

# Assessment Based Instruction Applied to a Course and Lab in Digital Signal Processing

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**Abstract** – This paper describes three instructional practices in the context of lecture and laboratory courses in Digital Signal Processing. The three concepts are: (1) In the course development process, articulate *learning outcomes* associated with each section meeting, then develop *assessments* for each learning outcome prior to developing instructional material for the course, and then, and only then, prepare instructional materials related to the learning outcomes. (First sense of “Assessment First”); (2) Start each section meeting with students completing assessments of the learning outcomes covered in the previous section meeting. (Second sense of “Assessment First”); and (3) Use the large number of assessments to evaluate student performance; i.e., when there are lots of assessments, relative frequency of assessment achievement is an adequate basis for assigning grades.

*Keywords:* Assessment first, learning outcome, digital signal processing, DSP, evaluation

## INTRODUCTION

This paper describes three instructional practices in the context of lecture and laboratory courses in Digital Signal Processing. The three concepts are:

- In the course development process, articulate *learning outcomes* associated with each section meeting, then develop *assessments* for each learning outcome prior to developing instructional material for the course, and then, and only then, prepare instructional materials related to the learning outcomes. (First sense of “Assessment First”);
- Start each section meeting with students completing assessments of the learning outcomes covered in the previous section meeting. (Second sense of “Assessment First”); and
- Use the large number of assessments to evaluate student performance; i.e., when there are lots of assessments, relative frequency of assessment achievement is an adequate basis for assigning grades.

The paper is structured as follows: What follows immediately is a section covering the background for how the courses were delivered, assessed, and evaluated. The following section presents the implementation of the courses during the fall 2008 semester at the Daytona Beach campus of Embry-Riddle Aeronautical University (ERAU–DB). The next section is a discussion of many of the issues raised by the approach. The final section is a summary of the paper.

## BACKGROUND

Digital Signal Processing (CEC 410, 3 semester hours, 3 contact hours/week) and Digital Signal Processing Laboratory (CEC 411, 1 semester hour, 3 contact hours/week) are required for the ERAU–DB Bachelor of Science

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in Electrical Engineering (BSEE) degree; together, they can be used to fulfill the Bachelor of Science in Computer Engineering (BSCE) “3+1” elective requirement (lecture course with accompanying laboratory). Since the inception of the BSCE in 1998 (the BSEE came online in fall 2005), the course had been offered only once, in spring 2004 in its old instantiation as EE 406, a three-hour lecture course that formally had no accompanying lab, although there were several informal lab sections conducted in lieu of lecture meetings. The author was the instructor in that offering, as well as in the more recent fall 2008 offering of CEC 410 and 411.

In preparation for that more recent offering, the author participated in a “Course Makeover” course offered over the summer of 2008 by the campus Center for Teaching and Learning Excellence. The five-week course, incorporating elements of Instructional Design from [Fink, 2] and others, presented a systematic process for preparing a course for instructional delivery. The process consisted of five steps:

- Dream: Prepare the course description;
- Define: Prepare learner and setting profiles, a course outline, a list of learning outcomes, and an assessment plan;
- Design: Prepare an architecture for instructional materials and instructional plans;
- Develop: Prepare the course and have it ready to teach; and
- Deliver: Deliver the course, then assess and evaluate the effectiveness of instruction.

Processes to review and revise materials accompany each of those stages.

It is beyond the scope of this paper to describe each stage of the process in greater detail; instead, in what follows, the author will describe the matters of learning outcomes, assessments, development of instructional materials, content delivery (including timing of assessments), and use of assessments in evaluating both instructional effectiveness and student performance.

## DESCRIPTION OF THE METHOD

For each course, *learning outcomes* were articulated with the content material to be presented in each section meeting. Table I, below, shows an excerpt from the Course Schedule for CEC 410 for the week of 08 September 2008. The excerpt shows the topic covered in the meeting, the reading from the textbook [Oppenheim, 5] covering the same topics, the specific learning outcomes associated with the section, and practice problems or other material that can be used to develop mastery of the given learning outcome. The most current versions of the schedule and other instructional materials are available on the instructor’s web site at <http://faculty.erau.edu/wilson/CEC410/> and <http://faculty.erau.edu/wilson/CEC411>.

