved to an integrated engineering curriculum based on the educational practices of the National Science Foundation Educational Coalitions[16]. Along with our freshman engineering course sequence, our freshman integrated curriculum includes differential and integral calculus courses, basic chemistry lecture and laboratory courses, and a calculus-based physics course, as summarized in Table 1; students also typically enroll in several non-technical courses during the freshman year. The freshman integrated courses are taken in "blocks" so that classes of 40 students share the same sections of each mathematics, science and engineering course during each quarter. The topics presented in the mathematics and science courses are coordinated to some degree with the topics presented in the engineering courses to motivate student learning and to provide for content overlap. The three engineering courses (ENGR 120, 121 and 122) are implemented as combined lecture / laboratory classes and meet twice a week for 1 hour and 50 minutes.

Table 1 – Technical courses of the freshman engineering curriculum.

Fall Quarter		**Winter Quarter**		**Spring Quarter**	
Course	*Credits*	*Course*	*Credits*	*Course*	*Credits*
ENGR 120	2	ENGR 121	2	ENGR 122	2
MATH 240	3	MATH 241	3	MATH 242	3
CHEM 100	2	CHEM 101/103	2/1	PHYSICS 201*	3

* Students in chemical engineering postpone physics and take an additional chemistry here.

The "original" ENGR 12X freshman engineering course sequence between 1998 and the spring of 2007 included engineering fundamentals (circuits, materials balance, and statics), computer applications (Excel, Mathcad, and Solid Edge), statistics, engineering economics, teamwork, communication skills, and a design project. The students did most of their work in teams, including homework problems, laboratory activities, and presentations. The year culminated in a design competition between the ENGR 122 teams.

With seed money provided by the university to purchase course supplies, we began what would eventually become the *Living with the Lab* freshman course sequence in 2002 with a group of 21 students who volunteered to participate in the new courses. The new courses were much like the original ENGR 12X courses, only with a much stronger project focus. These robotics-centered courses were offered on a pilot basis to 40 students in 2003-2004. Beginning in the fall of 2004 and continuing for the next three academic years, the new courses were offered to two groups of 20 honors engineering students each year. Funding from an NSF Course, Curriculum and Laboratory Improvement grant allowed us to extend the curriculum to all 280 freshman engineering students taking ENGR 120 in the fall of 2007. Approximately 400 freshman students have enrolled in the course sequences based on the *Living with the Lab* curriculum during the current 2007-2008 academic year.

During efforts to develop a formal assessment plan to determine the effectiveness of the new courses, we realized that we needed a set of guideposts to help us determine if our strategies were effective not only in teaching students, but also in preparing them for their engineering careers. We realized that the work sponsored by the National Academy of Engineering to identify attributes of "The Engineer of 2020"[17] aligned closely with our efforts. The ten attributes identified by the "The Engineer of 2020" Project impacted our work from that point forward. We began mapping our objectives to The Engineer of 2020 attributes, discarding objectives that didn't match well and adding objectives and activities to increase consonance with those attributes. For example, we determined that our students needed to participate in more professional development activities. We therefore boosted the requirement that students attend professional society meetings sponsored by the College of Engineering and Science from five per year to fifteen per year.

The "Engineer of 2020" Project

In 2001-02, the National Academy of Engineering established "The Engineer of 2020" Project, which sought to develop a vision for the engineering field and to predict the work environment of an engineer in 2020[17]. The report resulting from Phase 1 of this work identified ten key attributes to support the relevance of the engineering profession in 2020 and beyond. These attributes are presented in Table 2.

