ABET and Engineering Laboratory Learning Objectives: A Study at Virginia Tech

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In light of emerging simulated and remote engineering laboratory courses, the Accreditation Board for Engineering and Technology (ABET) has taken on the task of assessing whether these new courses can truly accomplish the goals of educational laboratories. The first step in reaching a judgment is a need to fully understand the goals of the traditional engineering laboratory. Once these goals are determined, ABET can determine whether a simulated or remote course is an adequate substitution for traditional hands-on experience. In January 2002, ABET held a colloquy to solicit input from a select group of experts to determine a taxonomy of engineering laboratory learning objectives. A list of 13 learning objectives was created that participants felt adequately describes the goals of the engineering laboratory. However, the participants of the colloquy requested that the list be validated and any new issues or challenges related to achieving the objectives be documented. This paper takes an initial step in that direction. It summarizes a study done at Virginia Tech in which instructors in four engineering departments were interviewed to determine the degree to which the objectives are achieved and the appropriateness of the objectives in the laboratory. With additional input from various institutions, ABET can confirm the goals of engineering laboratory courses and progress to assessing the ability of the simulated and remote courses to fulfill the objectives. Some background on learning objectives and laboratory courses and why they are important will provide the foundation for this paper.

Learning Objectives Defined

The mission of an educational institute along with national, state, and local requirements should dictate the educational goals the institute wishes to accomplish.[10] The goals describe the attributes of a well-educated person by incorporating many learning experiences.[3] Learning objectives are directly involved with these educational goals. Educational goals justify learning objectives in a sense because they are the reason *why* any one particular learning objective is included in an educational program. Similarly, learning objectives actualize educational goals because they show *how* a particular goal will be achieved.[3]

Learning objectives have been labeled many different ways; instructional objectives, educational objectives, behavioral objectives, and performance goals all imply nearly the same idea as learning objectives.[11; 12] Kibler, et al. define learning objectives as, "statements that describe what students will be able to do after completing a prescribed unit of instruction." [11] Robert Mager provides more detail, asserting that, "the objectives must include three characteristics: (1) a statement about what the learner must be able to do, (2) a description of the conditions under which the performance is to occur, and (3) a description of the criteria for acceptable performance." [13] A key phrase in both of these definitions centers on what the learner/student must *be able to do*. Learning objectives provide detailed descriptions about the exact behavior a student should demonstrate to show competence in a particular area. For this reason, objectives usually contain active verbs (ex: analyze, create, locate, perform) that explicitly state the behavior expected of the student that will be used as an indicator of completion of broader educational goals. In addition to specifications for individual learning objectives there are guidelines for sets of objectives for an entire program.

Possibly more important than any single learning objective is the set of objectives that a program uses. Certain guidelines must be followed to ensure a comprehensive set of objectives with the appropriate level of specificity. One set of guidelines, Bloom's taxonomy of educational objectives, classifies activities in a hierarchical pattern according to their level of specificity.[10] The taxonomy discusses three domains of educational objectives: cognitive, affective, and psychomotor. These domains are broken down further into categories ranging in skill level from basic to advance.[2] The taxonomy is widely accepted and highly influential in determining learning objectives. Along with using a taxonomy for objectives, designers of learning objectives should observe the following guidelines:

- *Objectives should be of moderate specificity.*
- *Objectives should appropriately cover all skill levels.*
- *Objectives should be attainable by the current set of students.*
- *Objectives should be appropriate to the instructional area and the philosophy of the school.*

The next step in understanding learning objectives is to realize their purpose and importance to the many people they affect. The next section discusses the functions of learning objectives and their importance to education.

The Importance of Learning Objectives

When learning objectives are properly stated, they serve many purposes and assist many groups of people.[10] Some of the functions of learning objectives are as follows:

- *Provide a focus for instruction.* Learning objectives provide a focus for instruction at both program and course levels in education.[10] Clearly stated learning objectives create a framework for planning a successful instructional program that concentrates on desired outcomes.[10] James Stice states, "Instructional objectives are the most important tool in the teacher's kit because they specify the outcome of the course." [17] Without specific learning objectives, there is a tendency for daily instruction to focus too heavily on the lower-level knowledge outcomes, rather than higher-level skills such as critical thinking and complex problem solving.[10]
- *Provide guidelines for learning.* Sharing learning objectives with students at the beginning of instruction allows students the opportunity to understand what is expected of them, to set personal goals, and to perform self-assessments of their learning progress.

Along with the objectives, students should be given the conditions under which performance should occur and a description of the criteria for acceptable performance.[7; 11]