**Table I. Excerpt from Course Schedule.**

Date	Topic	Reading	Learning Outcomes	Practice Problems
08 Sep	DTFT (II)	2.9 (58-65)	(13) List and use DTFT pairs (14) List and use DTFT theorems (15) Use the DTFT to find impulse response of systems described by LCCDEs	Table 2.3 Table 2.2 Ex. 2.29
10 Sep	<i>z</i> -Transform	3.0-3.2 (94-110)	(16) List <i>z</i> -transform pairs (17) List region of convergence properties	Pr. 3.1 Pr. 3.4
12 Sep	Inverse <i>z</i> -Transform	3.3 (111-118)	(18) Find sequence from <i>z</i> -transform	Pr. 3.6, 3.14

### Learning Outcomes

“Learning outcomes” are a set of distinct, fairly fine grained (but not necessarily the finest grained), skills, knowledge, or attitudes that result from an educational experience. They are a collection of behaviors students

should be able to engage in after the instruction process, stated in a form beginning with an action verb such as “list,” “find,” “go back and forth,” “use,” etc. They are *not* listing of the instructional activities or what the instructor does; they are listings of what students are expected to be able to demonstrate mastery of at the completion of a section, unit, or the entire course.

### “Assessment First”

“Assessment first” in the first sense refers to development of assessment materials for each learning outcome before other course content. Prior to development of instructional materials—e.g., lecture notes, handouts—an assessment was developed for each outcome. The assessments were similar to the assigned practice problems, and in some cases differed only by changing parameters within the problem; in other cases, the assessment was based on a combination of material from the assigned problems associated with a particular learning outcome. Each assessment included a grading rubric by which a score of Excellent (‘E,’ complete mastery of the material), Satisfactory (‘S,’ adequate mastery on the material), or Unsatisfactory (‘U,’ inadequate mastery of the material) was assigned to the student’s level of achievement of the learning outcome. Figure 1, below, shows the assessment associated with Learning Outcome 18, “Find sequence from z-transform.”

**Outcome 18 Assessment:**  
 For each z-transform below, determine the corresponding sequence.

(a)  $X(z) = \frac{1}{1 - \frac{1}{2}z^{-1}}, \quad |z| > \frac{1}{2}$

(b)  $X(z) = \frac{1}{1 - \frac{1}{2}z^{-1}}, \quad |z| < \frac{1}{2}$

(c)  $X(z) = \frac{1 + \frac{1}{2}z^{-1}}{1 + \frac{1}{2}z^{-1} - \frac{1}{8}z^{-2}}, \quad |z| > \frac{1}{2}$

**Grading Rubric:**  
 Excellent: All three sequences found or stated correctly.  
 Satisfactory: Two of the three sequences found or stated correctly.  
 Unsatisfactory: Fewer than two of the sequences found or stated correctly.

Figure 1. Example assessment.

After the complete set of assessment questions were prepared, then the author prepared lecture notes for each section meeting. Notes were prepared to exploit active-learning opportunities to as great a degree as possible. For example, derivations were included in the notes, but with particularly important lines left blank, allowing students to fill those in during the section meeting. Example problems similar to the practice problems were included, with room for the students to write down the problem solution. Those problems were worked in class with the author serving as scribe and guide, but with students contributing sequentially in a structured manner (i.e., going around the room).

“Assessment first” in the second sense refers to starting each section meeting with students completing the assessments associated with the material of the previous section. Referring to the Course Schedule excerpt in Table I again, the meeting after 12 September began with students performing the assessment for Learning Outcome 18 of Figure 1. The assessment questions are made available to students by the web using the Blackboard system. If the entire assessment fits on one screen, the instructor uses the classroom projector to display it. Assessments are available fifteen minutes prior to the start of class, and students have until fifteen minutes after the start of class to complete them. Students perform the assessments on paper supplied by the instructor. Figure 2 shows students working on one of the assessments.

