

A Lab for All Seasons, A Lab for All Reasons

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Introduction

With NSF SUCCEED funding, we initiated six years ago a laboratory in which new engineering students would use and take apart familiar consumer electronics and household devices(1). These future engineers, in teams of two or three, would move through a series of roles with each device assigned:

READ an explanatory chapter to learn history and principles,
USE the device to verify functionality and operability,
DISSECT and reassemble the device to view mechanics, optics, and circuit boards,
CALCULATE and analyze expected device performance, and
TEACH (present) to other teams the principles and lessons learned.

Depending on the lab purpose and the level of detail requested in assignments, each activity may take 30 minutes to 2 hours. Each device can thus be covered in a period ranging from 4 hours to two days, thereby providing a scheduling flexibility which allows facile adaptation to different program purposes.

We first discuss the various pedagogical motivations for such a lab (A Lab for All Reasons), then summarize our experiences and plans to utilize the lab year round (Lab for all Seasons).

A Lab for All Reasons

We have offered the course in several formats, described in the later section, "A Lab for All Seasons." In nearly all of these, a common set of educational advantages appears to pertain, as we now summarize.

1. "Hands-On"

The devices in our current lab include these consumer electronics and common household examples: bar code scanner, CD player, electric and acoustic guitars, facsimile (FAX) machines, the Internet (virtual device), internal combustion (lawnmower) engine, photocopier, optical fiber communication, satellite TV, video camera and videocassette recorder, and water purifier. The ability to touch, use, dissect, and reassemble these current engineering devices provides an holistic, direct experience with real world objects rather than with abstract

simplifications. This direct encounter with commercial reality instills a sense of competence in mechanical dissection and in the understanding of and self-paced learning about any technology.

The constant manipulation of devices also provides tactile inputs for learning, and a reminder of the importance of laboratory tinkering for understanding and invention. A reporter touring Edison's lab commented that even during conversations with visitors, the inventor seemed always to have objects in his hand, as though he communicated and learned through his fingers.

An older learning method, apprenticeship, is a form of craft training based upon the manual duplication of observed acts, including the repeated manipulation of materials to build-up an expertise in their performance under various forces and circumstances.

Lastly, tactile manipulation of solid objects is an antidote to the analytical and at times sterile atmosphere within which some classes are taught. As anecdotal evidence of the latter, the graduate students who wrote our lab chapter drafts, the seniors who tested the chapters against specific device incarnations, and the first entering students who experienced the lab as a summer technology camp, ALL commented that they were attracted to this dissection lab notion precisely because they were never encouraged to take apart everyday devices about which they were curious. Why do our home and school environments discourage curiosity so uniformly ?

2. Teamwork

Students work with each device in teams of two or three. Two appears ideal, as any conversation immediately requires full participation of all group members. Students talk in all phases of the team roles: they ask each other questions during the reading of the lab chapters, they give each other guidance and instruction during device usage, they observe and share manipulations and conclusions during the dissection and reassembly of the device. In all lab formats, students next work simple physics and math problems collaboratively, explaining to each other their thinking and logic. With these roles completed, and time permitting, the student team has a more formal communication role in presenting to and teaching other teams how a given device works and is characterized.

3. Student centered learning

“Student-centered instruction is a broad teaching approach that includes substituting active learning for lectures, holding students responsible for their learning, and using self-paced and/or cooperative (team based) learning”(2) The present lab requires accomplishment of student independent use, dissection, and problem solving first hand (active), holds students responsible for their own learning by requiring problem solution (and invention) and oral presentations without prior faculty or TA demonstrations, and carries all lab activities forward in team-based situations. Presentation time adds further active learning opportunity for imagination and invention: students have used the videocamera to pre-record their oral report, and one group even cast the video prerecorded teaching in the form of a mystery within which the secrets of the device were gradually revealed. Others explore creativity through construction of their own transparencies on later presentation cycles.

4. Communication

Since the lab has no formal lecture periods, all lab time is communication time. The forms of communication include casual conversation, questions to each other and to the TA, discussions during dissection and problem solving, and finally formal communication through the teaching to others using overhead projector, transparencies (provided or invented), and required oral participation by each team member. The student audience must subsequently pose questions after each team presentation. In our lab semester format, where teams rotate through six devices, the increasingly well informed audience, now including veteran users of all devices, poses progressively more challenging questions to the latest device team.

An old maxim says "Students learn more from each other than from the faculty". We see evidence of this: student audiences have an instinctive nose for "best practice" by other students, whether in oral presentation, problem invention, device explanation, transparency or printer artwork, etc. On repeated cycles through other devices, visual evidence of students adopting "best practice" from the previous presentation round is clear with each group.