- *Provide targets for assessment.* Three elements are necessary for student assessment to take place: a definition of the nature of the assignment, a display of the student's work (oral or written), and criteria for acceptable performance. Clearly stated learning objectives provide information to many people regarding the nature of the task that should be completed by the student. Without this statement describing the nature of the assignment, there would be no basis for assessment. The need for learning objectives in assessment is illustrated in Karen Yoshino's definition of the theory of assessment: "The systematic, intelligent generation and evaluation of student learning outcomes whose characteristics and properties achieve stated objectives and satisfy specified criteria." Yoshino describes learning objectives and performance criteria as the grounds for assessment of student learning.[18]
- *Convey instructional intent to others.* In addition to the impact that learning objectives have on those directly involved in education, namely the teachers and students, objectives can be useful for several other groups of people.[11] Other teachers, parents, administrators, course evaluators, and school boards all rely on stated learning objectives for information.
- *Provide for evaluation of instruction.* Gronlund states, "Clearly stated instructional objectives can illuminate the successes and failures in our instruction." [10] He describes the three main areas of instruction evaluation as methods, materials, and objectives. If the learning objectives are clearly stated and well defined, instructional evaluation can focus on teacher methods and available materials. If the objectives are not clearly stated, they may need to be modified or made clearer to students to achieve the desired performance of the students.[10]
- *Provide feedback for continuous improvement.* As previously discussed, the role of learning objectives in assessment is extensive. However, as Neelam Soundarajan points out, "…assessment is not, of course, the end-goal. The end-goal is to use the data gathered from assessment to arrive at possible improvements in the program." [16] In support of the importance of feedback channels and continuous improvement ABET states in the Engineering Criteria 2000, "[The program must have] a system of ongoing evaluation that demonstrates achievement of [educational] objectives and use the results to improve the effectiveness of the program." Furthermore, it states, "Evidence must be given that the results [of the assessment process] are applied to the further development and improvement of the program." [1] The first statement explicitly states the role of objectives in ongoing or continuous improvement. Both statements mention the results of the assessment process and their application to program improvements. The results of the assessment process mentioned in the two ABET statements imply the involvement of learning objectives in the continuous improvement process. As discussed earlier, assessments are conducted for the purpose of determining the level of achievement of an objective, with evaluations going one step further, by determining if performance criteria were met and learning objectives were achieved. Learning objectives are determined directly from the program goals and they provide the foundation for the rest of the assessment process, including the continuous feedback loop.

With the focus of this paper on learning objectives in the engineering laboratory, some background information will highlight the importance of laboratory courses in general and engineering laboratory courses in particular.

Importance of Laboratory Courses

Due to the recent increase in distance learning forms of engineering education, a question arises concerning the effectiveness of laboratory courses taken in the distance learning or simulated format.[6] To tackle the issue of the value of distance learning laboratory courses, the traditional engineering laboratory must first be studied. The need for and purpose of the traditional laboratory must be understood before engineering program administration can determine whether or not the distance learning laboratories satisfy the same need and purpose.[4; 6]

The need for and purpose of laboratory courses is generally satisfied by an ancient proverb that states, "Tell me, and I forget; Show me, and I remember; Involve me, and I understand." [7] This proverb provides considerable support for laboratory experiences, which tend to involve the student with hands-on exercises and thought-provoking challenges. It is reported that Edgar Dale's *cone of learning* describes students' learning abilities according to the type of senses used while learning.[7] Students tend to remember 20% of what they hear, 30% of what they see, and up to 90% of what they participate in. These percentages substantiate the need for laboratory courses to engage the students' audio, video, and tactile senses to increase the level of learning and understanding.

Multiple parties show concurrence with the need for laboratory courses by including them or the associated experiences in their expectations of educational programs. Bloom's taxonomy of educational objectives is widely accepted as an appropriate categorization of skills a student should posses.[10] Bloom's taxonomy suggests that a student's understanding should go beyond basic comprehension to enable them to analyze, synthesize, and evaluate stated facts.[2] Similarly, Perry's model of intellectual development advocates that a mature student will posses the ability to evaluate evidence to make sound judgments.[15] The achievement of the statements in the Bloom and Perry models require extensive development of critical thinking skills, which many educators believe can be accomplished in the laboratory setting.[19]

An even more obvious statement in support of laboratories is found in ABET's Engineering Criteria 2000 which requires program graduates to have, "an ability to design and conduct experiments, as well as to analyze and interpret data." [1] ABET clearly expects graduates to posses the high-level critical thinking skills that are necessary to make sound engineering judgments. The engineering industry also has an interest in the skill level of graduating engineers. Gillet, et al. believe that, "Practice is often the key to becoming an effective professional…particularly in engineering disciplines." [9] The engineering laboratory provides this "practice" and develops critical thinking skills, satisfying the desires of both academia and industry.

Realizing the importance of both learning objectives and laboratory courses, it is obvious that learning objectives play a role in creating successful laboratory experiences. Objectives that are designed for a lecture course will not be sufficient for hands-on learning. Following is a summary of the findings of a study done on engineering laboratory learning objectives.

Case Study Introduction

This study serves as follow up to the colloquy on learning objectives for engineering education that ABET held in January of 2002 with support from the Alfred P. Sloan Foundation. The colloquy was held in response to the question of whether or not a remote laboratory can fulfill the goals of the traditional engineering laboratory.[6] To determine if remote laboratories accomplish the goals of the laboratory experience it was first necessary to develop a comprehensive set of learning objectives that convey the attributes of engineering graduates that are developed in the laboratory setting. The direct result of the colloquy was a taxonomy of 13 laboratory learning objectives intended for use in improving traditional laboratories and providing a basis for remote laboratories to benchmark against. The objectives are listed here; their definitions may be found in Appendix A.

1) Instrumentation
2) Models
3) Experiment
4) Data Analysis
5) Design
6) Learn From Failure
7) Creativity
8) Psychomotor
9) Safety
10) Communication
11) Teamwork
12) Ethics in the Lab
13) Sensory Awareness

A near-term action item identified by the colloquy attendees was to, "Validate the…learning objectives…and note any new issues or challenges related to achieving them." [6] The remainder of this paper describes a study done at Virginia Tech seeking to validate the learning objectives and to explore issues and challenges associated with them.