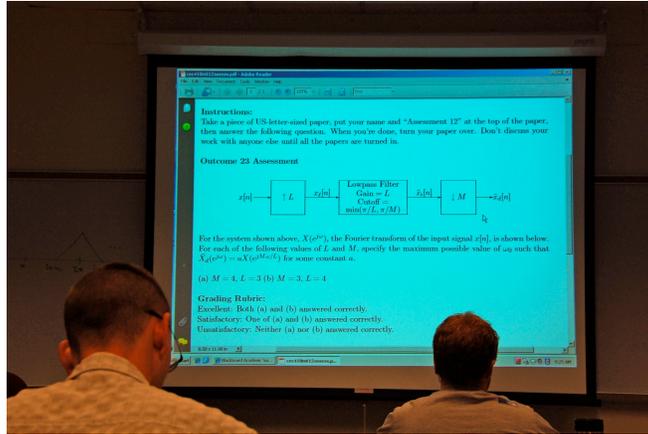


Figure 2. Students performing assessment at the start of class.

The remaining time, 45 minutes, of each class was devoted to presentation of the instructional materials described previously.

### Using Assessment Results in Evaluating Instructional Effectiveness

Results for each assessment were recorded on a worksheet in an Excel spreadsheet, an excerpt of which is shown in Table II, below. The top two sections of Table II show performance on assessments as delivered at the start of each section meeting. The top section of Table II shows the performance of each student on each assessment during the first unit of the class. The next section is a numerical tabulation of the relative achievement of each performance level ('E,' 'S,' or 'U,' with 'X' for excused absence and 'N' for unexcused absence).

Table II. Excerpt of assessment-performance worksheet.

Unit Meeting	01	02	03	04	05	06	07	08	09	10	11	12	13	14	15	16	17	18	19	20	21	22	23	
Outcome	01	02	03	04	05	06	07	08	09	10	11	12	13	14	15	16	17	18	19	20	21	22	23	
1	E	S	E	S	S	S	S	E	E	E	E	E	U	S	U	N	N	E	E	S	E	U	E	
2	S	E	E	E	U	S	U	S	S	U	U	S	E	S	U	E	S	E	E	E	E	S	X	
3	E	S	S	U	U	S	S	S	E	S	E	U	E	U	S	S	S	E	U	U	U	S	X	
4	S	E	S	U	U	S	U	U	U	U	U	U	U	E	U	U	U	U	U	U	X	U	X	
5	E	S	S	U	U	S	U	E	E	U	U	U	S	U	E	S	S	U	S	U	U	S	U	
Outcome	01	02	03	04	05	06	07	08	09	10	11	12	13	14	15	16	17	18	19	20	21	22	23	
E	3	2	2	1	0	0	0	2	2	2	1	2	1	1	2	1	0	2	3	1	2	0		
S	2	3	3	1	1	5	2	2	2	0	1	1	1	2	0	2	3	1	1	1	0	2		
U	0	0	0	3	4	0	3	1	1	3	3	2	3	2	3	1	1	2	1	3	2	3		
X	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0	1	0		
A	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0		
Exam 01	01	02	03	04	05	06	07	08	09	10	11	12	13	14	15	16	17	18	19	20	21	22	23	
1				E	E		U			E		E		E		E		E		E	E	E		
2				E	S		S			U		E		S		E		U		E	U	U		
3				U	U		U			S		S		U		E		E		S	E	U		
4				E	U		S			U		S		U		E		U		E	U	U		
5				S	S		U			U		S		U		E		U		U	S	U		
Exam 01	01	02	03	04	05	06	07	08	09	10	11	12	13	14	15	16	17	18	19	20	21	22	23	
E				3	1		0			1		2		1		5		2		3	2	1		
S				1	2		2			1		3		2		0		0		1	1	0		
U				1	2		3			3		0		2		0		3		1	2	4		
X				0	0		0			0		0		0		0		0		0	0	0		
A				0	0		0			0		0		0		0		0		0	0	0		
Combined Outcome	01	02	03	04	05	06	07	08	09	10	11	12	13	14	15	16	17	18	19	20	21	22	23	
1	E	S	E	E	S	S	S	E	E	E	E	E	U	E	U	E	U	E	E	E	E	E	E	
2	S	E	E	E	S	S	S	S	S	S	U	U	E	E	S	U	E	S	E	E	E	E	S	X
3	E	S	S	U	U	S	S	S	S	E	S	E	U	E	U	E	S	E	E	E	S	E	U	S
4	S	E	S	E	U	S	S	U	U	U	U	S	U	U	E	U	U	U	U	E	X	U	X	
5	E	S	S	S	S	S	U	E	E	U	U	S	S	S	E	E	S	U	S	U	S	U	U	
Combined	1	2	3	4	5	6	7	8	9	10	11	12	13	14	15	16	17	18	19	20	21	22	23	
E	3	2	2	3	1	0	0	2	2	2	1	3	1	2	2	5	0	3	3	3	3	1	1	
S	2	3	3	1	2	5	4	2	2	0	1	2	1	2	0	3	0	1	1	1	1	2	1	
U	0	0	0	1	2	0	1	1	1	3	3	0	3	1	3	0	2	2	1	1	0	2	1	
X	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0	1	0	2	
A	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0	

