

# Living WITH the Lab – A Freshman Curriculum to Boost Hands-on Learning, Student Confidence and Innovation

David Hall, Hisham Hegab, James Nelson  
Louisiana Tech University, dhall@latech.edu, hhegab@latech.edu, jdn@latech.edu

**Abstract** – A new freshman engineering curriculum has been implemented at Louisiana Tech University to boost hands-on learning, student confidence and innovation. The new curriculum, called Living WITH the Lab, increases experiential learning by moving the ownership and maintenance of laboratory equipment from the university to the students. Each student purchases a robotics kit with a programmable controller, sensors, servos, and software along with a toolkit to 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. The curriculum has been piloted for the past five years, and we are currently in the first year of full implementation to over 350 students thanks to a Phase II NSF CCLI grant. The paper presents the curriculum objectives, details of the three courses that make up the freshman curriculum, faculty training activities, and assessment results.

*Index Terms* – Robots, Experiential Learning, Freshman Curriculum, Innovation.

## INTRODUCTION

Project-based freshman engineering curricula began in the 1990s due in large part to the NSF Engineering Education Coalitions [1]-[4]. This trend towards hands-on freshman engineering programs with a significant design component continues today at a variety of universities across the country [5]-[7]. There is a significant amount of literature on the subject that shows many benefits of incorporating project-based instruction with design early and often within engineering curricula [1]-[11].

In traditional laboratory settings, faculty members must make sure 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, accomplishing this task over a long period of time and with a large number of students is difficult and is sometimes not sustainable.

The College of Engineering and Science at Louisiana Tech University has implemented a freshman engineering curriculum called "Living WITH the Lab" for over 350

students. The new curriculum seeks to achieve a major increase in experiential learning in a way that is sustainable by putting the ownership and maintenance of the "laboratory" into the hands of the students. Student-owned laboratories facilitate frequent hands-on learning and build the knowledge, skills and spirit that lead to innovation. This paper describes the new curriculum along with faculty training activities and assessment results.

## THE FRESHMAN CURRICULUM

In 1998 the College of Engineering and Science (COES) at Louisiana Tech University moved to an integrated engineering curriculum based on the educational practices of the NSF Educational Coalitions. Our freshman integrated curricula is shown in Table I.

The freshman integrated courses are taken in "blocks" so that classes of 40 students share the same mathematics, science and engineering courses. We attempt to coordinate topics in the mathematics and science courses with the topics in the engineering courses to motivate student learning and to assist in developing bridges across the disciplines. Assessment results indicate that students who completed the integrated curriculum were better prepared for more advanced math and engineering courses [12].

During the past five years, we have offered the "Living WITH the Lab" project-based sequence of ENGR 12X courses to pilot groups of freshman engineering students. The new courses were required for all freshman engineering students this past academic year thanks to funding from a Phase II NSF CCLI grant.

TABLE I  
FRESHMAN ENGINEERING CURRICULA

Fall Quarter		Winter Quarter		Spring Quarter	
Course	sch	Course	sch	Course	sch
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

The "Living WITH the Lab" curriculum seeks to immerse students in a skill-based, project-driven curriculum that builds creativity and a can-do spirit [13]. Curriculum objectives are divided into seven threads that run concurrently throughout the freshman year, as shown in

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Figure 1. Each of the objectives is mapped to one or more of the ten attributes of “The Engineer of 2020” [14]-[15] which serves as a set of guideposts for the curriculum.