Table 2. Key attributes that the "Engineer of 2020" should possess[17]

No.	Attribute
A1.	Strong analytical skills
A2.	Practical ingenuity
A3.	Creativity
A4.	Good communication skills
A5.	Lifelong learners
A6.	Dynamic, agile, resilient and flexible characteristics
A7.	High ethical standards
A8.	Leadership skills
A9.	Professionalism
A10.	Business and management skills

The revised freshman engineering course sequence at Louisiana Tech University seeks to provide a foundational educational experience to systematically instill these attributes in our students. The primary purpose of this paper is to describe how course outcomes for each of the three freshman courses are tied to the ten attributes through our overarching curriculum objectives. First, we will briefly describe our new curriculum that we call *"Living with the Lab."*

The *Living with the Lab* Concept

In the traditional laboratory and shop settings, faculty members or technical staff must ensure that the required equipment is ready and that supplies are on hand so that prototypes can be constructed or data can be acquired. While it's possible for energetic faculty members to guide students through creative design projects and laboratory experiences in a classroom or laboratory setting, accomplishing this task over a long period of time and with a large number of students is difficult and is sometimes not sustainable. Assignment of robotics kits to students or student groups makes it possible for the "laboratory" or "design platform" to travel with the students to the places where they spend their time – to their dorm rooms and apartments or to the local coffee shop. Tufts University[9] reports that students appreciate the freedom to work anywhere on their projects; further, they are able to solve the majority of their hardware problems either on their own or with a few tips. When students control and maintain their own hardware, significant increases in experiential learning is possible; students are *living with the lab*. The end result is more hands-on student activity without the excessive investment of faculty time.

The *Living with the Lab* Curriculum

The major aim of the *Living with the Lab* curriculum is to create innovative students with a can-do spirit through a project based curriculum where students repeatedly apply technology and fundamentals to solve problems. The new curriculum boosts experiential learning by putting the ownership and maintenance of the "lab" into the hands of the students. Each student must purchase a robotics kit (~$110) with a programmable controller, sensors, servos, and software, along with a toolkit (~$70) that together provide the basis for a mobile laboratory and design platform. A basic tenet of the curriculum is that student-owned labs motivate student learning and broaden the spectrum of projects and design topics that can be addressed, thus facilitating innovation.

Objectives for the Freshman Engineering (*Living with the Lab*) Curriculum

We have sought to implement a college-wide freshman course sequence focusing on "The Engineer of 2020" attributes A1 through A6 and to a lesser degree on the remaining attributes (A7-A10). The curriculum objectives are grouped into seven threads that span the freshman year, as shown in Figure 1. Linkages to the attributes of "The Engineer of 2020" (A1 through A10) are shown in parentheses after each objective. Each thread in the curriculum spans the entire freshman year. For example, every class has an engineering system that must be fabricated and tested, with the level of design involvement growing throughout the year as the project complexity increases.

Further detail is provided in Figures 2 – 4, where the specific outcomes for each engineering course in the freshman sequence (ENGR 120, 121, and 122) are identified. These outcomes are linked in the curriculum objectives in Figure 1. The outcomes clearly define the content in each of the three courses. The faculty members involved with this curriculum have created "student" and "instructor" course notes that further define the course content. These notes are freely available to students on the Internet; instructors continue to expand the notes by adding additional example problems when they perceive that students are having difficulty with the material. The notes will continue to be expanded over time to further eliminate the need for a course textbook.

Students are administered end-of-quarter surveys to determine their level of confidence in meeting each of the course outcomes. Thus by tying these outcomes to course objectives and compiling the results, student mastery of course outcomes and their confidence in further developing the attributes of The Engineer of 2020 can be indirectly measured.

Course outcomes for each course → curriculum objectives → attributes of the Engineer of 2020

We are currently collecting course assessment data that will be tabulated at the end of the academic year to quantify how well we are fostering the desired attributes in our students. Tracking overall scores for each attribute over time will allow us to systematically examine and alter our curriculum to better achieve the desired attributes. Our goal in the freshman curriculum is to prepare the students as effectively as possible for engineering careers.

