The Integrated Teaching and Learning Lab

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Abstract - *The College of Engineering and Applied Science at the University of Colorado (CU) is in the sixth year of a college-wide reform initiative that models the real world of engineering where skills in communication, teamwork, and leadership, as well as the ability and self-confidence to define and solve open-ended problems, are demanded. The engineering curriculum for the next century must be relevant to the lives of students and the needs of society. To better meet tomorrow's challenges, we have expanded our teaching methods to exploit teaming, active and group learning, and project-based design and problem-solving experiences. We have learned to value integration in addition to specialization and have come to understand that creating a seamless K-16 partnership is vital to our engineering mission and society.*

I. Introduction

The Integrated Teaching and Learning Laboratory (ITLL), a 34,400 sq. ft. hands-on learning facility that opened in January 1997, is the visible manifestation of a significant shift away from lecture based engineering education. The ITL Laboratory supports the new hands-on engineering curriculum in innovative and creative ways. CU has also become more involved in expanding engineering education to reach into the critical elementary through high school years.

The unique design and architecture of the ITLL facility was driven *entirely* by curricular reform objectives. It provides K-16 students with an interdisciplinary learning arena. K-12 learners experience the joys of learning in summer workshops. The principles of design are introduced during a student's first year in engineering. Theoretical engineering science courses in the middle two years are augmented with hands-on, open-ended discovery opportunities. Finally, interdisciplinary teams of seniors design, build and test real-world products for middle school science classes and youth museums.

II. Integrated Teaching and Learning

The vision statement articulated by a team of faculty and students in 1992 continues to drive College-wide curriculum reform: *To pioneer a multidisciplinary learning environment that integrates engineering theory with practice and promotes creative, team-oriented problem solving skills.*

The ITL curriculum integrates hands-on learning across all six engineering departments and throughout all four years of undergraduate study, beginning with the First Year Engineering Projects. This College-wide course introduces students to the excitement of engineering and to the practical considerations of the design process including experimental testing and analysis, oral and written communication, multidisciplinary teamwork, and project management [1,2]. Two dedicated design studios in the ITL Laboratory, shown in Figure 1, provide the capacity to teach this course to all first-year students. The major component of this course is a design project through which student's experience the complete design-build-test cycle that attracts many students to engineering in the first place. The design project is especially rewarding and more challenging when the student teams are meeting the needs of real customers from outside the University.

Figure 1: First Year Project Design Studio

Past client-based assistive technology projects include a page turner for an adult with cerebral palsy, a talking backpack that answers "yes" or "no" at the push of a button by a mute child, and an assistive glove that allows a quadriplegic classmate to grasp a can of soda. Another client-based design project theme is interactive learning exhibits: CU students learn while designing and building projects that help younger children learn basic concepts of science, either formally in a middle school class, or informally in a museum setting. Examples include a system of levers and pulleys for a middle school class studying simple machines, and a children's museum display that illustrates concepts of gravity and momentum when children race tennis balls down different tracks.

In their middle two years, undergraduate students encounter the difficult theoretical courses that define them as engineers. To cement the abstract concepts, interdepartmental faculty teams developed interdisciplinary focus courses that capitalize on the state-of-the-art equipment in the two large, open laboratory plazas in the ITL Laboratory, shown in Figure 2. Students gain hands-on reinforcement of the fundamental principles of fluid mechanics, electronics, measurements, structural mechanics, and thermodynamics. These are open design labs that allow first year students to watch the upper-class students doing experiments at the lab stations below. In addition, all students get further exposure to the process of engineering design by watching senior design projects unfold in the visible capstone design studios. Examples of these projects range from building a racecar to building a human-powered submarine.

Figure 2: ITLL Laboratory Plaza

III. ITL Assessment and Continuous Improvement

The College is committed to assessing the total qualitative and quantitative impact on student learning of the tightly coupled facility, equipment, and curricula that represent the ITL program. The six-year-old ITL program has benefited from conducting both formative and summative assessment.

