Living with the Lab: Application-focused Education for Engineering and the Physical Sciences

David E. Hall
Louisiana Tech University (United States)
dhall@latech.edu

Abstract

Living with the Lab is an educational approach that boosts experiential learning through student ownership of inexpensive laboratory equipment. First-year engineering students at Louisiana Tech University purchase a robotics kit along with a collection of tools, software and supplies to provide a platform for laboratory and design projects. Student ownership of laboratory equipment expands the scope and complexity of projects that can be undertaken with large groups and provides a mechanism for building the knowledge, skills and spirit that lead to innovation. Our first-year experience includes three courses taught in a year-long sequence. These courses are taken by all engineering majors, involving over 600 students and 12 faculty members each year. The courses include engineering and science fundamentals, projects, technical enabling skills, non-technical skills, and broadening activities. The first-year experience culminates in the open-ended design of a smart product conceived and prototyped by student teams and presented to panels of judges at the Design Expo.

The availability and ease of use of student-owned learning platforms provides important alternatives to virtual learning approaches. Students enjoy leaning by doing. This paper describes how our student-owned approach has produced a large and sustainable boost in hands-on learning with minimal increases in faculty workload. Other opportunities to use technology to boost hands-on learning are discussed.

1. Learning Platforms for STEM Education

The availability of flexible, inexpensive and easy-to-use hardware and software platforms is transforming STEM education. K-12 students are using littleBits [1], LEGO Mindstorms [2], Boe-Bots [3], VEX robots [4] and other electronic platforms to monitor, explore and control their physical world, programming in languages such as Scratch [5], NXT software [6], PBASIC [7], and ROBOTC [8]. These learning platforms are sometimes purchased by schools for classroom use, by teams of students for competitions [9-12], and by the students themselves for school or hobby use. The number of students impacted is growing as new platforms are introduced and as more teachers are trained.

The hands-on learning made possible by this increasingly ubiquitous technology is also spreading across higher education. This is driven partly by the student market; today's students want to do engineering and not just learn about it through books and computers. Most university-level programs that integrate a technology platform into their courses have been developed over the past 10 years. While Electrical and Computer Engineering programs have made the most use of these platforms, they have also found heavy use in digital measurement and mechatronics courses. First-year engineering programs frequently include robots, microcontrollers and programming.

Manufacturers have recognized the growing market for inexpensive kits. Examples include the myDAQ platform [13] from National Instruments that is programmed using LabVIEW [14], the Analog Discovery system from Digilent [15], the Raspberry Pi and associated hardware [16], and the BeagleBone [17]. The capabilities of these platforms are rapidly expanding while the cost drops. The number of available supporting devices is exploding, including sensors, I/O devices, and actuators.

In most of the cases listed above, the cost of the hardware and software platform is low enough that universities can expect students to purchase the equipment themselves. The cost, in many cases, is similar to the cost of a textbook. Putting the ownership and maintenance of the "lab" in the hands of the students provides a dramatic boost in hands-on learning that is sustainable in terms of faculty workload. Students can learn at any time and in any place, both on-campus and off-campus, in face-to-face settings and via distance learning.

2. Living with the Lab

Louisiana Tech's first-year engineering experience provides relevant, project-focused education for over 600 students each year. Our six semester-hour, three-course sequence, called "Living with the Lab," boosts experiential learning through student ownership of inexpensive laboratory equipment.

Each student purchases an Arduino microcontroller ($30), hardware components to interface with the Arduino ($70), software (~$100), and a collection of tools and supplies (~$150) to provide a platform for laboratory and design projects. Our platform is depicted in Fig. 1. All course materials are provided online at no cost to the students; see www.livingwiththelab.com.

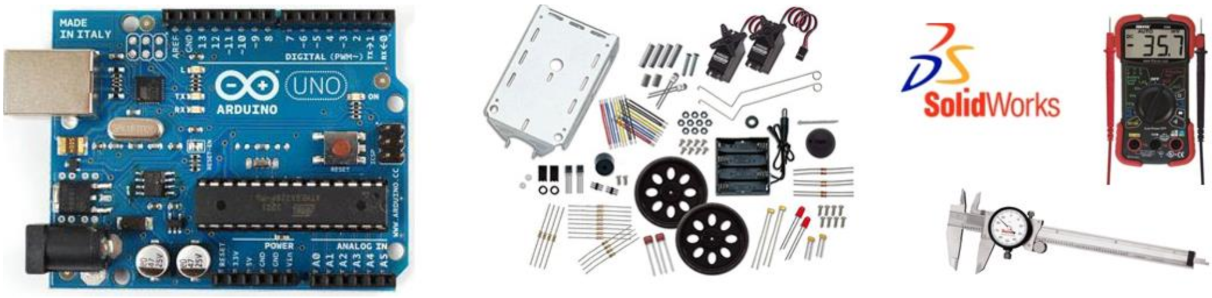

Fig. 1. Living with the Lab learning platform: Arduino (left), robot kit (center), software and tools (right).