Assessment results for each learning outcome provide immediate feedback as to whether or not students are achieving desired results. The relative number of scores for each category of achievement can be taken as an indicator for instructional effectiveness. For example, the top 2 sections in Table II show that learning outcome 4 (“Determine linearity, time-invariance, causality, stability of discrete-time systems”) was achieved satisfactorily by only one student with the remaining four receiving an unsatisfactory result on that assessment. Whether that is due to poor presentation of the material or inadequate effort on the part of the students becomes irrelevant: Clearly the students are not able to perform to the degree they ought to be able to regarding that learning outcome.

Each instructional unit culminated in a review session and then an examination. The examination consisted of a collection of assessments covering learning outcomes for which performance had previously been less than desirable. The next two sections of Table II show performance on the assessments that made up Exam 01. The third (from top) section of Table II shows the performance of each student on the first exam; the fourth section, the relative performance on the assessment.

### **Using Assessment Results in Evaluating Student Performance**

A student’s performance on the assessment during the unit exams was allowed to replace the section-meeting assessment. The lower two sections of Table II show the combined (in-class and exam) achievement of the learning outcomes associated with Unit 01 of the course. Improved aggregate performance of the class after the exam is evident by the increase in “the number of ‘E’ and ‘S’ assessment results, with corresponding decrease in number of ‘U’ results. In the aggregate, an unexcused absence (‘N’) turns into an unacceptable performance (‘U’) on the assessment.

Each student’s performance on all assessments was used to determine her or his grade according to an algorithm published in the course syllabus at the start of the semester. This being a senior-level course covering some graduate-level material, the course was graded on a ‘B’-centered scale, with grades being determined according to the following scheme.

Grades were based on the fraction of assessments scored Satisfactory or Excellent. A putative letter grade was assigned as follows:

- In order to pass, a student needs for 50% or better of all assessments, less excused absences, to be Satisfactory or Excellent;
- If a student passes, and if the fraction of Excellent assessments out of Satisfactory and Excellent assessments is less than 10%, then the putative grade will be a C;
- If a student passes, and if the fraction of Excellent assessments out of Satisfactory and Excellent assessments is 10% or better but less than 50%, then the putative grade will be a B;
- If a student passes, and if the fraction of Excellent assessments out of Satisfactory and Excellent assessments is 50% or better, then the putative grade will be an A.

Each student was allowed one unexcused absence. The actual letter grade assigned was the putative letter grade decreased by one for each unexcused absences in excess of the one allowed.

### **Differences for the Lab Course**

The CEC 411 lab course focused as much on utilizing on-chip features of the Texas Instrument TMS 320 C6416 fixed-point DSP microprocessor as it did algorithms for implementing particular DSP computational structures. Most, but not all, lab meetings began with an assessment of the learning outcomes for the previous lab session. While some outcomes were assessed using the quiz format from the lecture course, others involved a checklist that the student had demonstrated—to an Excellent, Satisfactory, or Unsatisfactory degree—mastery of the learning outcome. Figure 3 shows the assessment for learning outcome 14, “Configure EDMA [Extended Direct Memory Access] to perform channel sorting” of the lab course. In the figure, “McBSP” refers to the chip’s Multichannel Buffered Serial Port. The complete set of learning outcomes is available in the Course Schedule document at <http://faculty.erau.edu/wilson/CEC411>.

