Standards-Based Grading for Signals and Systems

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Abstract

Standards-based grading (SBG) is gaining popularity in K-12 education as it measures students' proficiency on a number of course objectives rather than to give a single grade that does not by itself convey how well the student understands each of the core concepts from the course. Whereas a single grade may be assigned based on the extent to which the student demonstrates proficiency on a number of course objectives, the focus is to give the student, as well as other educators, a more detailed breakdown of the assessment of individual course objectives.

This paper describes the implementation of SBG in a junior-level signals and systems course. SBG has been implemented in various undergraduate engineering courses [1-5] in recent years but, to date, no one has documented its implementation in signals and systems. Because the concepts taught in a signals and systems course are fundamental to subsequent electrical and computer engineering courses, such as digital signal processing and communication systems, SBG is appealing as an assessment tool for this course.

In this course, a number of course objectives have been identified from among the following key concepts: signal visualization in the time and frequency domains, system analysis in the time (convolution) and frequency (Fourier) domains, signal analysis (Fourier series and Fourier transform), and sampling (Nyquist's theorem). Proficiency on each of these objectives is assessed using a five-point scale, and the final course grade is calculated from a weighted average of the objective assessment scores. The objectives are assessed using weekly quizzes, midterm examinations, and a final examination.

This paper analyzes the effectiveness of the introduction of SBG in the signals and systems course at the author's institution. The study consists of a comparison of course objective assessment between students who took the signals and systems course before and since the implementation of SBG.

Background

Standards-based grading (SBG) has gained popularity in K-12 education in recent years as it gives better granularity in determining how well students have achieved competency on a number of course objectives rather than just for the entire course. More recently, SBG has been implemented in undergraduate engineering courses, such as a fluid mechanics course [2], a first-year introductory engineering course [3], a hybrid thermodynamics course [4], and project-based design courses [5]. Best practices [1] have been established by educators from several universities.

Continuous-time signals and systems (CTSS) is a fundamental electrical and computer engineering course in which students are introduced to mathematical models for common engineering signals and systems. The CTSS course is typically prerequisite to other ECE courses, such as digital signal processing, control systems, and communication systems. The concepts found in a CTSS course are among the most conceptually difficult [7-8] in a typical ECE curriculum. To that end, many attempts have been made to improve learning in signals and systems. A Signals and Systems Concept Inventory [6] has been developed to test students' knowledge of common CTSS concepts. Various approaches involving the use of in-class laboratory exercises [9-17] have been used to improve student learning of signals and systems. This paper marks the first known attempt to use standards-based grading to enhance learning in signals and systems.

Motivation for standards-based grading

Continuous-time signals and systems is a course that is fundamental to subsequent electrical and computer engineering courses such as digital signal processing, control systems, and communication systems. After attending a standards-based grading workshop [18] at a recent ASEE Annual Conference, the author was inspired to implement SBG in signals and systems because of its focus on assessing performance on individual course objectives rather than on an overall course grade.

For students, SBG offers several advantages over traditional grading on a 0-100 scale. Learning objectives are clearly presented at the beginning of the course, and each lecture topic is connected to one or more learning objectives. Each assessment is labeled with one or more objectives, which are assessed according to a Likert-scale rubric to be described in a later section. Throughout the course, students can access and track their assessment scores for each objective. Students are given multiple opportunities to show improvement on each objective through quizzes, midterm examinations, and the final examination. Final grades are then computed as a weighted average of the objective assessment scores.

Before the introduction of SBG, the course was taught using a traditional "chalk-and-talk" lecture style. Homework discussion sessions were offered on a weekly basis. Interactive modules for convolution and Fourier series signal and system analysis were developed [17] as additional homework assignments. The course was graded based on homework scores, midterm exam scores, and the final exam score. Students would have only been aware of their performance on a course concept by identifying the concept(s) involved with a homework or exam problem and comparing their score to the standard institutional grading scale.

After the introduction of SBG, the lecture style was intentionally not changed. Homework sessions continued as before, but quizzes were added on homework due dates to give a formative assessment of the most recently covered objective. Interactive modules were retained as additional homework assignments. However, the course grading was changed to a weighted combination of mainly objective assessment scores but also a small weighting of homework assignments. The current grading scheme is described in the subsequent section.