The PRESENTATION period allows students to maximize what they can teach to, and learn from, each other. The structure of this lab presents repeated opportunities for students to show what they know to all, and the other students appreciate this additional, non-faculty knowledge. In one honors group, a particularly informed and polished student presentation received a spontaneous round of applause from audience peers.

5. Retention of information

We have not yet formally assessed and evaluated the quality of learning in this self-paced lab format. However, nearly all of the team roles involve activities which yield, according to the "Cone of Learning" (3) hierarchy of learning, progressively higher levels of material retention than does the traditional chalkboard lecture. For example, the amount of material retained for one week increases in the following sequence of original activities: hear lecture, discuss material, see demonstration, manipulate materials/devices, and teach others

This "Cone of Learning" sequence suggests that retention after one week increases from 10-20% (hear lecture) to 70-80% (teach others). Comparison of this series to our laboratory sequence of team activities (READ, USE, DISSECT, CALCULATE, and TEACH suggests that the latter should be progressively more efficient at cementing retention. The retention may also be enhanced by repetitive visitations to the same device, but each time in the guise of a different inquirer (user, assembler, analyst, explicator). Intriguingly, it appears possible that a laboratory utterly free of formal lectures by the instructor nonetheless possesses deep learning opportunities.

6. Warming the cool technical atmosphere

US engineering practice and education has been a traditionally male, even white male, bastion. The creation of a first year laboratory which is full of team conversation, physical movement of students, and music from CD players and guitars creates an atmosphere which is emotionally

warmer and less intimidating than a conventional laboratory. Moreover, the choices of lab TAs and student assistants offers additional opportunities to increase the already inviting atmosphere, and also to provide strong role models for new students.

7. Student leadership training

The directed but self-paced chapter instructions leave the TA free to wander the lab, engage the students in questions and discussions, and provide repeated communication opportunities for enhancing first year student learning. We have utilized graduate and senior TAs, as well as sophomore, junior, and senior alumni of the lab as student assistants and as TAs. The undergraduate assistants rotate with each lab section, and provide a constant advisor to a group of 30-40 students. The lab TAs remain with the lab, and provide not only conversation and question, but also lab maintenance, replacement, and occasionally repairs as well. These opportunities to serve as educators and role models provide such students with a satisfying part time job, professional development, and the chance to receive the rewards derived from competent teaching and leadership of the next group of student engineers.

8. A Recipe for Lifelong Learning

The remarkable and sustained pace of technical change of the present world places as much a premium on the engineer's ability to learn quickly about new devices, concepts, and materials as on the mastery of any particular set of technical knowledge. Our team role cycle of READ, USE, DISSECT, CALCULATE, and TEACH is, we suggest here, a succinct professional engineering model for lifelong learning which could be used "on the job".

For example, one imagines with little difficulty the repeated challenge in professional life when offered a new project or product opportunity in a somewhat or completely unknown area. A useful response based on our lab sequence (as well as Dale's "Cone of Learning") is first to gather information (READ everything appropriate, and interview past participants involved), then get some samples of product or process to DISSECT/ASSEMBLE and otherwise characterize current successful examples, then CALCULATE/ANALYZE what improvements are needed in yield, performance, speed, cost reduction, etc. would be required to produce an upgrade or competitive product, and finally PRESENT/TEACH to a corporate management through oral and written progress reports. The parallels between professional and lab learning cycle are strong. Moreover, the lab provides the students with a chance to acquire the confidence that ANY device or process can be approached and conquered through this self-paced learning method. Hence, a recipe for lifelong learning is created.

The first year lab necessarily involves students who are not yet departmental majors, and consequently who are without strong predispositions as to what they are NOT responsible to know. Thus, each device can and does require them to learn and report on aspects of optics, electronics, physics, chemistry, software, music, etc., i.e., to consider all pertinent aspects of the "big picture".

The previous paragraphs have identified an approach which builds better engineers eight ways. We now summarize the various formats, and their seasonal incarnations, in which the lab has

been offered. We complete this next section with speculation on several additional purposes and settings for which such a lab may be useful, for both the student of the moment and for the life and times of the institution.

A Lab for All Seasons

Space in a college or university campus is a precious commodity. The institutionalization of such a device dissection lab logically requires a critical mass of academic allies. Indeed, Millar(4) has argued that any course institutionalization has as a crucial development stage the arranging for administrative allies. A lab course which occupies for several months a particular curricular objective, nonetheless occupies for twelve months a piece of real estate with many educational opportunities. Filling the total time is an intellectually and politically important objective for maximizing the impact and permanence of such a lab. We describe below several current and prospective roles for our lab space ; these examples allow a lab for all seasons: fall and spring stand alone or integrated course examples, and summer technology and training camps, as well as portions for student orientation and minority visitation programs.