The lab course involved no examinations beyond the learning-outcomes assessments; instead, students completed a term project of their own choosing. One of the requirements for the project was that it demonstrates mastery of the lab course outcomes, with achievement of those outcomes on the project replacing the in-lab assessment for

purposes of determining the letter grade. The letter grade was determined according to the same schedule as the lecture class.

**Learning Outcome 14: Configure EDMA to perform channel sorting**  
For a certain avionics system, four channels of analog data are digitized by an analog-to-digital converter. The ADC output is interfaced to one of the McBSPs on a C6416 DSP. The 16-bit samples from the channels are presented by the McBSP source in the interleaved order Channel 1, Channel 2, Channel 3, Channel 4, (i.e., 1-2-3-4-1-2-3-4-1···) and are to be sorted into individual buffers for each channel. The buffers were declared as follows:

```
short gBufIn1[50];
short gBufIn2[50];
short gBufIn3[50];
short gBufIn4[50];
```

Once again, software gnomes have struck, erasing certain parts of the code for the configuration structure for the EDMA receive channel, erasing the comments, but leaving behind ??? in place of the erased code. Repair the code in edma.c for the configuration structure of the EDMA receive channel to sort the interleaved 4-channel data into the four separate buffers.

**Grading Rubric:**  
Excellent: All or all less one missing parts of configuration structure restored.  
Satisfactory: Most missing parts of configuration structure restored.  
Unsatisfactory: Half or fewer of missing parts of configuration structure restored.

**Figure 3. Example assessment for the lab course.**

## DISCUSSION

The described method has several advantages over traditional instructional practices, but also has additional costs and potential downsides.

The upsides include:

- Clear articulation of what is to be learned in each and every section meeting;
- Very short turnaround between content presentation and when students are expected to display mastery of the associated learning outcomes;
- Rapid feedback, both for instructor and for students, as to the degree of mastery of each learning outcome;
- Elimination of issues associated with degree of collaboration, copying, and cheating on homework assignments;
- Elimination of grading of homework assignments; and
- Elimination of arbitrary point assignment in grading of student work.

Downsides include:

- Reduction in the time for presentation of course material;
- Requirement to grade and return assessment quickly;
- Upfront effort in articulation of learning outcomes and development of associated assessments; and
- Novelty of the method.

An issue less clearly labeled as upsides or downsides but also deserving of further discussion is the choice of grading rubrics. Finally, the process of putting assessments first has parallels within software engineering practice and the “test first” approach to software development. These issues are discussed in the subsections that follow.

## **Learning Outcome Articulation and Assessment Development Issues**

While the overhead of stating the learning outcomes and writing assessments for each one is non-trivial, the benefits from doing so are wide-ranging. First, there is advantage to the student that course expectations are clearly laid out. Second, there is advantage to the instructor that unessential material is allowed to fall by the way. Third, there is advantage to the instructor in that desired learning outcomes don't manifest themselves after topics have been covered (such as when one is preparing a mid-term exam). Fourth, since learning outcomes are stated in terms of actions students are expected to exhibit, development of associated assessments is not as difficult as might be imagined.

Having clearly articulated learning outcomes is of benefit to both students and instructor, and its value cannot be emphasized to an adequate degree. The reader has likely heard students, either informally or in end-of-term course evaluations, state that the instructor failed to state what was expected of them; has likely experienced understanding what she or he expected of students in the process of making an exam, possibly the final exam. The up front effort in understanding and stating what is to be learned not only alleviates those problems, it also focuses the instruction

