e-Learning: The Challenge for Engineering Education

George D. Peterson, Accreditation Board for Engineering and Technology; and
Lyle D. Feisel (Retired), State University of New York at Binghamton

I. Introduction

The face of the college-going student is changing in the United States and in many countries around the world. No longer are the majority of our students fresh from high school and living on campus. There are more students commuting, more students beginning their college careers at two-year community colleges, and more combining work and study in creative part-time/full-time arrangements in order to upgrade their workplace skills. Colleges and universities now are reaching out both to traditional students and to those who cannot participate in the residential, full-time academic environment; they are experimenting with alternative educational delivery systems: correspondence study, one-way and two-way audio, and video or internet-based asynchronous learning. They are experimenting with the promise of e-learning.

A UNITED ENGINEERING FOUNDATION CONFERENCE
Davos, Switzerland 11-16 August 2002
http://www.coe.gatech.edu/eTEE

Distance education is widely recognized as the alternative delivery system in which the student and the educator are separated either by distance or time or, in some cases, both. However, distance education (and e-learning) are not a new concepts, but rather have evolved from the ubiquitous correspondence courses of the past. In the modern implementation, information or distributed learning technology is the likely connector between the learner, the instructor, and the offering site [1]. Education at a distance may be as near as the on-campus residence halls or as far as a distant workplace.

When pursuing a distance education delivery system, institutions can address such issues as student advising, transfer credits, library and research activity, student-faculty and student-student interaction, and program oversight. But, one of the unique features of an engineering program is the live, hands-on laboratory and design experience. If an engineering program is offered online and it does not include a hands-on laboratory experience, it raises fundamental questions:

— What are the expected outcomes of the laboratory experiences in the curriculum anyway?

Can we describe the attributes of engineering graduates that are developed by the hands-on laboratory experience?

Could those attributes also be developed or enhanced through a program offered online?

The success with which institutions develop and document the answers to these questions will be the crucial factor to the future of e-learning. The institutions must demonstrate to the public that their online offerings prepare their graduates to enter the engineering profession at the entry level.

While still in the early stages, universities are already researching ways to offer traditional laboratories online; for example,

— A Computer Design course at Rensselaer Polytechnic Institute in which the professor is experimenting with providing the course through a remote distance learning mode <http://pxi2.cie.rpi.edu>.

— Brigham Young University's research experiments in distance control, the ability to control a device from a remote location, through the use of Net Meeting™ software and a research area on the institution's web site <http://research.et.byu.edu/dlc/main.html>.

— Sanitary Engineering Microbiology at University of Missouri-Columbia's College of Engineering, a course in which students currently view live samples on the course web page and, in the future, also will be able to take digital photos of culture experiments and post them to that course page <http://horizon.unc.edu/ts/cases/2000-01a.asp>.

— Digital Design Virtual Lab at Old Dominion University <http://www.odu.edu/~rjones/e315ld_fall_page.htm>.

In addition, the University of Colorado at Denver [2] is developing "an introductory-chemistry laboratory course-delivered via the Internet-in which students will conduct experiments in their own kitchens, using household chemicals." England's Open University already employs this method; students receive home kits as part of the course materials and are expected to conduct course experiments at home.

The relationship between higher education and information technology is considered by some to be a “dance with the devil” [3]. But the option to ponder the ramifications of such a pact has passed us by. The proliferation of online course offerings is rampant with established higher education institutions joining the rush, “increasing their distance education offerings by about one-third between fall 1995 and 1998.” [4] (This information is already three years out of date.) Online learning is happening, and, as the examples provided above support, it is happening in the field of engineering. But if a truly effective system of online education is to be established for engineering, some fundamental questions must be addressed:

Online education — the promise of e-learning — poses two questions to engineering education. Of vital interest to engineering (and to any practice-oriented profession) is the question:

> “Can practical, hands-on laboratory experience be achieved in an online setting, or is practical hands-on experience even necessary?”

The second question:

> “How do accrediting organizations assess an online program to determine if the graduate has acquired knowledge and skills sufficient to begin professional practice at the entry level?”

These questions arise because few faculty have, in modern times, constructively asked the question, “Are laboratories even necessary in an engineering program?”

Or, extended to the larger perspective:

> “What is the role of the laboratory in the educational process for the practice-oriented professions?”
>
> “Can the objectives of laboratory instruction be achieved outside the physical laboratory?”
>
> “How can the achievement of the objectives of laboratory instruction be demonstrated?”