1. Summer honors technology camp

Chronologically, the lab was first conceived and piloted as a residential, full-time two week summer camp(1). In two-hour segments, student teams read the chapters, then used the devices and experimented with ways in which various device versions could be used. A second day involved the mechanical dissection and calculation roles, and concluded with team presentations using transparency materials provided. A middle day in each of the two weeks was used for an off-campus tour of a manufacturing site: week one through a personal computer (PC) assembly plant nearby, and a second week visiting a manufacturing site for water purification systems. As the student teams had or would see the circuit boards and modular construction of videocassette recorders, water purifiers, and CD players in the lab, the connection of these designed devices to example sites of manufacture, and the visits to assembly lines and talks with line foremen, engineers, and managers provided the students with a complete technology tour, from chapter principles to packaged product and practicing engineer. This range of contacts presents a self-validating picture of the life of a device and the manufacturing world within which it is produced.

2. Summer minority transitions

The desirability of providing time for early orientation and campus life adaptation for various under-represented minorities has led often to establishment of introductory summer engineering programs, varying in length from several days to several weeks. We have involved the laboratory in a one week NCSU engineering summer activity, Student Transitions Program(STP), for entering minority students who will reside on campus, attend sample lectures in precalculus and physics, and experience the present lab for a day, which allows coverage of a single device. While the learning and perfection which arises from repetitive exposure to devices is lost, each team nonetheless reaps the benefit of working through one READ, USE, DISSECT, CALCULATE, and PRESENT cycle, with each role truncated to 1.5 hours to allow time for 10 minute team presentations at days end using furnished transparencies

derived or copied from chapter tables and figures. This lab day also provides a psychological break from the demanding lecture and homework schedule of the other four program days. The relaxed lab atmosphere provides substantial peer communication opportunities among the incoming students, albeit largely constrained to the field of the technical devices in view.

3. Fall and spring semester academic lab

With two successful summer pilots completed in 1993 and 1994, the lab for was reincarnated into a 2-unit, semester elective course, offered in honors and regular sections during the fall 1995 and spring 1996 semesters. Lab periods of 1 hour and 45 minutes, driven by the university class schedule, provided each team with one device cycle every two weeks. Students would receive and READ the chapter manual out of class, ahead of time, then over four periods in two weeks move through the USE, ASSEMBLE, CALCULATE, and TEACH team roles. This format was more familiar than the summer camp because (1) enrollment was handled through campus course catalog listing and dial-in enrollment, (2) students now received academic credit, and (3) student alumni and alumnae of the previous labs were available to act as undergraduate TAs and student assistants. In other words, the infrastructure for recruiting and enrolling, scheduling, advertising, and TA training were already established, and conventional mechanisms for course continuity were available. An NSF-DUE (Division of Undergraduate Education) grant helped us during the first two years to demonstrate this new, scaled-up configuration.

This semester length format we found most satisfying. Each period was long enough to allow accomplishment without loss of attention, and distinctive enough and sufficiently separated in time from others that a certain freshness of contact was maintained for the students. At the same time, the full semester allowed each group to move through six devices. This opportunity for the continuing student teams to perfect their roles through repetition (with a new device each time) produced students who became proactive and adept at reading chapters and instruction manuals, using small tools to dissect and reassemble common devices, and teaching of others. Students intuitively recognized competent student presenters (and teachers), and the peer presentation format appeared to promote excellence by imitation, one of the established forms of learning, with parallels to Suzuki style violin instruction, craft apprenticeships, etc. Similarly, student inventiveness was given some opportunities for expression, from creation of presentation transparencies (if desired) to the conception, solution, and presentation of new problems associated with each device.

The afternoon scheduling of this lab provides a change of pace from the more structured lectures of morning courses, and the social and team building interactions in the lab were welcomed by both students and instructors.

4. Integrated semester academic course

Within the last two years, NCSU has reorganized its disparate introduction to engineering elements into a more cohesive offering, which now includes a weekly lecture (engineering disciplines, safety, ethics, etc.), an introduction to the NCSU computing environment, our dissection lab, and a short design competition in bridge building. In this guise, the lab is part of the integrated course, which is experienced by the entire eleven hundred students of each

entering engineering class(5). Such enormous numbers passing through a single lab, of maximum capacity forty students, requires a total of 30-35 sections, and allows only a pair of two-hour labs per student. This hyperabbreviated encounter is nonetheless made to follow much of the previous cycle. Now, students enter the lab, READ the chapter for 30 minutes only, and USE the device, to show an understanding of device function and purpose. The concluding 20 minutes are spent in composing a ten sentence letter home to a high school science teacher wherein the student explains, in the most technical vocabulary which can be used, how the device actually operates. In the second lab period, the DISSECTION role is played, and as a concluding activity students CALCULATE device performance in group or individual activity. The PRESENTATION is missing, as time does not permit 1100 individual deliveries with attentive TA and faculty listening.