Methods

The set of objectives is intended to apply to any undergraduate engineering department, so a sample of four engineering departments was selected. Because any one course is not expected to fulfill all the objectives, data was collected for every required laboratory course in each department and the course data were combined to create a picture of each department.[6] The four departments selected were Biological Systems Engineering (BSE), Civil and Environmental Engineering (CEE), Engineering Science and Mechanics (ESM), and Industrial and Systems Engineering (ISE). In departments with internal focus areas or concentrations, the "general" track was selected whenever possible. However, in BSE no "general" track exists, so each of the track options was analyzed separately. Two of the departments (CEE and ISE) are considered mainstream and general, while the other two (BSE and ESM) are less common and more area specific. To gain insight into all of the required undergraduate laboratory courses in each department, an interview was conducted with each laboratory instructor. It is worth noting that the participants of the colloquy defined the instructional laboratory experience as, "personal interaction with equipment/tools leading to the accumulation of knowledge and skills required in a practice-oriented profession." [6] This definition dictated the set of courses included in the study.

The purpose of the interview was twofold: 1) to complete a survey questionnaire (located in Appendix A) in which the instructor compared the intended course outcomes to the set of proposed learning objectives and 2) to identify issues the instructor may have concerning the proposed objectives. The complex nature of the operational definitions of the objectives prompted a difficult decision in terms of the questionnaire format. To gain the most accurate representation of the course and its link to the proposed objectives, it would be helpful to split up the definition of each of the objectives into its individual components. The alternative was to leave the definitions as stated, with several topics mentioned in each objective's definition, forcing instructors to choose one answer for a multifaceted question. Ultimately, time restrictions dictated the need to keep the questionnaire brief, so the definitions were left whole for the purpose of data collection.

For each learning objective, the instructor was asked to rate the course's correlation and coverage according to the definition given. For clarity, correlation was defined as, "the depth in which one or more of the parts presented in the objective definition are addressed during the semester-long laboratory experience." The depth in which a course goes into for any one objective was based upon the most widely used or applied component of the definition because some components of a definition may apply very little or not at all to a particular course or department. The instructor could choose from *Strong*, *Moderate*, or *None* to describe the correlation between the course and the objective. A *Strong* correlation with an objective implies that one or more components of the objective are a main focus of the course or are applied routinely throughout the semester. A *Moderate* correlation covers a range from minimal to fair, including everything except the extreme points of *Strong* and *None.* Three broad categories were used instead of a five or ten-point scale for three reasons: 1) the subjective nature of the data would make assignments on a ten-point scale arbitrary, potentially skewing data, 2) in talking through the correlation with the instructor, it was typically clear which category best described the correlation, yielding accurate data, and 3) ABET has used similar category denominations in previous mappings of courses and programs to learning objectives.

Similarly, coverage was defined as, "the breadth in which the objective is covered in the semester-long experience." The instructor could choose between *Extensive* and *Narrow* coverage of an objective. *Extensive* coverage describes a course that covers a majority of the components of a definition during the semester and *Narrow* coverage describes one that covers a minority of the components of a definition. Collecting data on coverage helped supplement the correlation rating by documenting whether the course addresses many or few of the components of the definition, and was an alternative to splitting the definitions into components. The selection of the two categories was made for the same reasons that were stated for the selection of the correlation categories.

The instructor determined the ratings for correlation and coverage based upon both stated (in the syllabus or course materials) and unstated objectives, intentions, and outcomes of the course. Once the instructor rated the course's correlation with and coverage of each of the objectives, he/she was asked his/her opinion of the set of objectives. The instructor was asked if the set of objectives is comprehensive and if all the objectives are appropriate. The instructor was then asked to discuss any further issues he/she had with the 13 learning objectives.

Results

The primary instructor for each laboratory course was interviewed. The field of interviewees for the 20 laboratory courses included 19 instructors (17 professors and 2 graduate students). The instructors had a wide degree of expertise, varying from one semester to more than a decade of laboratory instruction for the course for which he/she was interviewed. The correlation and coverage results of the objective mapping for each course are located in Appendix B. Figures 1 and 2 present the departmental summaries of correlation and coverage per learning objective.

Figure1 creates a good overall picture of each department by showing the level of correlation the department has with each objective. The tables (Appendix B) show the number of courses receiving a correlation rating of *Strong*, *Moderate*, or *None* for each of the objectives with the maximum x-value equal to the total number of required laboratory courses in the department. In each of the departments, at least one objective received more ratings of *No* correlation than either of the other ratings, but no objective received *only* ratings of *No* correlation. This shows that all of the departments have some correlation with all of the proposed learning objectives. Furthermore, objectives 4 (Data Analysis), 10 (Communication), and 11 (Teamwork) received ratings indicating a very strong correlation across all of the departments.

Figure 2 provides insight into how well each department addresses the components of each objective. The tables (Appendix B) show the number of courses receiving a coverage rating of *Extensive* or *Narrow* for each of the objectives (courses that received a correlation rating of *None* were not assigned a coverage rating).