Implementation of SBG in signals and systems

This study was conducted by an electrical engineering faculty member at a medium-sized, teaching-focused university. This faculty member has taught the signals and systems course for more than ten years. The typical enrollment of a section of signals and systems at the Milwaukee School of Engineering (MSOE) ranges from the high teens to the high twenties. The signals and systems course is required for students in the biomedical engineering, computer engineering, and electrical engineering programs. The course has four hours of lecture per week over a ten-week term.

The following signals and systems concepts have been identified as course learning objectives:

- Compute the output of a continuous-time, LTI system (*system analysis*)
    - Using time-domain techniques (**convolution**)
    - Using frequency-domain techniques (**Fourier analysis**)
- Analyze a continuous-time signal (*signal analysis*)
    - Derive the **Fourier series** coefficients for a given periodic CT signal
    - Determine the **Fourier transform** of a signal by using the FT integral or a table of common pairs and properties
    - Compute the power or energy, as appropriate, of a CT signal using its time- or frequency-domain representation (**power/energy**)
- Plot a signal in the time or frequency domain (*signal visualization*)
    - Plot a signal as a function of time (**time plot**)
    - Determine and plot the magnitude and phase spectra of a CT signal using Fourier analysis (**Fourier spectrum**)
- Determine an appropriate *sampling* frequency and the subsequent frequency-domain representation of a sampled CT signal
    - Determine an appropriate sampling frequency in order to avoid aliasing of a CT signal (**Nyquist**)
    - Plot the magnitude and phase spectra of an impulse-train-sampled CT signal (**sampled spectrum**)

Grade determination using SBG in signals and systems

Each objective is graded using a Likert-scale rubric: 5 points for exceptional work, 4 for advanced, 3 for intermediate, 2 for novice, 1 for unacceptable, and 0 for incomplete. An example rubric and example quiz and exam questions are included in the Appendix. In the previous academic year, a scale of 0 to 4 was used: 4 – exceptional, 3 – advanced, 2 – intermediate, 1 – novice, 0 – unacceptable (including incomplete). An additional point was added to the bottom of the grading scale to motivate students to regularly submit homework assignments and to complete quizzes and examinations.

At the end of the course, each individual objective's overall score is computed using the following weightings: 20% from formative assessments (quizzes), 40% from intermediate assessments (midterm exams), and 40% from summative assessments (final exam). Quizzes are given weekly to provide initial feedback for each objective (one or two objectives per quiz). Midterm exams provide a second round of feedback after the completion of several objectives. Most objectives are assessed on only one quiz (or midterm exam), but for those that are assessed on multiple quizzes (or midterms), their scores may be computed as either the average or the maximum of the quiz (or midterm) scores. Institutional policy limits the score of the final exam to be worth no more than 40% of the overall course grade, hence the 40% weighting on the final exam.

It should be noted that homework assignments are given but are scored only for bona fide attempts. Homework questions are typically discussed in the class section on the day before the due date. Quizzes are given on homework due dates to assess one or two of the objectives introduced in each homework assignment.

Table 1 describes the weighting of each objective or assignment toward the overall course score.

Table 1: Weighting of objectives and assignments toward overall course score

Objective or assignments	**Percentage**
Completion of homework assignments	10%
Time plot*	5%
Power/energy	10%
Convolution	15%
Fourier series	15%
Fourier spectrum	10%
Fourier transform	10%
Fourier analysis	10%
Nyquist	10%
Sampled spectrum	5%
*New objective in AY 2019	

Finally, the course grade is assigned based on the overall course score as described in Table 2.

Table 2: Grade assignment based on overall course score

Range	**Grade**
4.50-5.00	A
4.00-4.49	AB
3.50-3.99	B
3.00-3.49	BC
2.50-2.99	C
2.00-2.49	D
< 2.00	F

Comparison of student objective assessment pre- and post-SBG

The hypothesis of this paper is that the introduction of standards-based grading will have had a positive impact on students' performance on course objectives. Because this change was first implemented in the Fall 2017 term, student final exam scores and overall course scores were collected for all students in the author's sections of signals and systems for two years prior and two years after the change. Course objectives on final exams prior to the change were regraded according to current rubrics to facilitate a closer comparison.

