A Colloquy on Learning Objectives For Engineering Education Laboratories

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Abstract

As distance learning programs become more prevalent and as we begin to offer undergraduate engineering programs in a distance format, the question of laboratories and their role in engineering education becomes increasingly important. There is an ongoing debate about whether a remote laboratory experience can *really* accomplish the goals of educational laboratories. This leads, then, to the question of what *are* the true goals of a laboratory experience. This question has been addressed before, but not extensively in the context of distance education or with regard to the massive computing power that now enables highly sophisticated simulations. In January 2002, ABET, with support from the Alfred P. Sloan Foundation, held a colloquy to explore this issue. This paper reports the preliminary conclusions of that colloquy.

Introduction

The face of the college-going student is changing. The majority of baccalaureate students are no longer fresh from high school and taking up residence on campus. They are more often commuter students, transitional students who begin their higher education at community colleges, and mature part-time students working their way through school. In response to this growing group of non-traditional students, many institutions are attempting to increase access to programs by experimenting with alternative educational delivery systems. Some courses employ correspondence study, for instance, others one-way and two-way audio, video, or internet-based learning. Many are using a combination of both. In some cases, distance education may be as near as the on-campus residence halls, the library, a student's bedroom, or his or her workplace.

One of the unique features of an educational program in a practice-oriented discipline such as engineering is that of the live, hands-on laboratory and design experience. If a distance education delivery mechanism is asynchronous (delivered without a real-time class session) and does not include this laboratory experience, it raises questions. Can the instructional objectives of the laboratory be achieved without the hands-on, practice-oriented experiences? But, more importantly, what are the expected outcomes of these practice-oriented experiences in the curriculum? Can we define the attributes of engineering graduates that are developed or enhanced by a hands-on laboratory experience? Could those attributes also be developed or enhanced through a program offered via distance education?

ABET, the Alfred P. Sloan Foundation, and many others invested in the quality of education in the practice-oriented professions have been mulling over these questions for some time. In order to begin to address them, a colloquy was organized by ABET and funded through the Sloan Foundation. Held in January 2002 in Mission Bay, California, this colloquy gathered together some of the best minds in engineering education, particularly in regard to the laboratory. The goal of the colloquy was to determine through consensus a taxonomy of laboratory learning objectives, which could be validated and disseminated throughout the educational community. It was believed that such a taxonomy would not only produce higher-quality traditional laboratories but also provide benchmarks against which asynchronous learning and virtual degree providers could assess the achievement of their program objectives. This paper reports the history, process, preliminary results, and future implications of that colloquy.

History

There has been a growing movement towards the democratization of higher education, towards the notion that anyone, anywhere, at any time should have access to learning. There is perhaps no greater proponent of this educational democracy than the Alfred P. Sloan Foundation. In its large-scale grant program *Learning Outside the Classroom: The Sloan Program in Asynchronous Learning, Anytime, Anywhere, Online*, managed by Program Director A. Frank Mayadas, the goal is to make quality higher education and training available anytime and anywhere for anyone who is motivated to seek it. Through this program, institutions receive grants to encourage their development and use of Asynchronous Learning Networks (ALNs) that enable electronic access to remote learning resources, such as instructors, fellow students, text, and software. According to Sloan, some sixty institutions have received such grants and are using them to implement ALNs. Together these institutions constitute the Sloan ALN Consortium. During academic year 1999-2000, consortium members enrolled over 100,000 students and recorded over 3000 faculty years of ALN teaching experience. They are committed, today, to providing over 50 degree programs.

Needless to say, when ABET presented the Sloan Foundation with its *Proposal to Examine Distance Education in the Practice-Oriented Professions* in April of 2000, Frank Mayadas and the Sloan Foundation met them with strong support.