5. Summer in Technology and Engineering (SITE)

Like many campuses, NCSU engineering sponsors summer technology programs. Our version, SITE, includes example lectures and demonstrations in various departments, lectures and videos on the engineering life, and a one-day visit, out of the five day program, to our device dissection laboratory. The lab format here is analogous to that for our minority student STP orientation. Teams are chosen randomly when our lab is the first SITE day for one section, and the last (Thursday) group arrives at the lab with friends already established for the week, so students self-selected for team formation. Teams of two appear ideal, but the press of numbers (seating capacity up to 40) with 15 experiments means that in some situations, three student teams are the norm, and on occasion one or two teams with four students. The latter is not preferred; it was best to add additional stations, so all students would have an opportunity for hands-on manipulation.

Overview of Lab Uses to Date

Each format above formats work, albeit with impacts increasing with the time of commitment available to the lab. The lab is cost efficient primarily because the activities are self-powered: the lab manual and student curiosity combine to provide directed, student driven inquiry. Manpower for the day-to-day operation is provided from a resident student population of former lab students. A PhD graduate student trains the new student assistants prior to each semester during the academic year (11 sections/week for the integrated semester course), and undergraduate and graduate TAs have manned the summer minority STP orientation and SITE programs. Faculty responsibilities include oversight for lab maintenance, replacement, manual updates, and device repairs.

Peering into the Future: Potential Lab Reincarnations

6. Women's technology camp

The "chilly climate" argued by some to reduce the interest of women in engineering may itself be reduced or alleviated through a lab created "For Women Only". The legal merits of such an approach aside, data indicates that a substantial portion of women do better in such a single gender course environment. Such a mechanical dissection lab has been offered elsewhere, at UC Davis, with the anecdotal results indicating a positive outcome. These results are

encouraging, but it is unknown how and whether such a gender constrained effort may be offered on other campuses. Nonetheless, the opportunity for women role models as instructors and TAs to lead such all or predominantly female labs may continue to appeal to some.

7. Technology literacy lab

A paradox of our times is that we live in a technology intensive society, yet a surprisingly small percentage of our population understands even qualitatively the working of the devices within it. If the need for an informed citizenry in a democracy extends to that of a technically informed population, then a hands-on lab again provides a setting within which "technology literacy" can be offered to non-engineers, or even non-technical students. Both Krupczak(6) and Byars(7) have authored informative pieces on the history of and experience with teaching "How It Works" courses to non-engineering students. The present lab could host such an engineering service course for the liberal arts, the reverse of the conventional situation. Moreover, such a lab could usefully build a bridge of reciprocity, with engineering faculty acknowledging a larger campus responsibility to educate not only the narrow cut of their own engineering majors, but also the broader student population.

Such a lab, taught by engineering faculty and students, could also reduce the "invisibility" of the engineer. The latter professional, in contrast to his and her brethren in physics, chemistry, biology and mathematics, is currently unseen by non-engineering students, and, by extension, by non-engineering citizens. This notion of the "invisible" engineer is explored elsewhere at this ASEE meeting.

8. Teacher technology training

The opportunities for high school and middle school science and mathematics teachers to convene and share teaching strategies and lab concepts could be augmented through creation of a summer workshop lab using the present and related devices. In one potential conception, the high school faculty would now proceed through similar team roles, albeit at a considerably faster pace. Beyond the READ, USE, and DISSECT roles, new opportunities are evident. For example, the teachers could identify and invent problems in physics of devices, chemistry of materials, and forms of math suitable for device description and modeling. The teachers' lab cycle could close with PRESENTATIONS wherein each team shared not only device principles as before, but then presented individual inventions and suggestions as to how such inexpensive technical devices could be incorporated into their own high school courses. Here, the central notion is to let the experts (the teachers) acquire further device knowledge in a collegial setting, with the professionals themselves being the "teachers" in the closing PRESENTATION act.

CODA: Reinvention and Renewal

Our world is full of inexpensive, modern devices which offer an opportunity, in many instructional formats such as those noted here, to engage students, faculty, and staff in exploration of the mysteries and revelations of the modern age of technology. We suggest here that the creation everywhere and widespread use of a device dissection laboratory could function as an kind of academic "Exploratorium", within which persons of quite diverse technical backgrounds could discover, through team engagement, an effective, pleasurable, and

inexpensive path to understanding technology and perhaps those who stand behind it, the engineers and technicians.

The ABET/EC 2000 guidelines for revamping engineering education contain a number of criteria which may be usefully addressed within one or more of the lab formats discussed above. Specifically, the ability to work in teams, the ability to understand the uses of science and technology within a larger economic and societal context, and the ability to communicate effectively in a variety of team circumstances, all indicate the substantial potential for Engineering Criteria 2000 to be addressed through "A Lab for All Reasons, A Lab for All Seasons"

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