For example, years of development and fine-tuning of the first-year course have been closely monitored through the use of course entrance/exit surveys, weekly instructor/teaching assistant (TA) meetings, student group feedback interviews, and a half-day semester-end instructor/TA debriefing session. Student tracking and retention rate comparisons of student participants in the ITL program's first-year course with those of the general College population gauge the impact of this experience. Initial results show that the retention of students who took the first-year course and remained in engineering into their junior year is 78%, while the retention of all engineering students (including first-year course students) is 55%. These data indicate that first-year design course students are more likely to remain in the engineering program and complete their degrees. In addition, many students cite the first-year design course as the single most important experience during their entire undergraduate engineering education.

We continuously improve the program incrementally by implementing a variety of assessment techniques. Recognizing that we must better understand the importance of specific experiences on each student's total educational experience, the Boulder campus funded a $20K ITL assessment grant in 1997. As part of the evolving ITL Laboratory program assessment plan, all ITL curricular and program components are being evaluated. This includes: new middle- and upper-division courses, experimental laboratory modules, hands-on homework units, living laboratory interactive features, senior design projects, signage and interactive exhibits, and a self-guided public tour.

IV. Unique ITLL Initiatives

The ITL Laboratory building *itself* is an interactive teaching tool, with the capability to expose, monitor, and manipulate the many engineering systems inside. From more than 200 sensors installed in building components throughout the facility, hundreds of precise measurements are taken every five minutes to monitor the status of the building systems, structural loading, thermal environment, and electrical load profile. Thus, the ITL Laboratory functions as a living laboratory. We will soon make its "pulse" accessible on the Internet as a technology and building systems resource for all engineering colleges. A self-guided interpretive tour shows first-hand what makes buildings function.

Integral to the ITL Laboratory's design are gallery spaces where interactive science exhibits and kinetic sculptures expose learners of all ages to the open-ended discovery experience. Nine hands-on exhibits enliven the two interactive galleries. This core set of exhibits is available to all CU students and the public. Children from throughout the region come to explore these exhibits and get their first taste of the world of engineering. A Rube Goldberg contraption features balls flying along steel tracks, triggering musical and kinetic devices which in turn demonstrate many principles of dynamics in a captivating show of sound and motion. Even the building's outdoor public art piece, "A Slice of Wind," is an interactive device that invites viewer participation and thoughtful engagement. When fitted with instrumentation and set up as experiments, the exhibits will provide function as serious engineering curriculum tools as well as provide opportunities for the casual observer to explore.

The ITL Laboratory hosts a variety of K-12 outreach initiatives. In conjunction with CU's Science Discovery Program, a summer 14 weeklong science, math, and technology classes for elementary and middle school children are conducted in the ITL Laboratory. "Go With the Flow" was an ITLL-sponsored weeklong class to explore hands-on experiments and curriculum modules in fluid mechanics for middle school students. This class is currently being expanded into a teacher training workshop for middle school teachers. A second engineering class, "Kinetics for Kids," was targeted to upper elementary children as the first step in developing activities, curriculum, and hands-on experiences for supporting a teacher workshop. "Exploring Science for Girls," was offered to give girls ages 11 to 14 the opportunity to actively participate and excel in rich science and math activities.

Together with the National Center for Atmospheric Research, ITLL hosts a three-week, National Science Foundation (NSF)-funded initiative that trains 38 rural Colorado middle school teachers in the math and science of weather and climate. The American Indian Science and Engineering Society brought 42 Native American high school students (representing 20 tribal nations across the U.S.) to the ITL Laboratory as part of a six-week "upward bound" program intended to prepare them for college environments. Part of their experience was to develop and present scientific proposals to address issues in their home communities. Each of these students will be the first in their family to attend college.

The College's Minority Engineering Program (MEP) partnered with ITL to conduct the first "Exploring Engineering" institute, a three-day pilot program that brought together 30 K-12 teachers, counselors and administrators from front range school districts to learn about incorporating pre-engineering curriculum and career guidance into their schools.