After completing the correlation and coverage ratings, the instructors were asked a few open-ended questions. These questions prompted some spirited discussion about the set of 13 learning objectives. Following is a summary of the issues that were discussed; a complete table of the responses to the open-ended questions is located in Appendix C. Fifteen of the 19 instructors feel that the list of objectives is comprehensive. Two instructors believe an objective should be added and two instructors believe a major concept should be added within an existing objective. Eighteen of the instructors believe all of the objectives are appropriate, while one thinks objective 13 (Sensory Awareness) should be eliminated. Ten of the 13 objectives received specific comments; the following list highlights the most frequently raised issues:

- Aspects of a definition are vague.
- Some items (though important to overall learning) may not be necessary in the laboratory.
- Time constraints in the laboratory prohibit some items from being addressed.
- The subjective nature of some items makes measurement difficult.
- There is overlap among objectives

Worthy of further discussion are objectives 5 (Design), 8 (Psychomotor), and 13 (Sensory Awareness). These three objectives were the focus of the majority of apprehension felt by the instructors. Instructors did not doubt the appropriateness of objective 5 (Design), but the operational definition and its suitability to the laboratory were questioned. Several instructors expressed concern regarding the phrase, "Design, build, or assemble…" Does the phrase mean to design and then to build or assemble what was designed, or does it mean design or build or