The objective of the ABET proposal was to advance the state of the art in distance education for the practice-oriented professions by examining how the objectives of laboratory experience in traditional programs might be achieved in distance education programs. The means to accomplish this goal were laid out as follows:

- Define the attributes developed in the graduate by the laboratory experience.
- Identify the learning objectives achieved or enhanced through traditional laboratory instruction.
- Initiate experiments in distance delivery programs that demonstrate the achievement of these learning objectives and that assess the quality of these programs.

The colloquy discussed in this paper was meant to address the first two actions above.

ABET's interest in distance education is simple: As a quality assurance organization that accredits programs in practice-oriented professions—engineering, technology, computing, and applied science—and as an organization whose own published strategic plan aims to "encourage and accommodate new educational paradigms" and "develop the capability to evaluate programs that use alternative delivery systems," ABET understands that it must take a proactive, consultative role in distance education; it must provide up-front guidance for developing high-quality distance education programs that comply with its established accreditation criteria. ABET, too, believes in democracy in education, but must ensure that that democracy also provides quality for all students who partake of it.

A third, and very important, partner in this examination of distance education in the practice-oriented professions is industry, for it is industry who makes online learning possible through technological innovation. One such important partner is Microsoft. Through several initiatives, including research and development in learning technologies, its TechNet for Education and Classroom Teacher Network programs, and its partnership in groups like the Learning Federation, Microsoft has made clear its dedication to educational democracy, and many others, such as IBM and Sun Microsystems, are following suit.

Activities Before the Colloquy

The colloquy began to take shape in early 2001 when a national steering committee was selected and later convened that February. Together, the group developed a plan for the colloquy, including format, issues to be addressed, potential speakers, and other concerns. It was established that professional facilitators experienced in similar engineering activities would be hired to lead the group as a whole and that steering committee members would serve as facilitators for breakout groups.

Requests were sent from ABET Executive Director George Peterson to deans of ABET-accredited engineering programs for recommendations of faculty who were not only high-quality engineering educators but had notable experience developing and teaching traditional engineering laboratories. Many faculty members received multiple recommendations, as there were no institutional boundaries laid out to the nominating deans. 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 52, including the steering committee, ABET staff, Sloan Foundation representatives, and paid facilitators. The participants also included faculty from the Hong Kong University of Science and Technology and the Chinese University of Hong Kong. [APPENDIX A]

The Speakers

The colloquy began on Sunday, January 6, 2002, with a brief introduction by George Peterson, outlining the purpose of the colloquy and ABET's role. Next, Frank Mayadas explained the Sloan Foundation's interest the activity. Lyle Feisel concluded the introduction by elaborating 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. First to present was Richard M. Felder of North Carolina State University. Felder engaged the audience with a talk based on his paper *Learning Objectives and Critical Skill Development in the Engineering Laboratory* (a pre-read for participants). 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, 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. [APPENDIX B] Felder's presentation significantly helped set the stage for the final list of fundamental educational objectives for the engineering laboratory.

Second to present was Randy J. Hinrichs of the Learning Science and Technology Group of Microsoft Research. 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. During the presentation of his paper *Call to Action,* 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 presenter 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.* 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. [APPENDIX C] 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."

Determining the Objectives

In between plenary sessions, participants formed 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?"

During each breakout session, the small groups worked and reworked their lists of objectives, both building up and trimming down, depending on the consensus. Their lists met more reshaping and refining during report-back sessions, when all participants had a chance to hear and discuss the objectives each group had formulated. In addition, one "captain" was chosen from each breakout group. Periodically, these captains met together with facilitators to try and gain further consensus on the objectives developed by each breakout.

On the third day of the colloquy, a semi-polished final list of objectives was presented to the entire group of participants for discussion. During that discussion, the participants agreed to define, in broad terms, the ***Instructional Laboratory Experience*** as "personal interaction with equipment/tools leading to the accumulation of knowledge and skills required in a practice-oriented profession." Based on the comments expressed during that discussion, a group of volunteer editors polished up a final version and presented it once again to the entire group of participants. That final list of 13 learning objectives developed by consensus of the participants appears below.