SYSTEMS:

1. **fabricate, test and evaluate the efficiency** of an engineering system (A1,A2,A3,A6)
2. **fabricate and test** an engineering system where two physical parameters are controlled (A1,A2,A3,A6)
3. **conceive, design, and fabricate** a prototype utilizing a controller, sensors and actuators (A1,A2,A3,A6)

ELECTROMECHANICAL:

4. **utilize** a programmable controller that interfaces with selected sensors and actuators (A1,A2)
5. **implement** functional circuits on a solderless breadboard for sensing and control applications (A1,A2)
6. **utilize** multimeters to troubleshoot circuits and to determine the power usage of a device (A1,A2)
7. **describe** the specifications, operating procedures, and underlying physics for the hardware utilized (A1,A2)

FABRICATION AND ACQUISITION:

8. **fabricate** parts using a wide range of conventional manufacturing processes (A2)
9. **design and fabricate** an RTD sensor using microfabrication processes (A1,A2)
10. **locate** materials, supplies and components in stores and from online suppliers (A2)
11. **specify and purchase** materials, supplies or components for projects (A2)

SOFTWARE:

12. **utilize** Excel, Mathcad and Solid Edge to assist in engineering analysis and design (A1,A2)
13. **formulate and implement** sequential computer programs for sensing and control applications (A1,A2)

FUNDAMENTALS:

14. **apply** concepts of electricity and DC electric circuits (A1)
15. **apply** basic statistics to quantify and model experimental data (A1)
16. **apply** conservation of energy to engineering systems (A1)
17. **apply** basic chemistry and electrochemistry to salt water mixtures (A1)
18. **apply** conservation of mass to engineering systems (A1)
19. **apply** least squares fitting to calibrate sensors (A1)
20. **apply** concepts of statics to engineering systems (A1)
21. **apply** engineering economics to solve time value of money problems (A1)

COMMUNICATION:

22. **utilize** the specified engineering problem solving approach when completing assignments (A1,A4)
23. **properly** present technical information in tables and graphs (A4)

10.communicate the results of investigations and projects both orally and in writing (A4)

BROADENING ACTIVITES:

24. **assess** potential impacts of selected global and societal forces on our planet and its inhabitants (A5,A6,A7)
25. **regularly attend** professional society meetings and other student-led functions (A7,A8,A9)
26. **work individually and collaboratively** to complete course assignments (A4,A8)
27. **apply** creative problem solving techniques for product design (A3)
28. **manage** time and resources during the development of an innovative product (A10)

Figure 1. Curriculum Objectives of the *Living with the Lab* Curriculum. Linkages with the attributes of The Engineer of 2020 (*see Table 2*) are shown in parentheses.

Outcomes: **Students completing ENGR 120 will:**

1. **explain** the trends and **assess** the implications of population growth and climate change on environmental sustainability, quality of life, the economy and the engineering profession through oral presentations and written reports (25)
2. **utilize** the prescribed solution format when solving problems - Given, Required, Solution, Discussion (22)
3. **properly** present technical data in tables and on graphs (23)
4. **explain** the origin of electric charge, and **define** electric current, voltage, resistance and power (14)
5. **compute** current, resistance, voltage and power for circuits composed of resistors and DC power sources using Ohm's law and Kirchoff's laws (14)
6. **compute** the mean, median, standard deviation and variance of a data set (12,15)
7. **determine** the best fit equation for a set of (x, y) data points, considering linear, power, polynomial and exponential functions (12,15)
8. **identify** and **describe** the purpose of each component on the BASIC Stamp II microcontroller, the Board of Education, and Boe-Bot (7)
9. **convert** between decimal numbers and binary numbers (7)
10. **explain** how programs and variables are stored in EEPROM and RAM on the BASIC Stamp II microcontroller (7)
11. **implement** whisker, photoresistor, LED and piezospeaker circuits on a the Board of Education breadboard based on circuit diagrams provided by the instructor or in the Robotics book (5)
12. **program** a BASIC Stamp II microcontroller using the PBASIC language to receive input from whisker and photoresistor circuits to control the speed and direction of servos, the illumination of LEDs, and the frequency and duration of sound output from piezospeakers (4,13)
13. **demonstrate** individual skill using selected manufacturing techniques, including soldering, layout, bending, sawing, drilling, milling, pressing, and cutting internal and external threads; show skill in utilizing a scale and a dial indicator (8)
14. **locate** specifications and prices for the supplies, parts and systems used in course projects from manufacturers and on-line retailers (10)
15. **fabricate** a centrifugal pump driven by a DC motor with an impeller drawn in Solid Edge and printed on a rapid prototyping machine (1)
16. **utilize** a multimeter to troubleshoot circuits and to measure the current, voltage and power usage of an electric pump (6)
17. **compute** the efficiency and **evaluate** the performance of a centrifugal pump using DC circuit analysis, conservation of energy, and linear regression analysis (1,14,15,16)
18. **create** Excel spreadsheets using formulas and built-in functions and **generate** plots of the spreadsheet data (12)
19. **utilize** Mathcad to perform simple numerical calculations, to build functions, to solve sets of linear equations and to create plots (12)
20. **generate** 3D models of pump components and assemblies using Solid Edge (12)
21. **work collaboratively** with one or more other students to complete the pump project (27)
22. **present** the results of assignments and projects using written and oral communication (24)
23. **attend** five professional society meetings or student-led functions