The Accreditation Board for Engineering and Technology (ABET) accredits programs in engineering, engineering technology, computing, and applied science. Accreditation informs students, parents, the institution, employers, and the public that the program has satisfied certain basic criteria. Recognizing that one of the strengths of the American educational system is the diversity of its programs, ABET’s goal is to ensure quality while encouraging innovation. E-learning is one such aspect of innovation occurring in America’s educational institutions. ABET welcomes this change and lists among the goals of its Strategic Plan [5] to “encourage and accommodate new educational paradigms” and “develop the capability to evaluate programs that use alternative delivery systems.”

ABET continually examines the elements that comprise a quality engineering program and in recent years made fundamental changes in its criteria for accrediting engineering programs — *Engineering Criteria 2000* [6]. The ABET engineering criteria asks of engineering programs that they define their educational objectives, have a clear method of assessing outcomes, and engage in continuous quality improvement. This is good news for programs with a bent toward pushing the envelope in innovative online education. But the criteria are explicit about the abilities of graduates entering the engineering profession.

Expressed as the “educational outcomes” of an engineering program, EC2000 requires that engineering programs demonstrate that their graduates have an ability to:

(a) apply knowledge of mathematics, science, and engineering;

(b) design and conduct experiments, as well as to analyze and interpret data;

(c) design a system, component, or process to meet desired needs;

(d) function on multi-disciplinary teams;

(e) identify, formulate, and solve engineering problems;

(f) use the techniques, skills, and modern engineering tools necessary for engineering practice; and

(g) communicate effectively.

In addition, they must also possess:

(h) an understanding of professional and ethical responsibility;

(i) the broad education necessary to understand the impact of engineering solutions in a global and societal context;

(j) a recognition of the need for, and an ability to engage in, life-long learning; and

(k) a knowledge of contemporary issues.

During a colloquy of some of the nation’s leading engineering faculty, ABET constructively raised the question: Why do we need laboratories in engineering education? We expected that this question would stimulate critical discussion — and possibly the conclusion that the knowledge and skills developed in the laboratory are necessary components of engineering education — and most practice-oriented professions. The objective of the colloquy was to advance the state of the art in e-leaning by defining the attributes developed in the engineering graduate by the laboratory experience, by identifying the learning objectives achieved or enhanced through successful traditional laboratory instruction. In other words, "How would we know if a laboratory experience offered online were successful?" More fundamentally, "How would we know if any laboratory experience were successful?"

II. A Colloquy on Learning Objectives for Engineering Education Laboratories

With funding from the Alfred P. Sloan Foundation, the colloquy took shape in early 2001 when a national steering committee was selected and later convened to develop the colloquy plan, including format, issues to be addressed, potential speakers, and other concerns [7]. Professional facilitators experienced in similar engineering activities were chosen to lead the colloquy group as a whole. The steering committee served as small breakout group facilitators.

Deans of ABET-accredited engineering programs were polled for recommendations for faculty who not only were high-quality engineering educators but also had notable experience developing and teaching traditional engineering laboratories. Many faculty members received multiple recommendations, as there were no institutional boundaries to constrain the nominations. Once all recommendations were received, the steering committee reviewed these, paying careful attention to ensure a wide representation of engineering sub-disciplines and a diverse institutional mix (two-year, four-year, public, private, etc.). The final number of selected participants was fifty-two, including the steering committee, representatives from ABET, the Sloan Foundation, and facilitators. The participants also included faculty from the Hong Kong University of Science and Technology and the Chinese University of Hong Kong.

The colloquy opened with a brief introduction, outlining the purpose and the role of ABET and the Sloan Foundation, and concluded with an elaboration on the focal question at hand: What are the fundamental objectives of engineering education laboratories?

During the two-and-a-half days comprising the colloquy, participants listened to three plenary session speakers, each an expert in his field. Richard M. Felder of North Carolina State University engaged the participants with a talk based on his invited essay, "Learning Objectives and Critical Skill Development in the Engineering Laboratory" (a pre-read for participants) [8]. Through his presentation, Felder gave participants a common understanding of the organization of knowledge and a common lexicon of learning objectives to work with during the colloquy. This helped prepare participants to define their own learning objectives for the laboratory and discuss in a productive manner those proposed by others. For the purpose of the colloquy, Felder defined learning objectives as *observable* and *measurable*. He explained that a good learning objective could be written as follows: "At the end of this [course, experiment, or lecture], the student will be able to [perform, list and discuss, design, define, or other observable action]…." Felder then went on to outline the taxonomy of educational objectives as they apply to the cognitive domain, the psychomotor domain, and the affective domain. Felder's presentation significantly helped set the stage for the final list of fundamental instructional objectives for the engineering laboratory.