- |   |
|---|
| <p><b>1. SYSTEMS</b></p> <ul style="list-style-type: none"> <li>• fabricate, test and evaluate the efficiency of an engineering system</li> <li>• fabricate and test an engineering system where two parameters are controlled</li> <li>• conceive, design and fabricate a prototype using a controller, sensors &amp; actuators</li> </ul> <p><b>2. ELECTROMECHANICAL</b></p> <ul style="list-style-type: none"> <li>• interface a programmable controller with selected sensors and actuators</li> <li>• implement circuits on a solderless breadboard for sensing / control applications</li> <li>• utilize multimeters for troubleshooting and to determine electrical power usage</li> <li>• describe the specifications, operating procedures, and underlying physics for the hardware utilized</li> </ul> <p><b>3. FABRICATION AND ACQUISITION</b></p> <ul style="list-style-type: none"> <li>• fabricate parts using a wide range of conventional manufacturing processes</li> <li>• design and fabricate an RTD sensor using microfabrication processes</li> <li>• locate materials, supplies and components in stores and from online suppliers</li> <li>• specify and purchase materials, supplies or components for projects</li> </ul> <p><b>4. SOFTWARE</b></p> <ul style="list-style-type: none"> <li>• utilize Excel, Mathcad and Solid Edge in engineering analysis and design</li> <li>• formulate and implement computer programs for sensing and control applications</li> </ul> <p><b>5. FUNDAMENTALS</b></p> <ul style="list-style-type: none"> <li>• apply concepts of electricity and DC electric circuits</li> <li>• apply conservation of energy to engineering systems</li> <li>• apply basic chemistry and electrochemistry to salt water mixtures</li> <li>• apply conservation of mass to engineering systems</li> <li>• apply least squares fitting to calibrate sensors</li> <li>• apply concepts of statics to engineering systems</li> <li>• apply engineering economics to solve time value of money problems</li> </ul> <p><b>6. COMMUNICATION</b></p> <ul style="list-style-type: none"> <li>• utilize the specified engineering problem solving approach</li> <li>• properly present technical information in tables and graphs</li> <li>• communicate the results of investigations and projects both orally and in writing</li> </ul> <p><b>7. BROADENING ACTIVITIES</b></p> <ul style="list-style-type: none"> <li>• assess potential impacts of selected global and societal forces on our planet and its inhabitants</li> <li>• regularly attend professional society meetings and other student-led functions</li> <li>• work individually and collaboratively to complete course assignments</li> <li>• apply creative problem solving techniques for product design</li> <li>• manage time and resources during the development of an innovative product</li> </ul> |
|---|

FIGURE 1  
OBJECTIVES OF LIVING WITH THE LAB CURRICULUM.

The content timing and delivery has been structured so that the knowledge, skills and attitudes associated with each of the seven threads are built progressively. Aspects of each of the seven threads are included in all three of the freshman courses to provide continuity throughout the freshman year.

**STUDENT-PURCHASED HARDWARE AND SOFTWARE**

Each freshman student is required to purchase a Parallax Boe-Bot [16], a tool kit, and several software packages to facilitate project-work. The Boe-Bot, shown in Figure 2, includes a Basic Stamp 2 microcontroller with 16 digital input/output pins, a 5-volt regulated power source, 2 continuous-rotation servos for robot locomotion, and a spiral bound book. The Boe-Bot also includes a solderless breadboard for implementing sensing and actuation circuits; the kit contains whiskers for sensing touch, photoresistors for sensing light levels, and infrared LED / receiver pairs for sensing objects without contact. The published price for a single Boe-Bot is ~\$160 [16], while discounts are available

for larger quantity purchases. Boe-Bot kits allow students to quickly develop skills in programming and circuit prototyping.

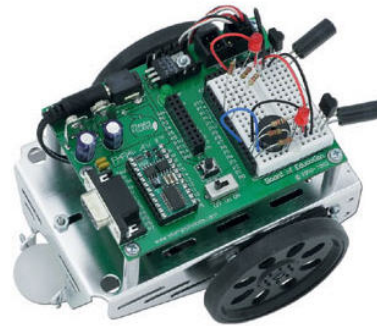


FIGURE 2  
BOE-BOT EQUIPPED CONFIGURED FOR INFRARED OBJECT DETECTION.

Students entering the curriculum are required to provide a laptop computer and software for engineering analysis, design and presentations; we use Excel®, Mathcad®, and Solid Edge®, and PowerPoint®. Students purchase tools and supplies that they are expected to use throughout the year, as summarized in Table II. These tools can be purchased for approximately \$60 from discount sources.

TABLE II  
STUDENT PURCHASED TOOLS AND SUPPLIES

Multimeter	Test clips for multimeter
Safety glasses	Tool bag
Needle nose plier	Stainless steel ruler
6-inch dial caliper	Phillips & Flat screwdrivers
Wire strippers / crimper	Alligator test leads
Fine-tip permanent marker	Electrical tape
Solder and flux	Knife
Batteries (9V and AA)	12VDC wall power supply
Extra Breadboard	Drill bits
Mini-hacksaw	Tape

**UNIVERSITY FACILITIES AND EQUIPMENT**

The freshman courses meet in the “Freshman Projects Laboratory” which was designed to seamlessly integrate lecture, laboratory and project work for a group of 40 students, as shown in Figure 3.