## **Assessment of Instructional Effectiveness and of Student Learning**

As noted previously, it is not immediately obvious how to distribute the cause for performance on a learning outcome between instructional and learning effectiveness. While in-class instructional effectiveness is highly desirable, students are resourceful and should be able to use course notes, the textbook, other students, and the web as resources when their understanding is unclear. Failure of students to achieve a high-level of performance on an assessment, while it may clearly indicate that students did not demonstrate mastery of the desired learning outcome, is not necessarily an indication that the instruction related to that topic was deficient. The primary goal, however, is that students master the learning outcomes: If the ensemble performance on a learning outcomes assessment was Unsatisfactory, then that topic needs additional attention at the level of the class, whether the fault lies with the instruction, with student effort or lack thereof, with the degree of difficulty of the material, with student background learning, etc.; however, individual Unsatisfactory performance when the ensemble performance tended towards Satisfactory or Excellent suggests that the instruction and supplemental resources were adequate, and that those individuals performing poorly need to spend additional time and effort to master the material.

## **Regular Assessments and No Homework Issues**

The rapid turnaround between student completion of each assessment and having it graded and ready to return by the next section meeting was not always achieved; however, by and large, since the grading rubric laid out clear guidelines for what constituted Excellent, Satisfactory, or Unsatisfactory performance, grading required substantially less effort as is the case with grading using a points-based system, either positive or negative.

The short turnaround between when material is presented and when it is assessed avoids the issue of learning being put off until the night before the assignment is due or the exam is to occur. Instead, students are put into a situation where the expectation that they are learning is brought to the forefront and into the immediate term. It is fair to note that this does require students to organize their academic week on a different basis than the weekly homework or weekly quiz model. While some students might express concern over that—and those concerns must be listened to and understood—it is entirely within instructional prerogative to expect one-class-to-the-next learning that is demonstrable through the generation of examinable artifacts, be those class-to-class homework or next-class assessment. As with any regularly scheduled course deliverable, students may have conflicts from other obligations such as team projects or job interviews that result in one or more missed assessments. Those have to be dealt with on a case-by-case basis.

The fact that there are assigned “Practice Problems” related to each learning outcome, but no homework assignments to be turned in and graded is beneficial for several reasons. It frees students to collaborate at their discretion, with the knowledge that each and every one of them must demonstrate mastery of the material independently of their collaborators. This liberates those who understand to help those who don't without feeling like they're doing the other student's work for them. From the author's selfish perspective, since this is a senior-level course, there are rarely students available to serve as graders, and the effort of grading assessments on a meeting-by-meeting basis was substantially less than that of grading weekly homework assignments.

## **Rubric Issues**

Having clearly stated learning outcomes not only facilitates the development of the associated assessments, it also facilitates development of each assessment's grading rubric: With mastery of the learning outcome as the goal, that mastery then corresponds to Excellent performance on the outcome and becomes a clearly articulated goal for student achievement. With a choice of three tiers of performance—Excellent, Satisfactory, and Unsatisfactory—Satisfactory is clearly not Excellent, so small deviations from mastery of the learning outcome clearly fall in the Satisfactory regime. With the 50% Satisfactory or better performance as the threshold for passing, it was surprisingly easy to demarcate the division between Satisfactory and Unsatisfactory performance largely as 50% satisfactory on any particular learning outcome.

For an assessment of a learning outcome such as being able to list Fourier Transform pairs, this made correct listing of all of them as Excellent performance, failure to list at least half of them as Unsatisfactory performance; Satisfactory performance then became listing at least half, but not all, of them. As few learning outcomes had a single way of demonstrating competence, this scheme or something very similar was frequently used.

Of course, the course, a three-level division for a grading rubric is one of only many possible choices. For other instructors in other situations, a coarser or finer granularity may be more appropriate. While it is not difficult to see how a two-level assessment (achieved, not achieved) could map into letter grades using relative frequencies, additional levels complicate the determination of letter grades based on relative frequencies.

## **Lack of 0-100% Scoring, Grading Based on Assessment Results, and Novelty of the Process**

Like all of us, students are creatures of habit. They have long been part of a system that amounts to, for many cases at least, an arbitrary mapping of performance to a score between 0 and 100 points. Sometimes that mapping is based on positive achievement (“Correct answer: 10 points”); sometimes, on failure to achieve (“Sign error: -1 point”). By and large, students are used to that system.