Sections included in the study are Spring 2015 (n = 26), Spring 2017 (n = 21), Fall 2017 (n = 52), Winter 2018 (n = 26), Fall 2018 (n = 23). The Spring 2015, Spring 2017, and Winter 2018 sections consisted of primarily electrical engineering students, whereas the Fall 2017 and Fall 2018 sections had a mixture of biomedical engineering, computer engineering, and electrical engineering students.

The chart in Figure 1 shows the average assessment score for each of the course objectives commonly assessed on final exams in the 2015 – 2019 academic years. The data show a general improvement in objective assessment scores since the introduction of SBG. Certainly, students after the change would have been better prepared for the final exam due to having clearer expectations and more formative feedback on graded quizzes, rather than sparser feedback on graded homework assignments.

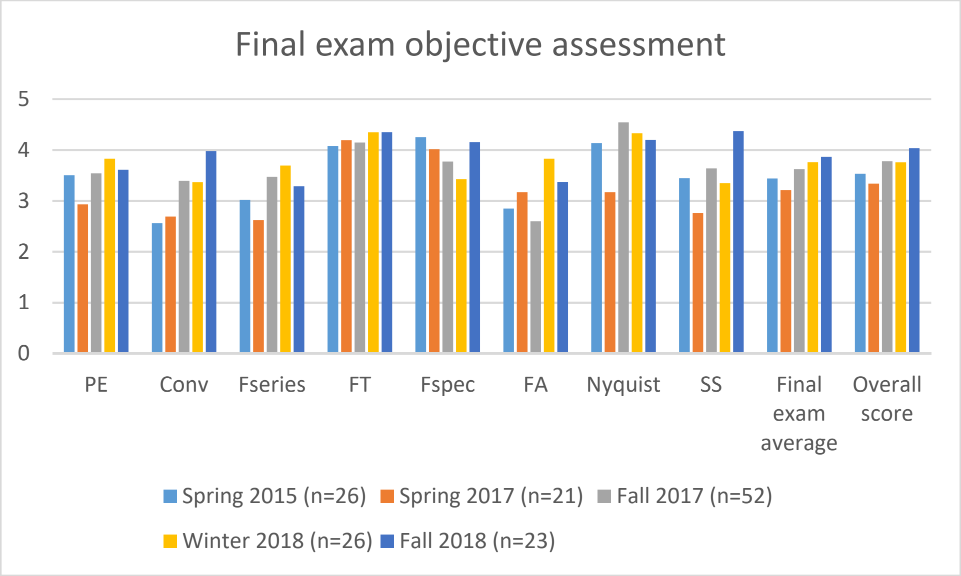

Figure 1: Final exam objective assessment for all common objectives pre- and post-SBG.

Table 3 is a breakdown of individual course objectives as assessed on the final exam for all sections in the study. Final exams for sections taught before the introduction of SBG were retained by the instructor and regraded using current rubrics. Questions pertaining to each of the common objectives were identified. Objective assessment scores were compared for students in sections pre-SBG (Spring 2015 and Spring 2017) and post-SBG (Fall 2017, Winter 2018, and Fall 2018) using a one-sided unpaired t-test, assuming unequal variance.

Table 3: Individual final exam objective assessment comparison pre- and post-SBG.