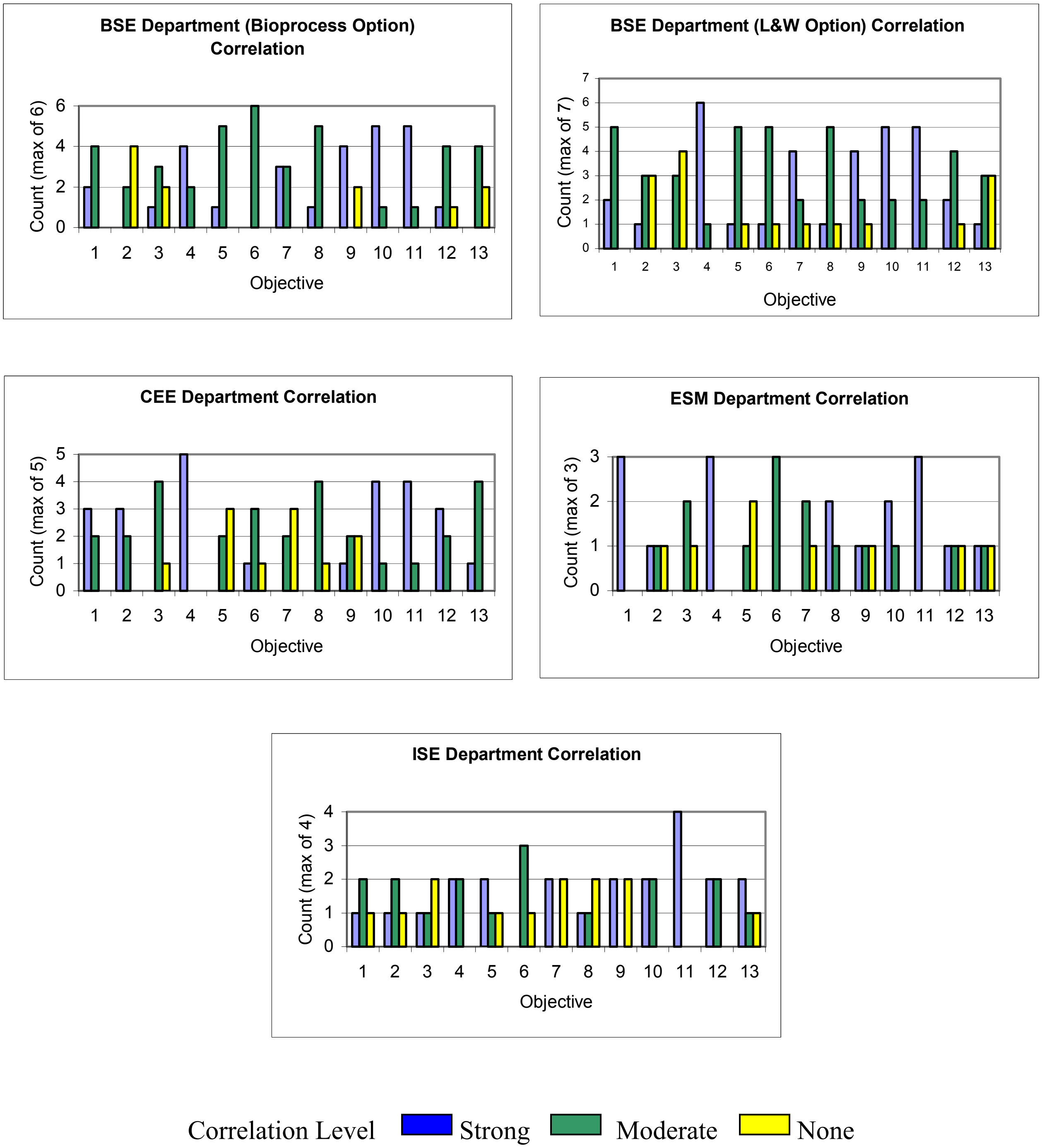

Figure 1 Correlation Levels for Each Department

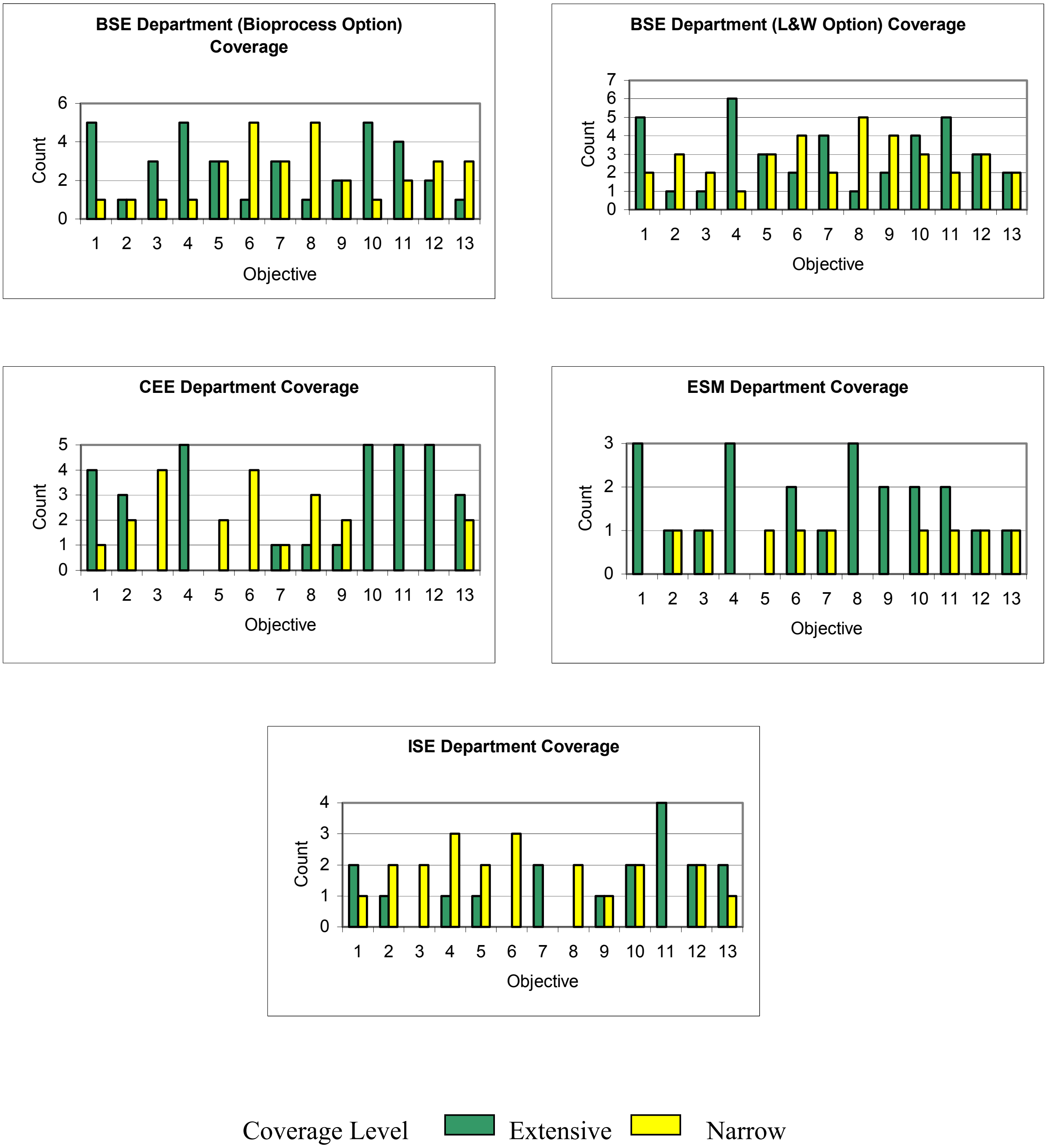

Figure 2 Coverage Levels for Each Department

assemble? The former interpretation implies design will be done and followed by some form of construction, making the definition too broad for a title of Design. The latter interpretation implies that one of the three operations will be completed, and not necessarily that of design, making the title inappropriate. Another instructor questioned the role of design in the engineering laboratory. The nature of introductory level laboratory courses and time constraints do not lend themselves to design. The instructor believes that perhaps design should be left to the lecture portion of the course.

Objective 8 (Psychomotor) prompted specific comments by six instructors and nominal remarks by many more. The term "psychomotor" was accompanied by puzzled looks and questions of its definition. One professor pointed out that some students may struggle with understanding the objective. The other main issue centered on the phrase, "…appropriate engineering tools and resources." Do tools and resources include such things as software, hardware, machinery, models, mathematical equations, and reference material? Are there restrictions on the type of tools and resources that the objective intends to include?

Nine of the instructors stated specific reservations about objective 13 (Sensory Awareness), and almost every instructor at least commented on either the term "sensory awareness" or "human senses." Many believe the objective title to be vague and inappropriate for undergraduate engineering education. Several instructors wondered about the meaning of "human senses;" does it imply the five traditional senses, does it include common sense and understanding, or does it encompass more than that? Again, instructors pointed out that if professors are having trouble interpreting the objective, certainly many students would also have trouble deciphering what is expected of them. This objective was termed "soft" by many, and its highly subjective nature was scoffed.