FIGURE 3  
FRESHMAN PROJECTS LABORATORY.

The 1,800-square foot laboratory includes a 20-foot whiteboard, a digital video projector, 10 tables for seating student teams, 10 milling machines with tooling,

microfabrication equipment, storage cabinets, and hand tools to facilitate project work. A milling machine workstation is shown in Figure 4. The classroom is configured to allow 10 teams of 4 students to work simultaneously. For projects that involve teams of 2 students, half of the teams perform alternate project activities at their tables while the milling machines are used by the other teams.



FIGURE 4  
ONE OF 10 MILLING MACHINES IN LABORATORY.

### CLASSROOM PEDAGOGY

The ENGR 120, 121 and 122 classes meet twice per week in the freshman projects laboratory for 1 hour and 50 minutes. These extended class periods provide an opportunity to “mix it up” by moving from one type of activity to another. Elements that define the classes include:

- Individual homework assignments due each class
- No textbook other than the Parallax Boe-Bot book
- Course notes with “holes” to encourage student involvement are available on the web:  
ENGR 120: [www2.latech.edu/~dehall/LWTL/ENGR120/main.html](http://www2.latech.edu/~dehall/LWTL/ENGR120/main.html)  
ENGR 121: [www2.latech.edu/~dehall/LWTL/ENGR121/main.html](http://www2.latech.edu/~dehall/LWTL/ENGR121/main.html)  
ENGR 122: [www2.latech.edu/~dehall/LWTL/ENGR122/main.html](http://www2.latech.edu/~dehall/LWTL/ENGR122/main.html)
- Instruction on course topics, varying from 10 to 60 minutes (circuits, sensors, fabrication, software, . . .)
- Student programming assignments (make your Boe-Bot whistle, Boe-Bot maze navigation, . . .)
- Group problem solving (material balance, statics, . . .) while the instructor circulates through the room
- Project work, such as prototyping circuits, drilling, assembly, measuring, programming, testing, . . .
- Open-ended design of an innovative product using the IDEO design philosophy [17]
- Student presentations of course project results
- Open discussion of global and societal issues
- Student attendance at professional society meetings or service projects
- Grading of homework, quizzes, projects, and exams
- Two-part, common exams (written and computer) administered in the evening to all ENGR course sections

### ENGR 120 – COURSE #1

Students begin implementing simple circuits on the Boe-Bot’s breadboard and verifying Kirchoff’s current and voltage laws. Students prototype LED, piezospeaker, 978-1-4244-1970-8/08/\$25.00 ©2008 IEEE

photoresistor, and whisker circuits and learn to control Boe-Bot motion by sending voltage pulses to wheel servos.

PBASIC programs are written to interface the BASIC Stamp 2 microcontroller with various circuits, sensors and with a laptop. Students write programs to guide the Boe-Bot around a book on their table (class 6), make a piezospeaker output a common whistle sound (class 9) and cause their Boe-Bot to follow a black line on a white surface (class 19).

Other topics in ENGR 120 include linear regression, conservation of energy, software skills (Mathcad®, Excel® and Solid Edge®), problem solving methodology, and presentation skills. Students also independently learn about and report on a “global and societal” issue that could impact their career. The issues covered in ENGR 120 this past year include human population and waste management.

The ENGR 120 project involves fabricating and quantifying the performance of a centrifugal pump [18], as shown in Figure 5. Student teams of two fabricate the pump from scratch using one of the milling machines shown earlier in Figure 4. The pump body and face plate are made of ultra high molecular weight polyethylene and the ABS plastic impellers are rendered on a rapid prototyping machine using a student-drawn Solid Edge model. A Solid Edge model of the pump is shown in Figure 6. Each pump costs less than \$4, and many of the parts can be reused.

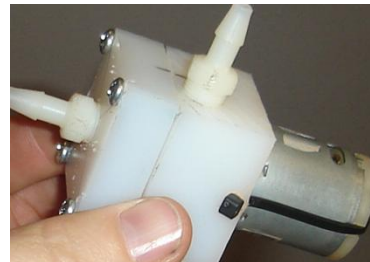


FIGURE 5  
PUMP FABRICATED BY TEAMS OF 2 IN ENGR 120.