Objective	**Mean assessment score pre-SBG (n = 47)**	**Pre-SBG mean plus 5% confidence interval**	**Mean assessment score post-SBG (n = 101)**	**Post-SBG mean minus 5% confidence interval**	**Unpaired t-test probability, 1-sided, unequal variance**
Convolution	2.62	2.95	3.52	3.25	4.86E-05**
Fourier system analysis	2.99	3.33	3.09	2.84	0.318
Power/energy	3.24	3.58	3.63	3.40	0.0323*
Fourier series	2.84	3.09	3.49	3.26	1.29E-04**
Fourier transform	4.13	4.45	4.24	4.04	0.274
Fourier spectrum	4.14	4.37	3.77	3.51	0.0158*
Nyquist	3.70	4.09	4.41	4.22	9.2E-04**
Sampled spectrum	3.14	3.51	3.73	3.50	4.18E-03**

The data in Table 3 show highly statistically significant ($P < 0.001$) improvements in the convolution, Fourier series, Nyquist, and sampled spectrum objectives. Statistically significant ($P < 0.05$) improvements are seen in the power/energy and Fourier transform objectives. Slight but not statistically significant improvements are seen in the Fourier system analysis and Fourier transform objectives. Interestingly, there is a significant decrease in the Fourier spectrum assessment score; however, this may be because the final exam question testing this concept pre-SBG had not been written specifically targeting this objective and would have been a less rigorous question than currently used.

Conclusions

This paper was written to show that using standards-based grading is a viable method for improving learning in signals and systems. Final exam assessment data for sections two years prior and two years after implementing standards-based grading show significant improvements in almost all course objectives. Although it cannot be concluded from a small study from one instructor's sections at a single institution that this approach would work universally, the data support the hypothesis that standards-based grading has had a positive impact on students' performance on course objectives.

A longer, multi-institutional study is needed to prove that using standards-based grading can truly improve learning in signals and systems. Adding other signals and systems instructors from a variety of institutions to the study would add credibility to the results presented in this paper. Administering the SSCI [6] to each student in the study at the beginning and end of the signals and systems course would normalize results for students with different instructors at different institutions.

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Appendix

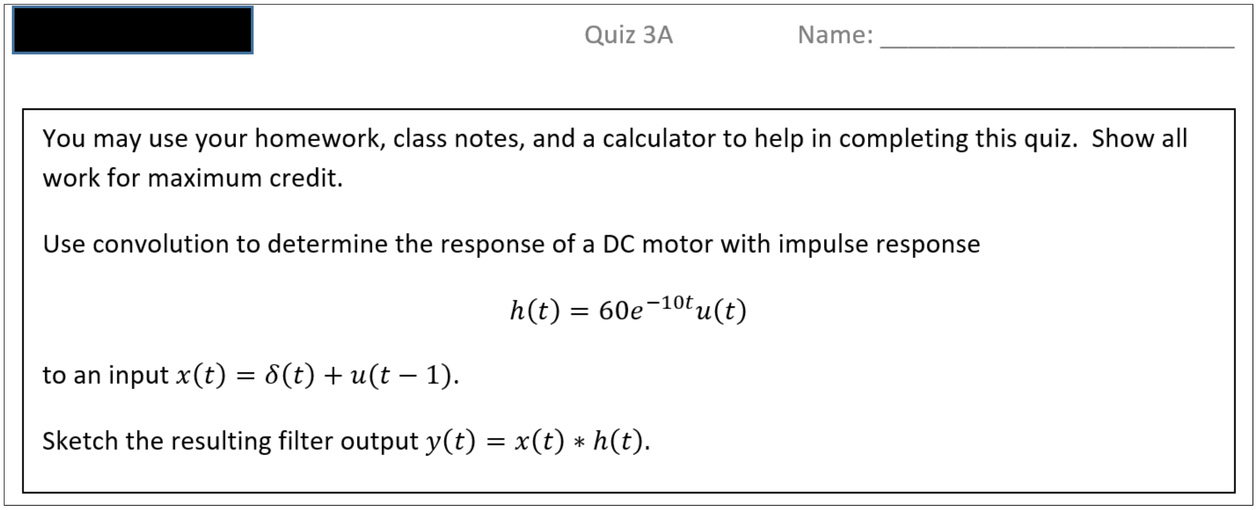
Table 4: Example rubric for convolution objective