Taken together, these activities suggest the breadth and depth of K-12 programming that can be successfully staged in the ITL Laboratory. Thousands of K-12 students have already toured the facility since its opening. Part of our web site includes a "virtual" tour so that students have pre- or post-visit access to the exhibits, Building-as-a-Learning-Tool features, and other topics they are studying or are curious about. As more groups visit, we "fine tune" both real and virtual field trip experiences and find additional ways to export the pedagogy of the ITL Laboratory to home classrooms.

V. Institutionalization

ITLL was conceived as a curriculum driven program. The natural measure of its success is the extent to which the faculty, students and staff have committed to the changes it symbolizes. In general, the laboratory has fared well in this regard. But in some areas, most notably in assessment of its efficacy in improving student outcomes, more work needs to be done.

A. Staff

The ITL team is participating in the Chancellor's newly launched campus-wide technological literacy initiative. Additionally, the campus contributes $100K annually towards the day-to-day operation of the ITL Laboratory and program. The College supports the ITL Laboratory in numerous ways, most notably by providing faculty and technical staff salaries. Full-time team members include an instrument maker, specialized software engineers, an experimental module engineer, an electronics engineer, a LabVIEW programmer, a technical assistant, and an equipment calibration technician. They ensure that students can exploit the unique capabilities of the ITL Laboratory. Two faculty share the responsibilities of the ITLL vision and administration; portions of their salaries are provided by an endowment made to the College for that purpose. Even more significantly, the College provides in-kind faculty salaries to modify curricula throughout the college to take advantage of the capabilities provided by the ITLL. During FY 97 the College is contributing $210K in-kind for this curriculum reform, resulting in the modification and/or development of 30 engineering courses now being taught in the ITLL.

B. Students

The commitment of CU to ITL begins at the grass roots—with student support. Since the inception of the ITL program, our students have provided essential and unique intellectual support. Engineering students have also been financial partners in the evolution of the ITL program since its beginning, and they continue to play a vital role in the success of the entire ITL program. In 1991, engineering students voluntarily imposed upon themselves an annual $200 differential in tuition and fees to underwrite the nationally unique Engineering Excellence Fund. The fund generates $700K annually; half of which is committed to operational support of the ITL program. The balance is competitively awarded for curricular innovations throughout the College, much of which is complementary to ITL.

In 1994, students lobbied the Colorado State legislature to support the ITL program and change traditional funding practices so that $478K of their funds could be used towards capital construction of the ITL Laboratory. Several students served on the original student/faculty curriculum task force that shaped the program, and dozens of students provided input into the conceptual design of the ITL Laboratory. Students continue to hold critical decision-making roles in the ITL Laboratory: upper division undergraduates serve as coaches in the First Year Engineering Projects course, teams of student "patrollers" ensure after-hours security in the facility, and students are helping to develop ethics case studies for incorporation into the first-year design experience. Faculty solicit, respect, and respond to student input. From the beginning, the ITL program was conceived to be by, and for, students.

C. External Review

To solicit objective critique and provide external accountability, the ITL program invites faculty from a number of forward-thinking institutions, including principal investigators from four NSF engineering education coalitions, to serve as external reviewers of the ITL program. This group has met twice annually since 1994 to provide critique and mutual exchange of ideas, many of which have been incorporated into the ITL curriculum and facility. For example, a portion of the University of Maryland's "Introduction to Engineering Design" course [3] provided inspiration for the design project portion of the First Year Engineering Projects course. Likewise, the reverse engineering component of our first-year course was adapted from Stanford University's mechanical dissection concept. An expert in informal science education from the San Francisco Exploratorium and former physics professor at MIT, joined the ITL External Review Board last year to help provide learning opportunities in which people of all ages engage in open-ended discovery.