Discussion

As evidenced by the graphs in Figure 1, the four engineering departments at Virginia Tech validate the 13 learning objectives proposed by ABET. On the surface, objectives 2 (Models), 3 (Experiment), 5 (Design), 7 (Creativity), and 8 (Psychomotor) received less than convincing ratings, particularly objectives 3 and 5. Judging from informal instructor feedback, objectives 3 and 5 are highly supported as important aspects of the laboratory experience, but time and resources seem to prohibit many of the instructors from addressing these more time-consuming topics. As some instructors pointed out, objectives 3 and 5 require student creativity, explaining the low scores seen in objective 7. The instructor designs many of the laboratory experiments and students are expected to follow procedures and analyze data, leaving little room for creativity. The low correlation with objective 8 may be partially explained by the ambiguous nature of the definition. Several instructors were not comfortable with the terms "engineering tools and resources" and decided to rate the course lower to be "on the safe side." Even though these few objectives received intermittent low scores, the overall correlation ratings of the departments suggests that the 13 learning objectives are indeed appropriate in today's traditional engineering laboratory.

Similarly, the graphs in Figure 2 provide support for the objectives. It is not assumed that every component of each objective is necessary or even applicable to all engineering departments;

therefore a *Narrow* coverage rating does not necessarily mean a course or department insufficiently covers a particular objective. A *Narrow* rating may indicate less than complete coverage or simply the inapplicability of aspects of the objective to the department. Further investigation into the reasons behind the number of *Narrow* coverage rating is necessary for objectives 3 (Experiment), 5 (Design), 6 (Learn from Failure), and 8 (Psychomotor). Overall, the coverage ratings provide further support for the objectives.

Sorting through the instructor feedback from the open-ended interview questions leads to a few conclusions: a few of the definitions need clarification, items may need to be added or subtracted from a definition, and some objectives may be eliminated to reduce overlap. Table 1 summarizes changes that should be considered to make the objectives more appropriate and user-friendly.

Table 1 Changes to Consider

Objective	Changes to Consider
5	Clarify the phrase 'design, build, or assemble'
6	Add 'measurements' to the list of faulty items
7	Eliminate, and let objectives 3 and 5 cover student creativity
8	Revise the title 'psychomotor' to ‘Application’ **
8	Clarify the phrase 'appropriate engineering tools and resources'
10	Eliminate oral communication from the definition
13	Specify what is meant by 'human senses'

**The term ‘psychomotor’ is grammatically incompatible with the rest of the list. Psychomotor is an adjective and does not fit in with the rest of the objective titles that are expressed as nouns and verbs.

In designing the objectives, the participants at the colloquy appropriately decided to form one list for all types of engineering for simplicity’s sake. However, since the proposed learning objectives are meant to apply to any engineering department at any institution, they are too general to perform the duty of course learning objectives – telling students exactly what they must *be able to do*. The learning objectives are appropriate program-level objectives. A program that wishes to use the 13 objectives as a framework must realize that each instructor will need to create appropriate learning *outcomes* that further specify what behaviors the students will have to demonstrate. (See [8] for information on writing course-level learning outcomes.)

Based upon literature on learning objectives, the objectives have appropriate characteristics for program-level use. The objective definitions all begin with action verbs describing the types of behaviors that should be involved in achieving the objective. In regard to Bloom’s taxonomy of educational objectives, the objectives adequately represent all six of the categories of the cognitive domain. This is especially noteworthy since, “Undergraduate instruction in engineering generally restricts itself to Levels 1-3…” [6] The appropriate distribution of the objectives across the taxonomy further validates the list of engineering laboratory learning objectives.

The limitations of this study centered on the subjective nature of the learning objectives and the instructors' perceptions. With only an objective title and a brief operational definition to go by, many instructors were confused as to the precise correlation between the objective and the course. Once an instructor decided on an interpretation of the definition, he/she had to decide the appropriate level of correlation and coverage. Even if the instructor properly interpreted the meaning of the objective and accurately rated the course accordingly, there is no guarantee that the students achieved that same level of completion of the objective. Instructor perceptions were the most readily available source of information, but actual student outcomes would provide an even more valid case for the learning objectives.

Conclusions and Recommendations

Comparing the 13 proposed engineering laboratory learning objectives to the instructors' perceptions of what is covered in class is a first step toward validating the set of objectives. Comparing the objectives with Bloom's taxonomy further validates the list by illustrating the wide range of skills and behaviors the objectives represent. Though a few changes may improve the list, the objectives accurately identify behaviors that are applied in the traditional engineering laboratory.

To expand upon these findings, researchers may perform the same study on additional engineering departments to confirm that the objectives apply to any engineering department. For a more precise mapping of the objectives, researchers may break down the objective definitions into components. Expanding the survey in this manner will provide information on each part of each objective and will eliminate the need to rate the coverage of the objective as a whole.

Although the objectives were positively confirmed through instructor interviews, it is important to note that, "Merely showing that concepts were covered in class is not sufficient. A pattern of evidence of students achieving outcomes is required." [5] To determine if the objectives are truly being achieved, accomplishments of the students in the program must be explored.[14] Student perceptions and actual student performance are more accurate sources of information than instructor perceptions when evaluating the achievement of learning objectives. It would be beneficial for researchers to request evidence of the completion of the learning objectives, in the form of student work or documented laboratory experiences, to provide more accurate data for evaluation. Interviewing students in each of the laboratory courses would also be a beneficial way to confirm the results found in this study and obtain more feedback on the set of proposed learning objectives. It may also be beneficial to seek the opinions of members of the engineering industry in the validation of the objectives. Industry has a concerted interest in the education of future engineers and may provide additional insight into the skills necessary to succeed in the professional world.