Exemplary (5)	**Advanced (4)**	**Intermediate (3)**	**Novice (2)**	**Unacceptable (1)**
Correct input and impulse response signals	One minor error:	Two minor errors or one major error:	Three or more minor errors	Not blank, but no significant progress
Convolution integral set up correctly	Solution has a math error	Incorrect or missing cases	Two major errors	More than two major errors
Correct cases and integration limits	Incorrect integral limits	Integrand has incorrect variable substitutions	One major error and one or two minor errors	
Correct sketch (if applicable)	Incorrect input or IR	Sketch is missing or mostly incorrect (if applicable)	Convolution misinterpreted as multiplication	
Correctly applied shortcuts (if allowed)	Sketch is partly incorrect (if applicable)	Misapplied a shortcut		

Comments:

Score:	

Examples of quiz and exam questions



[redacted] Quiz 3A Name: ____________________________

You may use your homework, class notes, and a calculator to help in completing this quiz. Show all work for maximum credit.

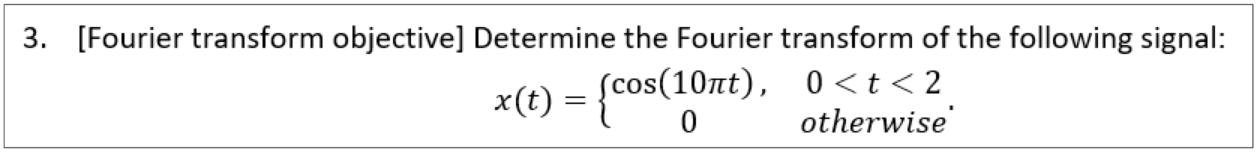
Use convolution to determine the response of a DC motor with impulse response

$$h(t) = 60e^{-10t}u(t)$$

to an input $x(t) = \delta(t) + u(t-1)$.

Sketch the resulting filter output $y(t) = x(t) * h(t)$.

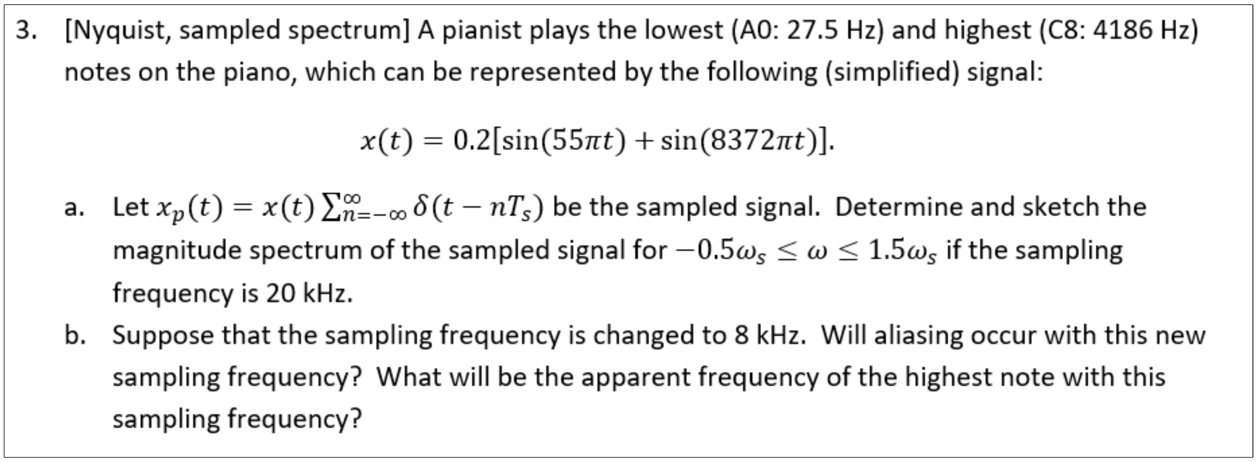
Figure 2: Example quiz question for assessing the convolution objective



3. [Fourier transform objective] Determine the Fourier transform of the following signal:

$$x(t) = \begin{cases} \cos(10\pi t), & 0 < t < 2 \\ 0 & otherwise \end{cases}.$$

Figure 3: Example midterm exam question for assessing the Fourier transform objective