Preliminary Results

The following are the complete set of learning objectives for the engineering laboratory developed and approved through consensus by the participants of the colloquy:

[These objectives apply to laboratory experiences over the entire undergraduate program.]

All objectives start with the following: "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.

Implications for the Future

The ABET and Alfred P. Sloan Foundation Colloquy served as an important first step in both improving the quality of existing engineering laboratories and opening the doors for discussion of how distance education may be applied to the practice-oriented professions. There are several more steps to follow, however, if we are to put what was learned at the colloquy into action. The following is a list of near- and medium-term action items compiled by colloquy participants:

- Develop a full report on the colloquy, its findings, and its implications.
- Validate the above final list of learning objectives both internally to the colloquy participants and externally to other institutions, 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 ethnographic 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.

LYLE D. FEISEL
Dean Emeritus Feisel was the Founding Dean of the Watson School of Engineering and Applied Science at SUNY Binghamton from 1983 to 2001. He served as President of ASEE in 1997-98 and is currently IEEE Vice President for Education. Now retired, he continues to do consulting for universities and colleges and remains active in the accreditation process.

GEORGE D. PETERSON
George D. Peterson, Ph.D., is the Executive Director of the Accreditation Board for Engineering and Technology. He is a former Program Officer in the Division of Undergraduate Development Education and in the Undergraduate Science, Engineering, and Mathematics Education Division at the National Science Foundation. He is a Fellow of the IEEE, of ABET, and of the Institution of Engineers in Ireland, as well as a licensed Professional Engineer in Colorado and Maryland.

APPENDIX A

Name	University/College	Discipline
Daniel J. Biezad	Cal Poly - San Luis Obispo	Aeronautical/Aerospace
Unny Menon	Cal Poly - San Luis Obispo	Industrial and Manufacturing Engineering
Pradeep Khosla	Carnegie Mellon University	Electrical and Computer Engineering
Lynn Carter	Carnegie Mellon University	Software Engineering Institute
Eli Fromm	Drexel University	Bioengineering
Pak-chung Ching	Chinese University of Hong Kong	Electrical Engineering
Philip C. H. Chan	Hong Kong University of Science and Technology	Electrical Engineering
Craig Hoff	Kettering University	Mechanical Engineering
Juan R. Pimentel	Kettering University	Electrical and Computer Engineering
John F. Greco	Lafayette College	Electrical and Computer Engineering
Jesus de Alamo	MIT	Electrical Engineering and Computer Science
James H. Lightbourne	National Science Foundation	Mathematics
David Dickinson	Ohio State University	Industrial Welding and Systems Engineering
Ray Eberts	Purdue University - West Lafayette	Industrial Engineering
David Hornbeck	Southern Polytechnic University	Civil Engineering Technology
Robert Ubell	Stevens Institute of Technology	Electrical Engineering
Sven K. Esche	Stevens Institute of Technology	Mechanical Engineering
Frederick L. Orthlieb	Swarthmore College	Civil and Mechanical Engineering
Jack Lohmann	Georgia Tech	Industrial Engineering
Robert Balmer	Union College	Mechanical Engineering
Vincent Wilczynski	United States Coast Guard Academy	Mechanical Engineering
Ozer Arnas	United States Military Academy	Civil and Mechanical Engineering
Joe Gillerlain	United States Naval Academy	Mechanical Engineering
Allen Klinger	University of California Los Angeles	Engineering and Applied Science
Melinda Piket-May	University of Colorado-Boulder	Electrical and Computer Engineering
Albert Rosa	University of Denver	Electrical Engineering
Tim Trick	University of Illinois - Urbana - Champaign	Electrical and Computer Engineering
Farhad Ansari	University of Illinois at Chicago	Civil and Materials Engineering
Frank P. Incropera	University of Notre Dame	Aerospace and Mechanical Engineering
Jed Lyons	University of South Carolina	Mechanical Engineering
Gary D. Bubenzer	University of Wisconsin-Madison	Biological Systems Engineering