Figure 2. Outcomes for ENGR 120 – Engineering Problem Solving I. Linkages with the Curriculum Objectives (*see Figure 1*) are shown in parentheses. Note that underlined topics may be replaced frequently by similar topics.

Outcomes: **Students completing ENGR 121 will:**

1. **explain** the trends and **assess** the implications of the book "The World is Flat" by Thomas Friedman and the availability of fresh water on environmental sustainability, quality of life, the economy and the engineering profession through oral presentations and written reports (25)
2. **utilize** the prescribed solution format when solving problems - Given, Required, Solution, Discussion (22)
3. **compute** the molarity, concentration, and mass of the constituents in a salt water mixture (17)
4. **compute** quantities such as ion concentration, mass of reactants and products, and electrical current for a salt water mixture undergoing oxidation/reduction reactions due to the presence of a conductivity probe (17)
5. **apply** conservation of mass to batch and rate problems to compute the inputs, outputs and changes of system constituents (18)
6. **apply** conservation of energy to a small volume of water that is heated using an electrical resistance heater, computing quantities such as heater wattage, temperature change, and heating time (16)
7. **design** an electrical resistance heater to heat a small volume of water in a specified period of time, where the design involves choosing the gage and length of a segment wire (14)
8. **evaluate** the compatibility of electrical components and devices (transistors, solenoid valves, heaters, pumps, sensors) with the BASIC Stamp II microcontroller, the Board of Education, and external power supplies (7,14)
9. **implement** cascaded switching circuits consisting of transistors and relays to allow the BASIC Stamp II microcontroller to switch solenoid valves, a resistance heater, and a pump (5)
10. **implement** RC circuits and PBASIC programs to interface the BASIC Stamp II microcontroller with temperature and conductivity sensors (5,13)
11. **utilize** linear regression analysis to calibrate temperature and conductivity sensors (19)
12. **explain** the microfabrication steps and processes used to fabricate a resistance temperature detector - RTD (9)
13. **design** a nickel-based RTD by computing the width and length of the resistor and by drawing the chosen resistor layout using Solid Edge (12)
14. **fabricate** a nickel-based RTD by spinning a photoresist onto a substrate coated with a thin layer of nickel, exposing the photoresist using a resistor pattern printed onto a mask, developing the photoresist, and etching away the exposed nickel to form the resistor pattern (9)
15. **design, fabricate and test** a system where the temperature and salinity of a small fluid volume are measured and controlled using a BASIC Stamp II microcontroller, a temperature probe, a conductivity sensor, two solenoid valves, a resistance heater and a pump (2)
16. **locate** specifications and prices for the supplies, parts and systems used in course projects from manufacturers and retailers (10)
17. **demonstrate** individual skill using selected manufacturing techniques, including layout, assembly, drilling, pressing, and cutting internal and external threads (8)
18. **generate** 3D models and assemblies of the fish tank project using Solid Edge (12)
19. **work collaboratively** with one or more other students to complete the fish tank project (2,27)
20. **present** the results of assignments and projects using written and oral communication (22,24)
21. **attend** five professional society meetings or student-led functions (26)

Figure 3. Outcomes for ENGR 121 – Engineering Problem Solving II. Linkages with the Curriculum Objectives (*see Figure 1*) are shown in parentheses. Note that underlined topics may be replaced frequently by similar topics.