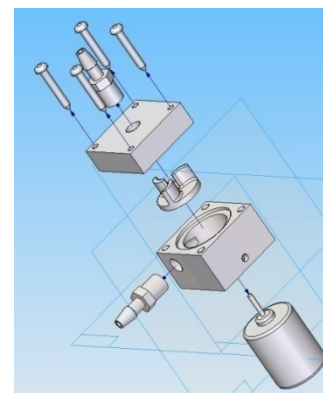


FIGURE 6  
SOLID MODEL OF PUMP ASSEMBLY.

Students apply conservation of energy to model the efficiency of the pump. Students use their multimeters to measure the electrical energy usage of the pump (voltage x

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current x time) and determine the energy imparted to the fluid through potential and kinetic energy changes.

Student teams are joined to form teams of four just before evaluating pump performance. Combining teams provides each team with two pumps to choose from and facilitates all of the students participating in seven-minute PowerPoint presentations of their project work; the entire class of 40 students can present their work in a single 110 minute class period.

### ENGR 121 – COURSE #2

ENGR 121 content is designed to support the “fish tank” project. Student teams fabricate a system to provide closed-loop control of the temperature and salinity of a small volume of salt water. The system, which is shown in Figure 7, includes the following components:

- A wooden support platform that is drilled, assembled and painted by the students
- A conductivity sensor that is fabricated and calibrated by the students
- A DC pump to circulate water through the in-line conductivity sensor
- A resistance temperature detector (RTD) that is fabricated and calibrated by the students [19]
- A resistance heater (an 18 ohm resistor driven by a 12VDC power supply)
- A “fish tank” chamber fabricated by the students from PVC pipe/fittings and nylon barbed fittings
- Two makeup water tanks at the top of the platform to provide salty or fresh water to the fish tank
- Two solenoid valves to control the delivery of salty or fresh water to the fish tank
- An overflow tank so that the level in the fish tank remains constant
- Several transistor/relay switching circuits
- A 555 timer circuit to interface with conductivity sensor
- An extra breadboard for implementing circuits
- The Boe-Bot control board (also called the Board of Education) to interface the sensors and actuators for a controllable system

Fundamental engineering and science course topics are provided “just-in-time” to support the project. The topics include salt water electrochemistry, material balance, and conservation of energy. The salt water chemistry is essential for understanding the oxidation and reduction reactions that occur at the probes of the conductivity sensor and the relationship of the rates of reaction to the electrical current. Conservation of mass is essential for understanding how much salt should be added to a volume of salt water to reach the “target salinity.” Conservation of energy allows the students to understand the heater power required to increase the temperature of the water in their fishtank in a reasonable amount of time. Students also apply the linear regression concepts learned in ENGR 120 repeatedly as they calibrate their conductivity and temperature sensors.

The fish tank project is a challenging one that requires a significant amount of troubleshooting to achieve a working system. The systems and PBASIC control programs are too complex to work on the first try, so students must learn to debug one system component at a time if they are to be successful. We have found that the project is most successful when using DI water with low salt concentrations; we use a 0.1% NaCl solution as our target salinity. ENGR 121 concludes with seven-minute student project presentations.



FIGURE 7  
ENGR 121 FISHTANK PROJECT DURING CALIBRATION OF RTD.

### ENGR 122 – COURSE #3

The theme of ENGR 122 is innovative product development. Student teams of four students conceive an idea for their own “smart product” based on a “bug list” [20] that they develop during the first half of the course. Examples projects are shown in Figure 8.

The IDEO design process that encourages prototyping early and often [17] is adopted for ENGR 122. Students learn the “Ten Faces of Innovation” [20], brainstorming techniques, and how to build mind maps as they prepare to design their innovative product. Each class before the initiation of the design project includes an introduction to a new sensor, fabrication technique, or mechanism that could be applied in student projects. A host of sensors are available to interface with the Boe-Bot platform, including ultrasonic, GPS, RFID, touch, force, and acceleration sensors.