Name		**University/College**	**Discipline**
Edward	McAssey	Villanova University	Mechanical Engineering
Mike P.	Deisenroth	Virginia Polytechnic Institute	Industrial and Systems Engineering
Dennis K.	George	Western Kentucky University	Engineering Technology
Karen	Lemone	Worcester Polytechnic Institute	Computer Science
		Essayists	
Richard M.	Felder	NC State University	Chemical Engineering
Randy J.	Hinrichs	Microsoft Research	Learning Sciences and Technology
Karl	Smith	University of Minnesota	Civil Engineering
		Steering Committee	
Lyle	Feisel	Binghamton University	Principal Investigator
George D.	Peterson	ABET	Principal Investigator
Barry A.	Benedict	Embry-Riddle Aeronautical University	Civil Engineering
William	Conger	Virginia Polytechnic Institute	Chemical Engineering
Edward W.	Ernst	University of South Carolina	Electrical Engineering
Burks	Oakley	University of Illinois	Electrical Engineering
William M.	Worek	University of Illinois Chicago Circle	Mechanical Engineering
		Sloan Foundation	
Frank	Mayadas	Program Officer, Sloan Foundation	Electrical Engineering
		Professional Staff	
James	Ware	Information Systems & Technology Director	Professional Staff
Kathryn	Aberle	Associate Executive Director	Professional Staff
Elizabeth	Glazer	Communications Coordinator	Professional Staff
Dan	Hodge	Accreditation Director	Professional Staff
Dayne	Aldridge	Adjunct Accreditation Director	Professional Staff
		Facilitators	
Bill	Lowell	*Business Development Directives*	Professional Staff
Judy	Whalen	*Business Development Directives*	Professional Staff

APPENDIX B

Table 1

Taxonomy of Educational Objectives: Cognitive Domain[*]

1. **Knowledge**—repeating information verbatim. [*Examples*: *list* the first ten alkanes; *state* the steps in the procedure for calibrating a gas chromatograph.]
2. **Comprehension—**demonstrating understanding of terms, concepts, and principles. [Examples: *explain* in your own words the concept of vapor pressure; *interpret* the output from a strip chart recorder or potentiometer.]
3. **Application—**applying concepts and principles to solve problems. [Examples: *calculate* the probability that two sample means will differ by more than 5%; *solve* the compressibility factor equation of state for P, T, or V from given values of the other two.]
4. **Analysis**—breaking things down into their elements, formulating theoretical explanations or mathematical or logical models for observed phenomena. [Examples: *interpret* discrepancies between a predicted experimental response and the measured response; *model* the dynamic performance of a laboratory stirred-tank reactor.]
5. **Synthesis—**creating something, combining elements in novel ways**.** [Examples: *formulate* a model-based control algorithm for the process studied in last week's lab experiment; *make up* a homework problem involving material covered in class this week; *design* a concrete canoe or solar-powered car.]
6. **Evaluation**—judging the value of material, choosing from among alternatives and justifying the choice using specified criteria. [Examples: *select* from among available options for measuring an experimental system response and justify your selection; *critique* a lab report.]

Levels 1–3 are sometimes termed *lower-level cognitive outcomes* and Levels 4–6 are commonly referred to as *higher-level thinking skills*. Undergraduate instruction in engineering generally restricts itself to Levels 1–3 (especially 3), although sometimes Level 4 questions appear on examinations. If Level 4, 5, and 6 outcomes are desired, however, the way to maximize the chances of achieving them is to provide exercises that call for the required skills and constructive feedback on the responses throughout the curriculum, not just in a senior capstone course.

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[*] Krathwohl, D.R., and B.S. Bloom. 1984a. *Taxonomy of educational objectives. Handbook 1. Cognitive domain*. New York: Longman.