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Appendix A

Interview Form - Engineering Laboratory Learning Objectives

For each objective, please check one box for correlation and one for coverage as it applies to the lab you are responsible for. Please provide examples as applicable. Please keep in mind the following definitions:
Correlation – the depth in which one or more of the parts presented in the objective definition are addressed during the semester-long laboratory experience. If you fill in 'None' then no response for Coverage is needed.
Coverage – the breadth in which the objective is covered in the semester-long laboratory experience. Extensive - a majority of parts of the definition are covered; Narrow – few parts of the definition are covered.

		Correlation			Coverage	
Objective	Definition	Strong	Moderate	None	Extensive	Narrow
1 Instrumentation	Apply appropriate sensors, instrumentation, and/or software tools to make measurements of physical quantities.					
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.					
3 Experiment	Devise an experimental approach, specify appropriate equipment and procedures, implement these procedures, and interpret the resulting data to characterize engineering material, component, or system.					
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.					
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.					
6 Learn from Failure	Recognize unsuccessful outcomes due to faulty equipment, parts, code, construction, process, or design, and then re-engineer effective solutions.					
7 Creativity	Demonstrate appropriate levels of independent thought, creativity, and capability in real-world problem solving.					

		Correlation			Coverage	
Objective	Definition	Strong	Moderate	None	Extensive	Narrow
8 Psychomotor	Demonstrate competence in selection, modification, and operation of appropriate engineering tools and resources.					
9 Safety	Recognize health, safety, and environmental issues related to technological processes and activities, and deal with them responsibly.					
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.					
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.					
12 Ethics in the Lab	Behave with highest ethical standards, including reporting information objectively and interacting with integrity.					
13 Sensory Awareness	Use the human senses to gather information and to make sound engineering judgments in formulating conclusions about real-world problems.					

After reviewing the list of 13 proposed engineering laboratory learning objectives, please provide your opinion on the following questions:
Keep in mind that the list is for fundamental topics that the student should be exposed to in any engineering department.

Is the set of learning objectives comprehensive?

If not, what general topics are missing?

Are all of the learning objectives appropriate? (Keep in mind each objective as a whole, rather than the individual parts presented in the definition.)

Appendix B

The correlation and coverage of each objective and each course are grouped by department. The following legend applies to each of the tables:

● Strong Correlation
○ Moderate Correlation
▭ No Correlation

\+ Extensive Coverage
\- Narrow Coverage

Table B-1 Biological Systems Engineering, Bioprocess Engineering Option

Objective		Intro to BSE I	Intro to BSE II	Physical Properties of Biological Materials	Unit Operations in BSE	Instrumentation & Experimentation Mechanics	Design of Machinery Systems
1	Instrumentation	○+	○+	●+	○+	●+	○-
2	Models			○+			○-
3	Experiment			●+	○+	○+	○-
4	Data Analysis	●+	●+	○+	●+	●+	○-
5	Design	○+	○+	○-	○-	○-	●+
6	Learn from Failure	○-	○-	○-	○-	○+	○-
7	Creativity	●+	●+	○-	○-	○-	●+
8	Psychomotor	○-	○-	○-	○-	●+	○-
9	Safety	●-	●-		●+		●+
10	Communication	●+	●+	●+	●+	○-	●+
11	Teamwork	●+	●+	○-	●+	●+	●-
12	Ethics in the Lab	○-	○-	○+	●+		○-
13	Sensory Awareness			○-	○+	○-	○-

Table B-2 Biological Systems Engineering, Land & Water resources Option

Objective		Intro to BSE I	Intro to BSE II	Land & Water Resources Eng I	Land & Water Resources Eng II	Instrumentation & Experimentation Mechanics	Nonpoint Source Pollution Modeling & Management	Design of Machinery Systems
1	Instrumentation	○+	○+	●+	○+	●+	○-	○-
2	Models			○-	○-		●+	○-
3	Experiment				○-	○+		○-
4	Data Analysis	●+	●+	●+	●+	●+	●+	○-
5	Design	○+	○+		○-	○-	○-	●+
6	Learn from Failure	○-	○-	○-		○+	●+	○-
7	Creativity	●+	●+	○-	●+	○-		●+
8	Psychomotor	○-	○-	○-	○-	●+		○-
9	Safety	●-	●-	○-	●+		○-	●+
10	Communication	●+	●+	○-	●-	○-	●+	●+
11	Teamwork	●+	●+	○+	●+	●+	○-	●-
12	Ethics in the Lab	○-	○-	●+	●+		○+	○-
13	Sensory Awareness			○+	●+	○-		○-