2.1 Motivation for Living with the Lab

In 2004, the National Academy of Engineering published a report entitled “The Engineer of 2020: Visions of Engineering in the New Century [18].” The Engineer of 2020 project sought to develop a vision for the engineering field and to predict the work environment of future engineers. The phase 1 report identified ten key attributes to support the future relevance of the engineering profession:

1. Strong analytical skills
2. Practical ingenuity
3. Creativity
4. Good communication skills
5. Lifelong learners
6. Dynamic, agile, resilient, flexible
7. High ethical standards
8. Leadership skills
9. Professionalism
10. Business and management skills

Engineering education has traditionally focused on building strong analytical skills with limited curriculum elements in place to foster attributes 2 through 10. Living with the Lab seeks to develop a learning environment to support these attributes through individual challenges and team projects [19].

2.2 Nuts and Bolts of Living with the Lab

Our primary objective is to foster a can-do, entrepreneurial spirit through a constant back and forth between fundamentals and applications. Fundamental topics include circuits, linear regression, conservation of energy, material balance, statics and engineering economics. The courses also include a heavy project focus, technical enabling skills (software, measurement and control, prototyping), non-technical enabling skills (communication, teamwork, creative design strategies), and broadening activities (professional society meetings, global issues, service). The first-year experience culminates in the open-ended design of a smart product conceived and prototyped by student teams and presented to panels of judges at the Freshman Projects Expo. Applications in the course that are facilitated by the technology platform include:

- fabricating and testing a centrifugal pump using 3D printed impellers (Fig. 2)
- assembling a mobile robot from off-the-shelf components (Fig. 2)
- participating in a robot programming challenge
- controlling the temperature and salinity of water (Fig. 2)
    - fabricating a wooden support structure & a flow loop
    - calibrating conductivity & temperature sensors
    - integrating system components: transistors, relays, solenoid valves, pump, heater
    - controlling the system using an Arduino microcontroller with a C-program
- inventing a smart product, from concept through prototyping, testing, and presentation (Fig. 3)

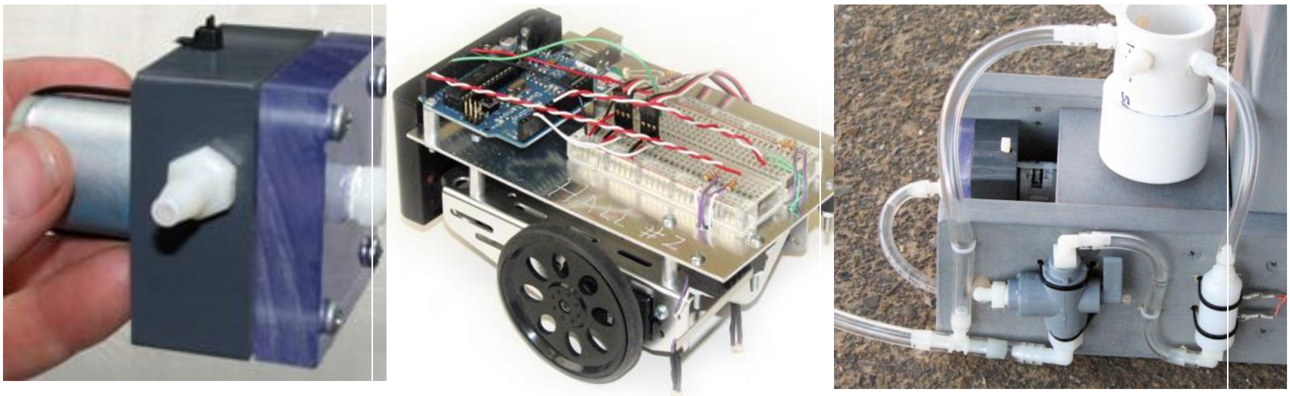

Fig. 2. Student fabricated pumps (left), robots (center), temperature & salinity control system (right)

creep & beep 3000 *tracking TV cabinet* *sun tracking umbrella*

contact lens cleaner *smart product circuit* *tricorder 1.0*

Fig 3. Teams displaying smart products at our annual Freshman Projects Expo.

2.3 Our Classrooms

The three engineering courses (ENGR 120, 121 and 122) are taught in classrooms with tables seating four students and with ready-to-use fabrication equipment, including soldering irons, milling machines, lathes, and sheet metal shear/brake combinations. Coupling fixed, university-owned equipment with each student's personal laboratory allows faculty to mix it up in class, rolling together lecture, group problem solving, laboratory exercises, prototyping, and shop activities.

Fig. 4 – Panarama view of classroom that seats 44 students (tables, whiteboard, video, workstations).