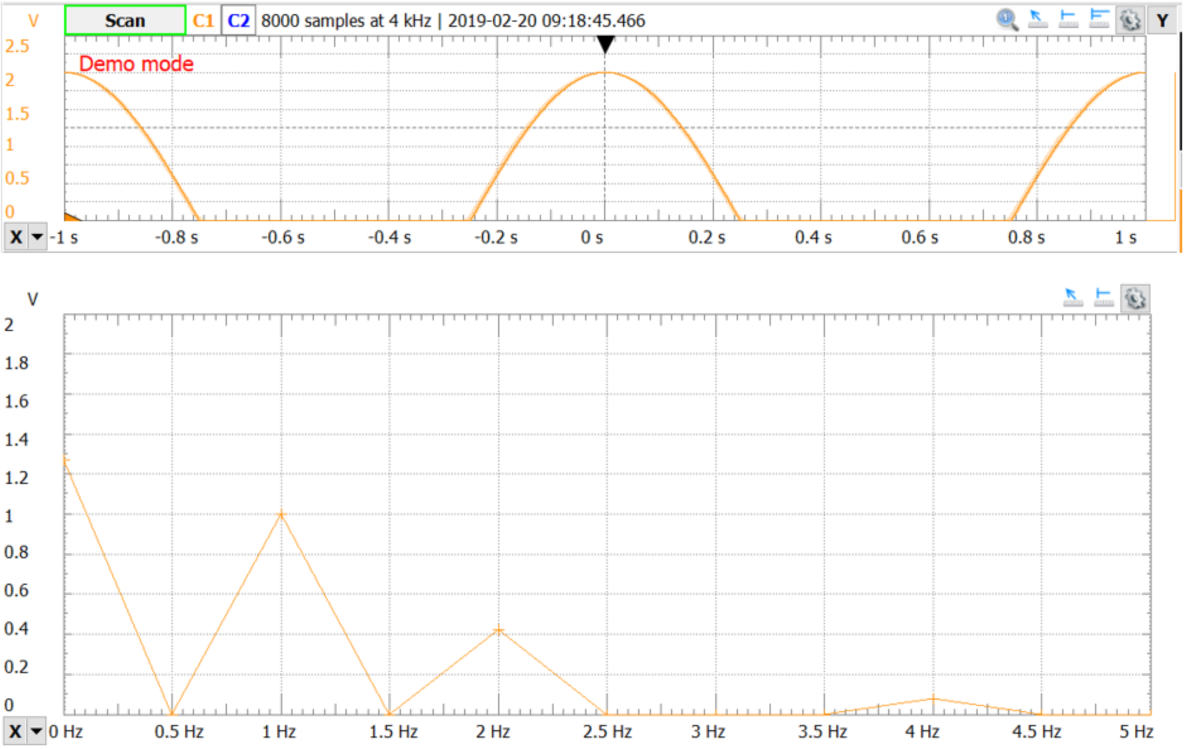
3. [Nyquist, sampled spectrum] A pianist plays the lowest (A0: 27.5 Hz) and highest (C8: 4186 Hz) notes on the piano, which can be represented by the following (simplified) signal:

$$x(t) = 0.2[\sin(55\pi t) + \sin(8372\pi t)].$$

   a. Let $x_p(t) = x(t)\sum_{n=-\infty}^{\infty}\delta(t - nT_s)$ be the sampled signal. Determine and sketch the magnitude spectrum of the sampled signal for $-0.5\omega_s \leq \omega \leq 1.5\omega_s$ if the sampling frequency is 20 kHz.
   b. Suppose that the sampling frequency is changed to 8 kHz. Will aliasing occur with this new sampling frequency? What will be the apparent frequency of the highest note with this sampling frequency?

Figure 4: Example final exam question for assessing the Nyquist and sampled spectrum objectives

1. [Fourier series] The following signal is a 2-V, 1-Hz cosine wave that has been clipped on the oscilloscope screen. The resulting magnitude spectrum is shown in terms of peak voltage versus frequency on the subsequent plot.



Verify the measured peak voltage spectrum values at DC (0 Hz), 1 Hz and 2 Hz. Are all values correctly reported by the spectrum analyzer?

Figure 5: Example final exam question for assessing the Fourier series objective