# AC 2007-546: ANALYSIS OF ASSESSMENT RESULTS IN A LINEAR SYSTEMS COURSE

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## Analysis of Assessment Results in a Linear Systems Course


### Abstract

Linear (signals and) systems course is a core component of undergraduate curricula in electrical engineering programs worldwide.

The Signals and Systems Concept Inventory (SSCI) is a set of multiple-choice questions that measures students' understanding of fundamental concepts such as signal transformations, linearity, time-invariance, transforms, convolution, etc. There are two versions of the SSCI for Linear Systems. One deals with Continuous-Time (CT) systems and the other deals with Discrete-Time (DT) systems.

Beginning Fall 2005, the CT SSCI Tests (developed externally) have been administered in almost every offering of our Linear systems course. These tests fulfill the ABET requirement for assessment. They also help track the effectiveness of teaching styles by testing whether the students are learning the basic concepts in the course.

In this paper, we present the results of the tests for both Fall 2005 and Fall 2006 and analyze the results to assess the students' performance and determine evidence of learning outcomes. Some suggestions for future offerings of the course are also presented.

These results are also compared with other assessment tools (developed internally) prior to the use of the SSCI Tests. Some conclusions are made on the efficacy of the prior tests and the SSCI tests.

The SSCI Discrete-Time (DT) Tests has also been administered in the subsequent course. Results of that study will be disseminated elsewhere.

## Introduction

A course in linear (signals and) systems is a core component of undergraduate curricula in electrical engineering programs worldwide. Typically the course is offered at the junior level. At the Santa Clara University, the course is titled "Linear Systems" (ELEN 110) and taken by all juniors in the Fall term/semester.

Over the last two years when the author has taught the course, an assessment of the student learning outcomes have been done using both a test prepared by the school and a standard test known as the SSCI.

The Signals and Systems Concept Inventory (SSCI) [2-3] is a set of multiple-choice questions that measures students' understanding of fundamental concepts such as signal transformations, linearity, time-invariance, transforms, convolution, etc. There are two versions of the SSCI for Linear Systems. One deals with Continuous-Time (CT) systems and the other deals with Discrete-Time (DT) systems.

The paper is divided into six sections. In Section 2, we describe our Electrical Engineering undergraduate curriculum. In Section 3, we describe the Linear Systems course contents. In Section 4, we discuss an assessment test used previously to test some pre-requisite skills (like Electric Circuits I and II) which are both pre-requisites to the Linear Systems course. These are part of the assessment tools we developed and used prior to the use of the SSCI Test.
Later, in Section 5, we briefly describe the SSCI CT Test which was administered in our Linear systems class at the Santa Clara University in both Fall 2005 and Fall 2006. The SSCI CT Test is given to assess the students' performance and determine evidence of learning outcomes.

The goals of our study are :
(1) To determine how much conceptual understanding the students have developed by the end of the class (compared to the beginning of the class).
(2) To correlate the performance on the end-of-term exam with the performance on the SSCI Post-Test which is designed to test the conceptual understanding, but not necessarily the steps of problem solving and system design.
(3) To determine the concepts which the students have had difficulty understanding so that there may be more emphasis on those concepts the next time the course is offered.
(4) To relate the performance of students on their ability to relate pre-requisite course material (in Electric Circuits) with the new material in the Linear Systems course.
(5) To recommend alternate pedagogical methods for presenting the material in the Linear Systems course based on the results of our study.

In Section 6, the results from the two offerings of the tests are presented and analyzed. Some suggestions for future offerings of the course are also presented. The efficacy of the tests to help us achieve our stated goals are determined.

**Undergraduate Curriculum at the Santa Clara University**

At the Santa Clara University, as in most universities, we offer a four-year BS program in Electrical Engineering. In this program, we require that students take basic sciences and mathematics in the first year. In the second year, they take a few engineering courses but still continue to get a strong science and mathematics foundation. In the third year, they complete the set of core electrical engineering courses. In the final year, they take mostly elective courses. During the four year program, the students also have to complete university-required core curriculum courses in areas like English, ethics, political science, religious studies, etc. Table 1 shows the outline of our program. Also see Figure 1. We also offer flexible Junior Spring term for students to work (as co-op or intern), or study abroad or take more technical electives or graduate classes.

The core of the Electrical Engineering program (which every undergraduate student has to take) are the following 9 courses:

1. ELEN 21 (Logic Design)
2. ELEN 33 (Introduction to Digital Signal Processing Systems)
3. ELEN 50 (Electric Circuits I)
4. ELEN 100 (Electric Circuits II)
5. ELEN 104 (Electromagnetics I)
6. ELEN 105 (Electromagnetics II)
7. ***ELEN 110 (Linear Systems)***
8. ELEN 115 (Electronic Circuits I)
9. ELEN 151 (Semi-conductor Devices)

There are technical elective courses in the areas Wireless Communications, Analog Electronic Circuits, Digital Signal Processing, Integrated Circuits (IC) Design, Semiconductor Devices and Materials, Control Systems, Robotics, Storage Devices, etc.