***Outcomes:* Students completing ENGR 122 will:**

1. **explain** the trends and **assess** the implications of the availability of energy and the recent tendencies toward a global economy on environmental sustainability, quality of life, the economy and the engineering profession through oral presentations and written reports (25)
2. **apply** statics to determine resultants of force systems (20)
3. **apply** statics to determine unknown forces and moments for concurrent and non-concurrent force systems (20)
4. **apply** the principles of electrical circuits, statics and conservation of energy to evaluate the efficiency of a motor / gearbox system, computing quantities such as electrical power usage, mechanical power output, torque and angular velocity (14,16,20)
5. **compute** present worth, future worth, annuity schedules to perform engineering economic analyses (21)
6. **utilize** Mathcad and Excel to assist in solving engineering problems (12)
7. **implement** an infrared LED / receiver circuit (IR pair) to detect objects (5,7)
8. **implement** a Hall-effect sensor circuit as a proximity sensor (5,7)
9. **list** the specifications and PBASIC commands to interface selected sensors to the BASIC Stamp II microcontroller, and **explain** the physics behind how the sensors function (7)
10. **explain** the roles of the ten "Faces of Innovation" as discussed in "The Ten Faces of Innovation" by Tom Kelley (28)
11. **create** a Mind Map to organize ideas around a central topic (28)
12. **list** the five steps in the IDEO design methodology (28)
13. **list** the "Seven Secrets for Better Brainstorming" as described in "The Art of Innovation" by Tom Kelley ()
14. **apply** the Pugh method to evaluate concept ideas (28)
15. **conceive, design, fabricate and test** a functional prototype of an innovative product that utilizes one or more sensors, actuators or other output devices, and the BASIC Stamp II microcontroller (3)
16. **specify, locate and purchase** supplies and parts for an innovative product (11)
17. **generate** a 3D model of an innovative product using Solid Edge (12)
18. **work collaboratively** with one or more other students to develop an innovative product (27)
19. **develop** a work plan to manage your time and resources to successfully produce a prototype of an innovative product (29)
20. **present** the results of assignments and projects using written and oral communication (24)
21. **attend** five professional society meetings or student-led functions (26)

Figure 4. Outcomes for ENGR 122 – Engineering Problem Solving III. Linkages with the Curriculum Objectives (*see Figure 1*) are shown in parentheses. Note that underlined topics may be replaced frequently by similar topics.

Facilities and Resources

The Freshman Projects Classroom is an 1800-square foot classroom that has been completely remodeled for teaching the new freshman engineering sequence of classes (*see Figure 5*). The classroom includes:

- 11 tables that seat 4 students each, with electrical outlets in the floor near each table;
- 1 desktop computer system at the front of the room for faculty use;
- 1 LCD projector and a 10-foot projection screen;
- 2 portable lathes;
- 1 belt sander;
- 10 milling/drilling machines; and,
- ample cabinet space for storage of course tooling and supplies.

In addition, parts kits are provided to students which include, as needed, handheld drills, drill bits, and soldering irons, along with miscellaneous parts and accessories.

Figure 5. Layout of the integrated freshman classroom / laboratory / shop area.

Figure 5 shows the spacing of the milling / drilling machines. A single workstation with one of these machines is shown in Figure 6, along with a student who is working to fabricate the centrifugal pump, which is the project that drives the course content for ENGR 120.

Figure 6. Students using a milling / drilling machine to fabricate a centrifugal pump.

A total of 10 teams of two students can use the machines at the same time, or half of a class of 40 students (which we have established as our limit). Students use instructor PowerPoint presentations to guide them through the fabrication process, allowing the student groups to work independently without the need for constant instructor supervision. The instructor is free to roam around the classroom to help student groups when needed. The course is structured so that the other half of the class performs an alternate activity when the milling / drilling machines are in use by the other students. In the case of the pump project, while half the students are performing fabrication activities, the others work on developing a 3D model of the pump assembly using Solid Edge. Both the pump and the solid model are shown in Figure 7 to provide the reader with an idea of the type of project completed in the course.