VI. Results

Student performance expectations in the ITL Laboratory are high, particularly in the First Year Engineering Projects course. Our experience during the past four years has shown that students rise to the challenge and are rewarded for their investment of time and energy. For example, the team of first-year students who designed a prosthetic glove for their paralyzed classmate now has a U.S. patent pending for their invention. On several occasions, students have voluntarily worked during the semester break, and even into the next semester, to bring an assistive technology product to a high-enough quality level to deliver it to their client.

Faculty from several departments teaching senior design projects report that our students are now better able to deal with open-ended, ill-defined problems than in the past. Admittedly anecdotal, this suggests that *learning by doing*, the central precept of ITLL, is better preparing students for the challenges they will encounter in the engineering world. The ITL program has provided many valuable leadership opportunities for undergraduate students. Because they have a financial as well as an intellectual stake in the ITL Laboratory, volunteer student ambassadors have partnered with our staff to change the culture of learning from one of entitlement to one of responsibility. Any student who wishes after-hours access to ITL Laboratory, or a computer log-in, must first participate in a student-led orientation session, and sign a contract agreeing to follow a high standard of conduct in the facility. The Engineering Excellence Fund also allows students to gain valuable experience managing a significant resource base and improving the educational opportunities for future students.

VII. Ideas for Future Developers

Now that the ITL facility has been in use for over a year, various areas for improvement need to be addressed. Again, the ITL concept of *learning by doing* applies to the actual development of the program. We now have the hindsight to be able to identify some of the weaknesses of the development of the program. We will present some of these issues in this section assuming that others can learn from these weaknesses.

With the growing presence of the internet in the K-12 schools, integrating web-based learning strategies into the curricula becomes very important. Students entering the university now expect to find information for a course available via the WWW. In fact, not only can the web be used to make learning more accessible, it is possible that it can promote improved learning by making learning more appealing and flexible [4]. Of course, how effective web-based learning is will be dependent on how it is used for a course. Internet access is readily available throughout the ITL Laboratory in classrooms, laboratories, and study rooms. In general, the ITL program has not utilized this capability to its fullest. For instance, many classes do not have all the class handouts and schedules available on the web. In addition, the software and technology that are currently available are not always integrated fully into the classes. This failing may be due to lack of time, or the course instructor's lack of training or support.

In general, the ITL program did not develop and integrate sufficient outcomes assessment methods. Assessment is being conducted in some of the ITL classes but it needs to be expanded to all of the ITL courses. We strongly feel that the overall program is helping to improve the engineering education experience at CU. However, the overall success of the program has been primarily anecdotal rather than statistical. Preliminary studies have been conducted regarding the retention of the first year course students within the College. However, the interpretation of 78% retention rate needs to be understood in the context of the curriculum. In other words, because the students were not required to take this course, were the students who were predisposed staying in the College most likely to voluntarily take this time-demanding course? Also how much does this statistic change now that the first year course is required for some majors and the ITL experience is no longer limited to the freshman year? Also, high retention of students should not be the only criteria in which to judge the success of the program. Are the skills that are emphasized in the courses preparing the students to succeed in other courses as well as after graduation? We are currently struggling to determine what type of data needs to be collected to support the anecdotal evidence. Clearly, more longitudinal studies are needed to determine the long-term effects of the program and paradigm shift. Along with other engineering departments that are addressing the same issues with the approach of ABET 2000 [5], we are currently trying to evolve the current assessment methods to help answer these questions.

We believe that another area that could have been improved included parallel curriculum planning with the building design. Curriculum drove the building design, however given the limited resources available, especially in the early phases of development; capital building and equipment issues took precedence. We encourage new developers to not skimp in supporting this crucial element.

We have a fantastic building but it is not being used to its full potential yet because of this oversight.

VIII. Conclusion

Clearly we still have work to do institutionalizing active and interactive engineering education. We have achieved significant success and made significant steps towards institutionalization, but in hindsight, as we discussed, many things could be improved if we had it to do over again.

References

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