Table B-3 Civil and Environmental Engineering

Objective		CEE Measurements	Fluid Mechanics for CEE	Water Resource Engineering	Soil Mechanics	CEE Materials
1	Instrumentation	●+	○+	●+	○-	●+
2	Models	○-	●+	●+	●+	○-
3	Experiment	○-	○-		○-	○-
4	Data Analysis	●+	●+	●+	●+	●+
5	Design	○-			○-	
6	Learn from Failure	○-	○-	○-		●-
7	Creativity	○+				○-
8	Psychomotor	○+		○-	○-	○-
9	Safety		○-	○-		●+
10	Communication	○+	●+	●+	●+	●+
11	Teamwork	●+	○+	●+	●+	●+
12	Ethics in the Lab	●+	○+	○+	●+	●+
13	Sensory Awareness	○+	○+	●+	○-	○-

Table B-4 Engineering Science and Mechanics

Objective		Fluid Mechanics	Mechanics of Materials	Instrumentation & Experimental Mechanics
1	Instrumentation	●+	●+	●+
2	Models	●+	○-	
3	Experiment		○-	○+
4	Data Analysis	●+	●+	●+
5	Design			○-
6	Learn from Failure	○+	○-	○+
7	Creativity	○+		○-
8	Psychomotor	○+	●+	●+
9	Safety	●+	○+	
10	Communication	●+	●+	○-
11	Teamwork	●+	●-	●+
12	Ethics in the Lab	●+	○-	
13	Sensory Awareness	●+		○-

Table B-5 Industrial and Systems Engineering

Objective		Manufacturing Processes	Work Measurement & Methods Eng	Discrete-Event Computer Simulation	Intro to Human Factors Eng
1	Instrumentation	○+	●+		○-
2	Models	○-	○-	●+	
3	Experiment		○-	●-	
4	Data Analysis	○-	●+	○-	●-
5	Design	●+	●-	○-	
6	Learn from Failure	○-	○-	○-	
7	Creativity		●+	●+	
8	Psychomotor	●-	○-		
9	Safety	●+	●-		
10	Communication	○-	●+	●+	○-
11	Teamwork	●+	●+	●+	●+
12	Ethics in the Lab	●+	●+	○-	○-
13	Sensory Awareness	●+	●+		○-

Appendix C Instructor Responses to Open-Ended Questions

"Number of Instructors" indicates the number of instructors who expressed the opinion of the associated general comment. Specific comments are documented where applicable.

Number of Instructors	General Comments	Specific Comments
15	The set of learning objectives is comprehensive	* Set seems exhaustive
4	A main concept is missing	* Following documented procedures (highly important in manufacturing) should be covered - either add into objective 8 or create new * Objective 5 should be titled "Design/Synthesis" * Objective 4 should be titled "Data Analysis/ Evaluation" * Objective 10 should include 'write a proposal' in the definition - important part of engineering * Awareness of life-long learning may need to be added to the list * Construction is important in the lab - should separate from objective 5 and make its own objective
18	All of the learning objectives are appropriate	
1	An objective should be eliminated	* Objective 13 should be eliminated
5	There is some overlap between objectives	* Objective 13 overlaps with objective 4 * Objective 7 is covered in objective 5 * Objective 13 is just a combination of several others, including 4, 6, 12 * Creativity is implicitly covered in objectives 3 and 5 * Objective 4 leads to the achievement of objective 2 * Objectives 3 and 5 are highly related
2	Issues with the sequencing of the objectives	* Objectives 7 and 12 should come at the end of the list
1	Issues with measuring the objectives	* Qualitative nature of some objectives will make them difficult to measure
1	Issues with the aim of the objectives	* The objectives may apply more to the "straight sciences" and research than to undergraduate engineering * Objective 3 is geared toward research, whereas most of undergrad study is not
1	Issues with designers of the list of objectives	* It's important to ask the students what is worth teaching (i.e. what the objectives should be)
2	Issues with objective 1	* 'Sensors' and 'instrumentation' are vague * The word 'appropriate' should read 'current' or 'state-of-the-art' to keep programs up-to-date
1	Issues with objective 3	* Objective is very difficult to carry out with equipment and time available

3	Issues with objective 5	* 'Assemble' and 'build' should not be in the same category as 'design' * One designs, and then builds or assembles, they are not on the same level * Design is important but not necessary in the lab
2	Issues with objective 6	* Add 'measurements' to the list of faulty items - inability to measure accurately leads to error propagation * Appropriate, but does not appear to be on the same level as the other 12 objectives
1	Issues with objective 7	* Creativity is necessary in the lecture course but not in lab * Not enough time during labs for creativity
6	Issues with objective 8	* What kind of tools and resources, hardware, software, equations…? * Term 'psychomotor' is unclear to professors and certainly to students
2	Issues with objective 9	* Include safety related to construction and technological processes and activities (environmental awareness) * Does the word 'deal' in the definition mean to apply the issues or form solutions to the issues?
1	Issues with objective 10	* Oral communication is not appropriate for labs
2	Issues with objective 11	* Does achievement of this objective require the instructor explicitly assigning roles, monitoring progress, etc…or rather letting students accomplish these tasks on their own?
9	Issues with objective 13	* Do not understand the meaning of the objective * Most engineering concepts are not meant to be perceived, but measured with instrumentation * Do common sense and understanding count as 'human senses'? * Are sight, smell, sound, taste, and touch the only 'human senses' under consideration? * Making engineering judgments may be inappropriate for students - more appropriate outside the academic setting * The need to tune your senses to your given field is a characteristic that is embodied in objectives 1-5 * Objective should get away from subjective assessment and lean toward quantitative assessment * How does one interpret 'human senses'? *Seems too 'touchy-feely' or soft