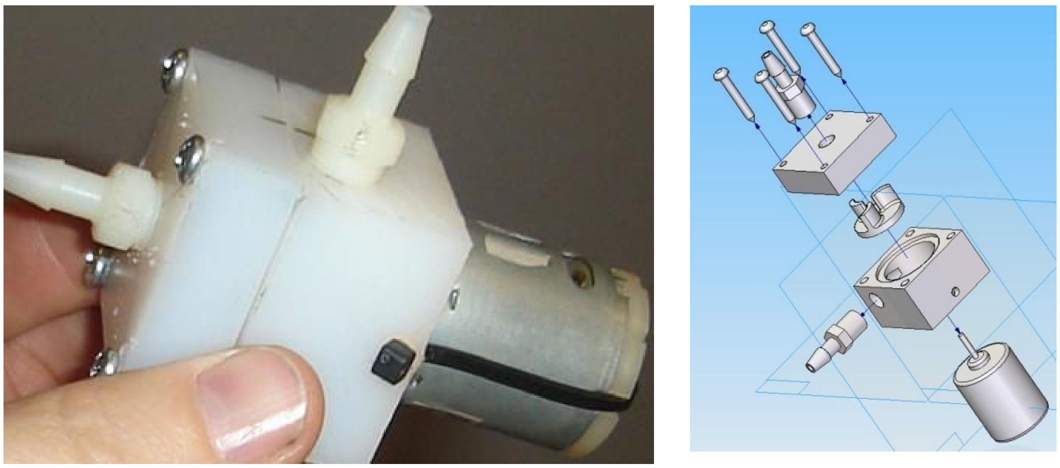


Figure 7. Centrifugal pump and its solid model.

The project in ENGR 121 is a fish tank project where students develop a system to control the temperature and salinity of a small volume of water. Students build almost the entire system from scratch, including the pump, the conductivity sensor, and a microfabricated resistance temperature detector (RTD) (*See Figure 8.*). This course is almost entirely focused on presenting the fundamentals (salt water chemistry, conservation of mass, conservation of energy), knowledge and skills required to implement the project. Figure 8 shows a student calibrating his RTD on his fish tank.

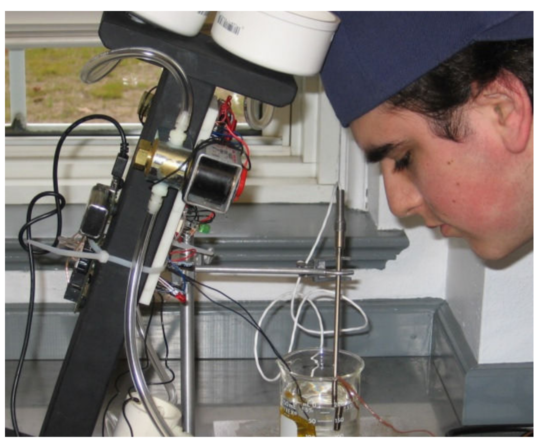
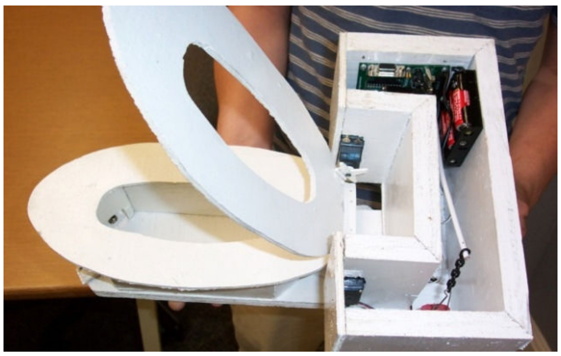


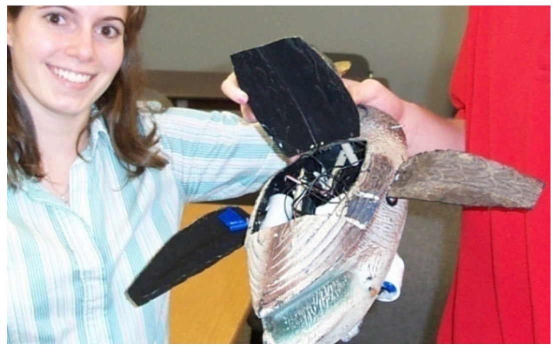
Figure 8. Student calibrating his RTD on the winter quarter fishtank project

Students are required to design an “smart product” as part of ENGR 122, the last of the three courses. Examples of these projects are shown in Figure 9.