Table 1 : The 4-year BS in Electrical Engineering program at the Santa Clara University

| Class | Fall | Winter | Spring |
|---|---|---|---|
| Freshman | Math 11<br>Chemistry 11<br>ENGR 1<br>English 1 | Math 12<br>Physics 31<br>MECH 10<br>English 12 | Math 13<br>Physics 32<br>University Core<br>Religious Studies |
| Sophomore | Math 21<br>Physics 33<br>CIVIL 41<br>ELEN 21 | AMTH 106<br>Physics 34<br>ELEN 50<br>University Core | COEN 9<br>ELEN 33<br>ELEN 100<br>University Core |
| Junior | ***ELEN 110***<br>ELEN 104<br>ELEN 151<br>University Core | AMTH 108<br>ELEN 115<br>ELEN 105<br>University Core | Co-op or<br>Study-Abroad or<br>Additional Technical Elective |

| | | | |
|---|---|---|---|
| Senior | ELEN 194<br>ENGL 182<br>Technical Elective<br>University Core | ELEN 195<br>MECH 10<br>Technical Elective<br>Technical Elective | ELEN 196<br>Technical Elective<br>Free Elective<br>Free Elective |

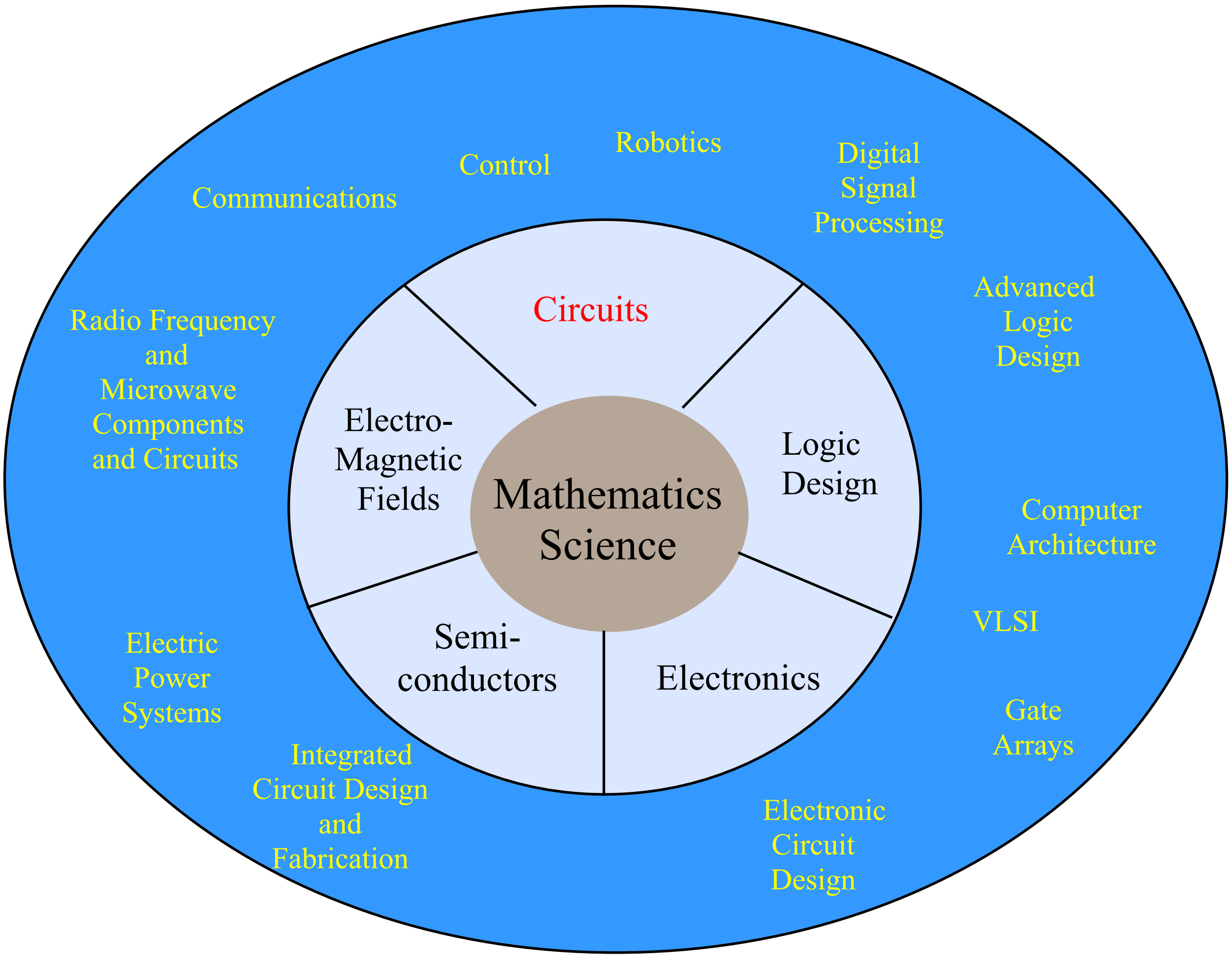



Figure 1 : A concentric circle view of BS EE program at the Santa Clara University

ELEN 110 (Linear Systems) is a junior-level course and is a pre-requisite to most control, communications, signal processing and other "system"-type technical elective courses that are taken at the senior level. We have modified this course since its inception. We have moved some material from ELEN 133 (Digital Signal Processing), a senior technical elective into ELEN 110 so that ELEN 133 can focus more on Z-transforms, digital filter design, Fast Fourier Transform (FFT), and other topics. We also emphasize use of MATLAB in ELEN 110 as well as in most of our ELEN courses.