ENGR 122 includes static force and moment analysis. This content builds toward a small project where students dissect their Boe-Bot servos, count the teeth on each gear in the gearbox, and relate the torque and RPM at the output shaft to that of the small DC motor that drives the servo. Figure 9 shows a servo with the cover removed.

ENGR 122 also includes engineering economics and two in-class discussions of global and societal issues. The spring quarter offering of ENGR 122 concludes with the Freshman Design Expo where all student teams come together at the University Student Center to present their projects and celebrate their successes.

FACULTY TRAINING

In the summer of 2007, we offered a two-week, in-house faculty training workshop for six faculty members who would be teaching the ENGR 12X courses. Each participant received their own Boe-Bot and worked through the same in-class and homework assignments that students would be expected to complete. They fabricated centrifugal pumps, RTDs, conductivity sensors, and fish tank systems. The workshop also introduced the faculty to the philosophy of the Living WITH the Lab curriculum, which often involves switching from one thing to another several times during a single class period. Spending two weeks together to focus on the curriculum provided for close bonding between the workshop participants, allowing us to build a strong team with open communication. We continue to meet weekly as we work together to deliver and improve the curriculum.

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 for all freshmen. Students enrolled in both the traditional ENGR 122 classes (which followed a freshman engineering textbook and included an end-of-year design project) and the ENGR 122 Honors sections were surveyed on how often they performed a variety of skill-based activities. Table III shows a comparison of the number of hands-on activities reported by each group of students during the quarter. A Student's t-test on the "hands-on" application means in Table III demonstrates that the differences between the mean values are highly significant ( $p < 0.005$ ); the new project-based curriculum is providing students with significantly more hands-on experiences than the previous integrated curriculum. Assessment of course and curriculum outcomes is ongoing with promising initial results [21]. Surveys of ENGR 120 students show that they overwhelmingly felt that the skills gained in the course would be useful to them in their engineering education and career.



RF coasters - transmits a message to waiter to fill drink



Smart pants – built-in IR object detection



smart pot – maintains temperature in pot at setpoint



smart toilet – a way to stay clean in the restroom

FIGURE 8  
EXAMPLE "PRODUCTS" DEVELOPED IN ENGR 122.

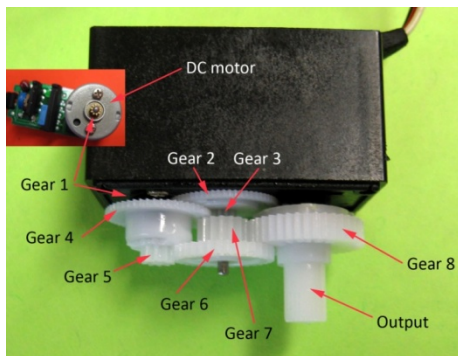


FIGURE 9  
ENGR 122 BOE-BOT SERVO PROJECT.

TABLE III  
COMPARISON OF HANDS-ON ACTIVITIES FOR NEW AND OLD CURRICULUM

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

## CONCLUSIONS

A new project-based freshman curriculum has been implemented at Louisiana Tech University that includes three two-semester hour engineering courses. The new curriculum, called Living with the Lab, boosts experiential learning by putting the ownership and maintenance of the “lab” into the hands of the students. Each student purchases a Parallax Boe-Bot that provides a platform for laboratory and design exercises. Students begin the freshman year learning to program their robots to navigate based on input from various sensors. By the middle of the year, they are programming their microcontroller to regulate the temperature and salinity of a small volume using temperature and conductivity sensors that they fabricate and calibrate themselves. As the year passes, students learn engineering and science fundamentals as well as software, fabrication, communication, teamwork, and systems-level thinking skills. An increasing level of independence is expected as students fabricate and test projects that are increasingly complex and open-ended. The freshman year culminates in the Freshman Design Expo where student teams showcase prototypes of their smart products. Initial assessment results show large gains in hands-on learning relative to the previous curriculum.

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## AUTHOR INFORMATION

**David Hall**, Program Chair, Mechanical Engineering, [dhall@latech.edu](mailto:dhall@latech.edu).

**Hisham Hegab** Program Chair Micro/Nanosystems Engineering, [hhegab@latech.edu](mailto:hhegab@latech.edu).

**James Nelson**, Associate Dean for Undergraduate Studies, College of Engineering and Science, [jdn@latech.edu](mailto:jdn@latech.edu)