RF coasters - transmits a message to waiter to fill drink


remote control dog harness with 4 built-in vibrators


smart toilet – a way to stay clean in the restroom


remote controlled duck


Smart pants – built-in IR object detection


poker chip sorter – uses color sensor


smart pot – maintains temperature in pot at setpoint


musical relaxation fountain

Figure 9 – Example projects from the third freshman course

The Freshman Projects Classroom provides very flexible delivery of course content. The instructor can deliver a typical lecture, and can easily move around the room to assist students with in-class assignments. Also, the instructor is able to show videos on the operation of equipment, demonstrate the operation of the equipment, and then monitor the students as they use the equipment.

Providing tables and in-class workstations facilitates teamwork. Most in-class projects require the students to work in teams of two; projects with more involved fabrication may have students working in teams of four.

Because many students have technical difficulties with installing software on their computers or getting the Boe-Bots to work, a Help Desk was established for providing technical assistance. The Help Desk is manned by two students who have been through the *Living with the Lab* curriculum, offering assistance for ten hours per week during the quarter. The implementation of the Help Desk has reduced the number of requests for technical assistance previously fielded by the instructors, in part because:

(a) The Help Desk is operated in the evening, when faculty members are typically unavailable.
(b) Students seem less intimidated to ask for help from other students.

Linkages of the Curriculum to the Engineering Disciplines

Perceived linkages between the freshman curriculum and individual engineering disciplines are summarized in Figure 10. These linkages were evaluated by a faculty member from each discipline and indicates their opinion as to the importance/relevance of the topic to their discipline. Clearly, the importance will vary from one faculty member to another. Some faculty members, such as the civil engineering faculty member interviewed, believed that all of the fundamental topics are relevant to civil engineers (he felt that they should all have an understanding of the fundamentals), whereas the faculty member from industrial engineering only checked the fundamentals that were essential for industrial engineers. However, at least one objective from each of the seven threads was checked by every discipline.

Whereas all disciplines thought that designing a smart product was important for their discipline, very few disciplines indicated that implementing circuits on a breadboard was important. However, the skill of breadboarding and most of the other skills in the electromechanical, fabrication & acquisition, and software threads are essential for having the competence to conceive, design and fabricate a smart product. So, some of the objectives are clearly dependent on other objectives, and, for these cases, it would be difficult to eliminate one objective without affecting another (the projects require most of the course content in one way or the other).

Class Activity	Biomedical	Chemical	Civil	Electrical	Industrial	Mechanical
SYSTEMS						
Fabricate, test and evaluate a centrifugal pump	■	■	■	■		■
Fabricate and test a tank system where salinity and temperature are controlled	■	■	■	■		■
Conceive, design and fabricate a smart product	■	■	■	■	■	■
ELECTROMECHANICAL						
Utilize a programmer controller to interface with sensors and actuators	■	■		■	■	■
Implement functional circuits on breadboards	■			■		
Utilize multimeters for troubleshooting and circuit analysis	■		■	■		■
Describe the specs, operating procedures and underlying physics of hardware	■		■	■		■
FABRICATION AND ACQUISITION						
Fabricate parts using conventional manufacturing processes	■				■	■
Design and fabricate an RTD sensor using microfabrication processes	■	■		■		
Locate materials, supplies and components in stores and from online suppliers	■		■	■	■	■
Specify and purchase materials, supplies or components for projects	■		■	■	■	■
SOFTWARE						
Utilize Excel, Mathcad and Solid Edge to assist in engineering analysis and design	■	■	■	■	■	■
Formulate and implement sequential computer programs	■	■	■	■		■
FUNDAMENTALS						
Electricity and DC circuits	■		■	■		
Statistics and data modeling	■	■	■		■	■
Conservation of energy	■	■	■	■		■
Basic chemistry and electrochemistry of salt water mixtures	■	■	■			■
Conservation of mass	■	■	■			■
Least squares curve fitting	■	■	■	■	■	■
Statics	■		■			■
Engineering economics	■	■	■		■	■
COMMUNICATION						
Use engineering solution format (GIVEN, REQUIRED, SOLUTION, DISCUSSION)	■	■	■	■	■	■
Properly present technical information in tables and graphs	■	■	■	■	■	■
Write reports and give oral presentations	■	■	■	■	■	■
BROADENING ACTIVITIES						
Assess impacts of selected global & societal issues	■	■	■	■	■	■
Attend professional society meetings and other student functions	■	■	■	■	■	■
Apply creative problem solving techniques	■	■	■	■	■	■
Manage time and resources during projects	■	■	■	■	■	■