While the workshop was not intended to design new distance laboratory programs or to critique those that currently exist, it was important that the participants had a feeling that almost anything is — or will be — possible in the way of technology-enhanced learning. The steering committee did not want participants' thinking to be limited by the feeling that an objective is not valid or valuable simply because it cannot be achieved by current technology. Randy J. Hinrichs of the Learning Science and Technology Group of Microsoft Research challenged the group with "A Call for Action" [9]. Hinrichs introduced the participants to a wide range of technological possibilities that are now available or will be available in the near- and medium-term future. Among those are Web-based laboratories and simulations, game-based learning using the principles of popular computer games, and live Internet classes using audio and video. He explained to participants what the next generation of traditional college freshmen would look like and how acutely experienced with technology they already are. Hinrichs' presentation helped underscore the need for quality distance education, as well as opened the minds of participants to the possibilities of technology, regardless of whether it is used exclusively for distance learning or in conjunction with a typical lecture or lab course.

The colloquy's final essayist was Karl A. Smith of the University of Minnesota. Smith helped participants better understand how students learn in the lab through a presentation based on his paper "Inquiry and Cooperative Learning in the Laboratory" [10]. It has been demonstrated that student learning is more efficient and effective if the instructor employs techniques that enable "inquiry-based learning." In addition, collaboration among students not only increases learning effectiveness but also teaches the student some essential life skills. Since inquiry and collaborative learning can be extended to the laboratory, it was important that workshop participants understood the principles of these techniques. This enabled them to discuss the extent to which the benefits of an "active and collaborative" experience should be considered fundamental goals of the laboratory experience. It also initiated thinking about whether and how such experiences can be realized in distance education. Smith used several different models to explain how students learn through inquiry and cooperation. He also explained the correlations between engineering design and learning, the importance of collaboration, and a new paradigm in learning that states that "learning is a social activity"; "innovative learning requires ambiguity"; and "all learning requires un-learning."

Between plenary sessions, participants formed small breakout groups, consisting of roughly eight participants each. The breakout groups were designed with the diversity of engineering sub-disciplines in mind, and these diverse groups stayed together throughout the colloquy. Each breakout group met a total of four times to answer the question, "What are the fundamental objectives of engineering education laboratories?" In addition, one "captain" was chosen from each breakout group. Periodically, these captains met with facilitators to try to forge a consensus on the objectives developed in each breakout.

Framing the question in this context required a working definition of the instructional laboratory experience. The consensus suggested a broadly defined definition:

> *The instructional laboratory experience is personal interaction with equipment and tools leading to the accumulation of knowledge and skills required in a practice-oriented profession.*

On the final day of the colloquy, a semi-polished list of objectives was presented to the entire group of participants for discussion. A group of volunteer editors polished up a final version and presented it once again to all participants.

The following is the final list of learning objectives for the engineering laboratory developed through consensus by the participants of the ABET and Alfred P. Sloan Foundation Colloquy. These objectives apply to laboratory experiences over the entire undergraduate engineering program. These objectives begin with the following statement:

> *"By completing the laboratories in the engineering undergraduate curriculum, you will be able to…."*
>
> *Objective 1. Instrumentation*
> — *Apply appropriate sensors, instrumentation, and/or software tools to make measurements of physical quantities.*
>
> *Objective 2: Models*
> — *Identify the strengths and limitations of theoretical models as predictors of real world behaviors. This may include evaluating whether a theory adequately describes a physical event and establishing or validating a relationship between measured data and underlying physical principles.*

Objective 3: Experiment
— *Devise an experimental approach, specify appropriate equipment and procedures, implement these procedures, and interpret the resulting data to characterize an engineering material, component, or system.*

Objective 4: Data Analysis
— *Demonstrate the ability to collect, analyze, and interpret data, and to form and support conclusions. Make order of magnitude judgments, and know measurement unit systems and conversions.*

Objective 5: Design
— *Design, build, or assemble a part, product, or system, including using specific methodologies, equipment, or materials; meeting client requirements; developing system specifications from requirements; and testing and debugging a prototype, system, or process using appropriate tools to satisfy requirements.*

Objective 6: Learn from Failure
— *Recognize unsuccessful outcomes due to faulty equipment, parts, code, construction, process, or design, and then re-engineer effective solutions.*

Objective 7: Creativity
— *Demonstrate appropriate levels of independent thought, creativity, and capability in real-world problem solving.*

Objective 8: Psychomotor
— *Demonstrate competence in selection, modification, and operation of appropriate engineering tools and resources.*

Objective 9: Safety
— *Recognize health, safety, and environmental issues related to technological processes and activities, and deal with them responsibly.*

Objective 10: Communication
— *Communicate effectively about laboratory work with a specific audience, both orally and in writing, at levels ranging from executive summaries to comprehensive technical reports.*

Objective 11: Teamwork
— *Work effectively in teams, including structure individual and joint accountability; assign roles, responsibilities, and tasks; monitor progress; meet deadlines; and integrate individual contributions into a final deliverable.*