2.4 Mixed Course Delivery Modes
The three engineering courses each meet twice per week for 10 weeks, resulting in 60 class meetings during the academic year (2 meetings per week x 10 weeks per course x 3 courses). Each class lasts 110 minutes. Students also take mathematics, basic science and elective courses along with the three engineering courses. Our classroom pedagogy involves moving between lecture, laboratory, project work, team activities, and fabrication. Student-owned labs also facilitate moving hands-on learning experiences out of the physical classroom and into student housing, the library or the coffee shop. This mixed delivery mode reaches a broader set of learners than “book-centered approaches” and begins cultivating an “engineering mindset” from the very beginning. These real world applications excite students, build confidence, promote retention of knowledge, and provide a much-needed, hands-on context for students living in a digital age.

2.5 Sustainability in Terms of Effort and Cost
In traditional laboratory settings, faculty members must ensure that equipment is ready or that supplies are on hand so that prototypes can be constructed or so that data can be acquired. While energetic faculty members sometimes can and do 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 often not sustainable. The Living with the Lab student-owned lab approach addresses this problem by putting the ownership and maintenance of a “personal lab” into the hands of the students. Student ownership expands the scope and complexity of projects that can be undertaken with large groups and provides a mechanism for building the knowledge, skills, and spirit that lead to innovation. With low recurring costs, we have provided a large number of students with a program that pushes them to apply fundamental engineering knowledge to real-world situations. Our goal is for instructors to be able to walk into the classroom without having to worry about equipment or supplies, making their net effort similar to that of a lecture-based course.

2.6 Impact of Living with the Lab
Students completing the Living with the Lab, first-year experience report a 550% increase in hands-on activity from our previous “hands-on” curriculum. Table 1 shows the average number of hands-on experiences for the three courses (ENGR 120, 121 and 122) that make up the Living with the Lab freshman course sequence. The number of outside meetings and the number of service hours completed each term is also summarized in Table 1. Since fall 2007, a total of 20 faculty members have cumulatively taught 294 course sections with combined enrollments of 8,574 students.

Table 1. Key quantitative results for our three courses: ENGR 120, 121 and 122).

average per student	120	121	122
hands-on activities	205.5	182.2	224.6
meetings attended	5.2	4.8	5.1
service hours	2.9	5.6	5.8

3. Future Opportunities for Broader Audiences
A wide array of technology products are available to support STEM learning for all ages, as detailed in section 1. This technology provides an important link between the learner and the physical world. These technology platforms are becoming more capable, easier to use, and more ubiquitous. For example, many cell phones now include the following sensors:

- a camera to measure light level, to track objects, to identify constellations in the night sky, etc.
- an accelerometer to measure tilt and movements in three dimensions
- a gyroscope to provide accurate orientation information
- a magnetometer to sense magnetic fields and to act as a compass
- a proximity sensor to measure distance
- a light sensor to measure the brightness of ambient light
- A thermometer to measure temperature

Some phones are now including a humidity sensors, a barometer, a pedometer and a heart rate monitor. As more sensors are included devices such as phones and as more supporting devices are developed (that can be interfaced through Wi-Fi or Bluetooth), educational applications will be developed that open the “technology door” to a broader audience of teachers and learners. For example, interfacing a phone with heart rate and blood pressure measuring equipment through Bluetooth will extend allow for fun experiences in psychology, biology and kinesiology. Coupling this sort of technology with traditional face-to-face learning environments and with virtual learning environments provide exciting opportunities to deliver content in more varied and engaging ways.

4. Conclusions

Louisiana Tech University has embedded a student-owned technology platform into first-year engineering courses to boost the level of hands on learning in a way that is sustainable in terms of faculty workload and cost. This technology platform motivates the learning of STEM topics and facilitates the inclusion of a creative, team-based design project at the end of the first-year courses. Students value the skills that are developed, and these skills improve confidence for those transitioning into scientific and industrial jobs. While Louisiana Tech uses the Arduino microcontroller as the centerpiece of our learning platform, a host of technology elements are available to support learners of all ages and abilities. Educators across the academic disciplines can look toward an exciting future where technology elements are increasingly used to connect learners with the physical world.

References

[1] http://littlebits.cc/
[2] http://mindstorms.lego.com/en-us/default.aspx
[3] http://www.parallax.com/go/boebot
[4] http://www.vexrobotics.com/
[5] http://scratch.mit.edu/
[6] http://www.nxtprograms.com/
[7] http://www.parallax.com/downloads/basic-stamp-editor-software
[8] http://www.robotc.net/
[9] http://firstlegoleague.org/
[10] http://www.usfirst.org/
[11] http://www.bestinc.org/
[12] http://www.roboticseducation.org/
[13] http://www.ni.com/mydaq/
[14] http://www.ni.com/labview/
[15] https://www.digilentinc.com/
[16] http://www.raspberrypi.org/
[17] http://beagleboard.org/Products/BeagleBone
[18] National Academy of Engineering, “The Engineer of 2020.” The National Academies Press, Washington DC, 2004. www.nap.edu
[19] Hall, D.E., Cronk, S.R., Brackin, P.D., Barker, J.M., Crittenden, K.B. Living with the Lab: A Curriculum to Prepare Freshman Students to Meet the Attributes of "The Engineer of 2020," American Society for Engineering Education Annual Conference and Exposition, June 2008.