Table 2

Taxonomy of Educational Objectives: Affective Domain[*]

1. *Receiving*—attending to a stimulus. [Examples: read a handout; listen attentively to instructions.]
2. *Responding*—reacting to a stimulus. [Examples: carry out an assignment; participate in a discussion.]
3. *Valuing*—attaching value to an object, phenomenon, behavior, or principle. [Examples: demonstrate through expression or action an appreciation of the importance of data replication or good teamwork in a laboratory setting.]
4. *Organization*—organizing different values into the beginning of an internally consistent value system. [Examples: adopt a systematic approach to problem solving; demonstrate recognition of a need to balance freedom and responsibility; formulate a career plan.]
5. *Characterization by a value or value complex*—internalizing a value system and behaving accordingly in a pervasive, consistent, and predictable manner. [Examples: work independently and diligently, function effectively in group activities, act ethically.]

Table 3

Taxonomy of Educational Objectives: Psychomotor Domain[**]

1. *Perception*—using sense organs to obtain cues about a motor activity. [Example: repeat oral or written instructions for performing an experiment.]
2. *Set*—demonstrating readiness to take a particular action. [Example: explain the series of steps required to operate a convection furnace.]
3. *Guided response*—early stage of learning a performance skill including imitation and trial-and-error. [Example: carry out a gas chromatograph calibration procedure by following stepwise instructions.]
4. *Mechanism*—later stage of learning a performance skill when it can be performed with proficiency. [Example: follow the same procedure smoothly and confidently.]
5. *Complex overt response*—skillful performance of a complex movement pattern [Example: perform routine maintenance of electronic equipment quickly and accurately.]
6. *Adaptation*—skills that are so well-developed that the individual can modify them to fit the situation. [Example: alter a routine equipment maintenance procedure to deal with an unfamiliar problem.]
7. *Origination*—creating new movement patterns based on highly developed skills. [Example: develop a procedure for testing a prototype of a novel device.]

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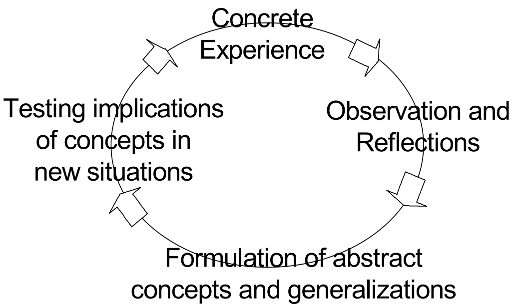
[*] Krathwohl, D.R., B.S. Bloom, and B.B. Masia. 1984b. *Taxonomy of educational objectives. Handbook 2. Affective domain.* New York: Longman.

[**] Simpson, E.J. 1972. *The classification of educational objectives in the psychomotor domain.* Washington, DC: Gryphon House.

APPENDIX C

Kolb’s Experiential Learning Cycle

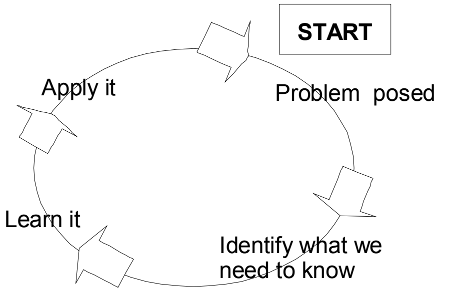

Concrete Experience

Observation and Reflections

Formulation of abstract concepts and generalizations

Testing implications of concepts in new situations

Problem-Based Learning


START

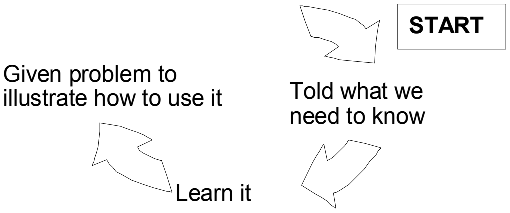
Problem posed

Identify what we need to know

Learn it

Apply it

Subject-Based Learning


START

Told what we need to know

Learn it

Given problem to illustrate how to use it