Objective 12: Ethics in the Lab

— *Behave with highest ethical standards, including reporting information objectively and interacting with integrity.*

Objective 13: Sensory Awareness

— *Use the human senses to gather information and to make sound engineering judgments in formulating conclusions about real-world problems.*

These objectives have since been calibrated via a survey of 120 engineering department heads at 14 colleges of engineering across the country. The survey was a simple one; it asked the chair (or a faculty member that is intimately involved in the undergraduate laboratory) to rate each of the 13 objectives using a five-point scale that ranged from "Absolutely Essential" to "Not at all Important." Responses were received from 60 departments, yielding a 50% response rate.

While such a limited survey does not demonstrate universal validity of the objectives, it does indicate a general acceptance of the premise that they do describe the laboratory experience. Most objectives received reasonably high scores although a definite hierarchy evolved. Some objectives are considered less important than others, but this is not interpreted to mean that they are not important to other parts of the curriculum of an engineering program. It also appears that the set is effectively complete, as there were no responses alluding to missing objectives.

III. Implications for the Future of e-Learning

The concern for a sound laboratory instructional pedagogy was raised more than 20 years ago by A. Richard Graham in his paper titled, "Needed: A Theory of Laboratory Instruction"[11]:

> "The need for a better understanding of the teaching/learning process in the laboratory is evident. There appears to be little relevant research in this area…. This lack of research may be because nothing unique happens in the laboratory. If this is the case, we have adopted an expensive alternate mode of instruction. A more probable situation is that we have been working on the wrong problem, concentrating on "what" (goals, specific experiments, etc.), "how" (equipment setup, data acquisition, etc.], rather than "why" (an understanding of learning through the experience). In that case, we are guilty of the engineer's greatest error—leaping to problem solution without understanding the problem."

The ABET and Alfred P. Sloan Foundation colloquy served as an important first step in the potential for both improving the quality of traditional engineering laboratories and opening the doors for discussion on how distance education may be applied to the practice-oriented professions. The colloquy sorted out the "how" and "what" and stimulated interest in the question, "why?" And the future of e-learning in an engineering setting may have received a serendipitous boost. A sound understanding of the role of the laboratory in the traditional educational process permits us to experiment with alternative means of achieving desired outcomes, and, further, to determine whether these outcomes can be achieved outside the physical setting of a laboratory — that is, in an online engineering program.

There are several more steps to follow if we are to put what was learned at the colloquy into action. The following is a list of near-term and medium-term action items recommended by the colloquy participants:

— Calibrate the final list of laboratory instructional objectives with the objective of discriminating between engineering disciplines and note any new issues or challenges related to achieving them.

— Develop a collection of distance education projects being conducted among the practice-oriented professions and encourage the development of such projects.

— Develop quality assurance mechanisms for assessing and evaluating the effectiveness of distance learning in engineering education.

— Encourage ethnographical research on the process of learning in the traditional engineering laboratory.

— Develop benchmarks for distance education in engineering based on the progress of other educational fields and industry.

— Finally, provide full reporting on the colloquy, its findings, and its implications for the future of e-learning.

This is a work in progress. It remains to be seen if we move closer to e-learning and a distance education delivery system sooner, rather than later. But with the challenge already at hand, we suggest that it is preferable to be more proactive than to back into the future.

References

[1] Policy Statement, Commission on Higher Education, February 1997.

[2] *The Chronicle of Higher Education*, January 14, 2000.

[3] *Dancing with the Devil: Information and the New Competition in Higher Education*, Richard N. Katz and Associates, 1999.

[4] *Distance Education at Postsecondary Education Institutions: 1997-98*, National Center for Education Statistics, December 1999.

[5] *Strategic Plan*, ABET, Inc., November 1, 1997.

[6] *Engineering Criteria 2000*, ABET, Inc., December, 1997.

[7] Lyle Feisel, and George Peterson, "A Colloquy On Learning Objectives for Engineering Education Laboratories," *Proceedings of the 2002 American Society for Engineering Education Annual Conference & Exposition*, Montreal, Canada.

[8] Richard M. Felder, "Learning Objectives and Critical Skill Development in the Engineering Laboratory," Invited Essay, Distance Education Colloquy, January 2002.

[9] Randy J. Hinrichs, "A Call for Action," Invited Essay, Distance Education Colloquy, January 2002.

[10] Karl A. Smith, "Inquiry and Cooperative Learning," Invited Essay, Distance Education Colloquy, January 2002

[11] A. Richard Graham, “Needed: A Theory of Laboratory Instruction”, The Undergraduate Engineering Laboratory, Engineering Foundation Publication, 1983.