This approach offers students little in the way of familiarity with that more comfortable system. While students may rapidly grasp and appreciate the rapid feedback on their performance into simple categories like Excellent, Satisfactory, and Unsatisfactory, the use of relative number of each of those to assign a grade is novel. The author acknowledges that the two-step process of assigning grades is somewhat arbitrary, although it arguably is closer to determining relative fraction of achievement than is a system whereby accumulating 70-79 points results in the grade of ‘C.’ Since the subjects in question were senior level courses with what could be seen as some graduate-level material, placing the pass threshold at 50% achievement of Satisfactory or better seemed reasonable; one could argue for moving it up or down some small amount. Were the subject of interest a lower division course or arguably more introductory in nature, a higher threshold for passing would seem more reasonable.

As with the pass-fail threshold, the method allows a great deal of flexibility in setting grade thresholds. Determination of letter grade ‘A,’ ‘B,’ or ‘C’ is similarly acknowledged as arbitrary, but based on the idea of a ‘B’-centered course. Alternatives considered were setting the threshold for an ‘A’ at twice as many ‘E’s as ‘S’s and for a ‘C’ as twice as many ‘S’s as ‘E’s. That one can do so derives from there being so many learning outcomes to be assessed (61 for the lecture course, 19 for the lab course). In that sense, when there are many assessments, relative frequency of assessment performance is an adequate basis by which to evaluate student performance and assign a letter grade.

The author is exploring use of a four-anchor scale—‘E,’ ‘S,’ ‘N,’ and ‘U,’ with ‘N’ for “needs improvement”—for assessment scoring, where each letter maps to a numeric value (100, 84, 67, 50) that is used with traditional letter grade thresholds (90, 80, etc.) to determine the course letter grade.

## **Relationship to Software Engineering Practices, Program Outcomes Assessment, Other Educational Practices, and Suggestions for Further Research**

The assessment-first approach has similar elements to Meyer's Testable, Reusable, Units of Cognition (TRUC) approach, in particular the importance of developing a means to measure learning performance prior to the development of instructional material [Meyer, 4]. It also has parallels in software development practices. In Test-Driven Development [Janzen, 3], unit tests for software under development are written prior to the software to be tested. Not only can the software developer immediately test the code after it is written, the clear articulation of what the code is to do leads the programmer down a different decision tree than if the code were developed prior to

writing the test software. Also known as Test First, the approach has been shown to have positive benefits: “We believe that advancing development one test at a time...encourages better decomposition, improves understanding of the underlying requirements, and reduces the scope of tasks to be performed” [Erdogmus, 1].

At the time of this writing, the author’s department is considering incorporation of performance on selected learning outcomes as indication of achievement of Program Outcomes for the purposes of demonstrating that the program satisfies Criterion 3 of ABET Criteria for Program Accreditation. In that approach, achievement of some subset of learning outcomes from each of several courses is taken as achievement of one Program Outcome. For example, learning outcomes from the CEC 410 would be evidence of achievement of Program Outcome (a), “...math, science, and engineering.”

The author regrets that a more formal consideration of the efficacy of the approach was not incorporated into this initial trial. The online end-of-term course evaluation was completed by three of the five students, but the structure of that evaluation did not allow for additional questions. Student comments on that evaluation and hallway conversations suggest students appreciate the articulation of learning outcomes and like the daily assessment approach (but find the transition to it and away from a weekly-homework approach difficult).

As of this writing, the approach is being used in a junior-level signal-processing course with enrollment of 25 from computer engineering, electrical engineering, and aerospace engineering students. The Signals and Systems Concept Inventory [Wage, 6] is being administered at the start and end of the term to measure learning gain and compare the results with previous delivery in the same course using a more traditional homework-based approach. A formal comparison between the assessment-first approach and more traditional instructional methodologies is suggested for further study. Whether engineering students, compared to students in other disciplines, benefit from such an approach is another avenue to be considered.

## SUMMARY

An instructional approach involving (1) determination of learning outcomes and assessments for each, (2) assessment of the most recently presented material at the start of each section meeting, and (3) use of assessments in evaluating student performance and determining the semester letter grade.

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