Figure 10. Linkages between the freshman curriculum and the engineering disciplines

Assessment

During the 2006-07 academic year, the *Living with the Lab* curriculum was tested in pilot sections of honors students one last time before being fully implemented throughout the College of Engineering and Science. Students enrolled in both the traditional ENGR 122 classes and the ENGR 122 Honors sections were surveyed on how often they performed a variety of skill-based activities. Table 3 shows a comparison of the number of hands-on activities reported by each group of students during the quarter.

Table 3. "Hands-on" Application Means by Course[18]

Application	ENGR 122	ENGR 122H
Assembly	3.10	11.19
Bending	4.77	3.32
Cutting internal or external threads	.55	1.62
Drilling	4.29	13.14
Implementing circuits on a breadboard	.62	21.73
Layout	2.24	10.05
Milling	.09	.36
Rapid Prototyping	.71	.30
Sawing	2.05	7.77
Soldering	2.17	13.83
Using a dial indicator	.17	2.71
Using a lathe	.06	1.17
Using a multimeter	2.28	3.55
Using a scale	3.59	2.27
Writing PBASIC programs	.02	20.23

A Student's *t*-test on the "hands-on" application means in Table 3 demonstrates that the differences between the mean values are highly significant ($p = 0.004181$). We are confident that the project-based *Living with the Lab* curriculum is fulfilling our goal of providing the students with the practical experiences that they will need in their engineering careers.

Table 4 shows a comparison of the common course outcome performance means between the traditional curriculum and the *Living with the Lab* curriculum. Student responses could range from 1 ("completely unconfident") to 6 ("completely confident").

Table 4. Comparison of Common Course Outcome Performance Means between the Traditional and the *Living with the Lab* Curricula

Item	ENGR 120 (trad.)	ENGR 120 (LWTL)
Utilize the prescribed solution format when solving problems.	5.66	5.09
Work collaboratively with one or more other students.	5.36	5.27
Present the results of assignments and projects using written communication.	4.79	4.86
Present the results of assignments and projects using oral communication.	3.91	4.42
Generate 3D models of engineering components and assemblies using Solid Edge.	2.41	4.43
Present technical data in tables and on graphs in a professional manner.	4.53	5.09
Locate specifications and prices for the supplies, parts and systems used in course projects from manufacturers and on-line retailers.	3.15	5.01
Use linear regression analysis as appropriate in class projects.	3.58	4.75
Utilize MathCAD to assist in solving engineering problems.	1.32	4.97
Utilize Excel to assist in solving engineering problems.	5.26	5.20

A Student's *t*-test was performed to compare the performance means of the common course outcomes between the traditional and the *Living with the Lab* curricula. The performance means for the *Living with the Lab* curriculum were found to be significantly higher ($p = 0.025738$) than those for the traditional curriculum. It can be seen in Table 4 that students in the traditional curriculum did master some of the course outcomes to a higher degree; this was in part due to the fact that more instructional time was provided for several of the outcomes.

We are convinced that the new project-based *Living with the Lab* curriculum is effective in offering the students many more opportunities to develop the skill sets associated with "The Engineer of 2020," and we are enthusiastic about carrying this philosophy of blending theory with practical project-based experience to courses throughout the engineering disciplines.

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