**The Linear Systems Course at Santa Clara University**

Course Contents

The Linear Systems course at Santa Clara University requires the completion of the Electric Circuits I and II sequence.
It follows the 2-part series of courses on Electric Circuits: ELEN 50, ELEN 100, Electric Circuits I and II. This course deals with the fundamentals of Linear Systems.
We cover topics such as description and analysis of continuous-time and discrete-time signals and systems, differential equations and difference equations, convolution, Z-transforms, transfer function. The Fourier Series, Fourier Transforms, Fourier Integral, etc. (see course outline for more details).

In short, there are five main parts to this course:
1. Continuous-Time (CT) Signals,
2. Continuous-Time (CT) Systems
3. Transforms (Laplace, Fourier, Z)
4. Discrete-Time (DT) Signals
5. Discrete-Time (DT) Systems

The textbook for the course is [1] Philips, Parr and Riskin, Signals, Systems and Transforms, Prentice-Hall publishers, Third edition, 2003. The book has an associated website with java program applets for demonstrating the various concepts such as convolution, etc. The specific topics covered are

- Course overview (Signals, Systems and Transforms, Continuous-Time/Discrete-Time)
- Transformations of Continuous-Time Signals (Time Reversal, Time Scale, and Time Shift)
- Signal Characteristics (Even, Odd, and Periodic) and Common Signals in Engineering (Exponentials)
- Singularity Functions (Unit Step Function, Unit Impulse Function and its Properties)
- Continuous-Time Systems, Properties of Continuous-Time Systems (Memory, Invertibility, Causality, Stability, Time-Invariance, and Linearity)
- Impulse Representation of Continuous-Time Signals
- Continuous Time Convolution (Graphical Convolution Examples)
- Properties of Convolution (Cascade and Parallel interconnections)
- Properties of Continuous-Time LTI systems (Memory, Invertibility, Causality, Stability, and Unit Step Response)
- Differential-Equation Models (Solution of Differential Equations - Natural and Forced response)
- Terms in the Natural Response (Stability), System Response for Complex-Exponential Inputs
- Approximating Periodic Functions, Fourier Series
- Fourier Coefficients, Frequency Spectra, and Properties of Fourier Series

- LTI System Analysis
- Definition of the Fourier Transform, Finding the Fourier Transform
- Properties of the Fourier Transform (Linearity, Time Scaling, Time Shifting, and Duality, Convolution, Multiplication of Signals, and Frequency Shifting/Modulation)
- Fourier Transform of Time Functions (DC Signal, Periodic Signals, and Pulsed Cosine)
- Fourier Transforms of Sampled Signals
- Applications of the Fourier Transform of Ideal Filters (Sinusoidal Amplitude Modulation)
- Discrete-Time Signals and Systems
- Discrete-Time Linear, Time-Invariant (LTI) Systems, Direct-Forms I and II for LTI Systems
- Z- Transforms, Properties, Applications for LTI System Analysis

Lab Contents

The laboratory part of the course consists of five laboratory assignments. Some of the labs require the use of MATLAB. The titles of the labs are :
Lab 1: Review of Laplace Transforms
Lab 2: Convolution and Impulse Response
Lab 3: Fourier Series
Lab 4: Testing Fourier Transforms
Lab 5: Digital Simulator.

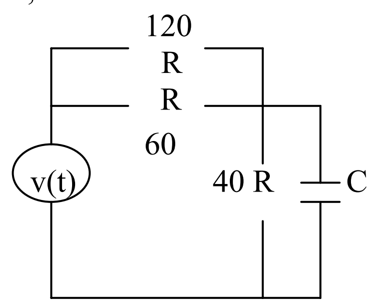
Many universities, including ours, continually strive to improve their programs by assessing its impact and learning outcomes and modifying, changing or deleting, adding courses based on academic and industrial technology trends [3-12]. This is actually required by the Accreditation Board for Engineering Technology (ABET) [13] as part of accreditation requirements. In the area of Digital Signal Processing (DSP), many universities have recently shared their experiences and curriculum changes [3-12] in the Linear Systems and Digital Signal Processing education areas.

**The Linear Systems Course Pre-Test Assessment Tool**

During the first week of class, an assessment tool (developed at the Santa Clara University) was used to determine the students retention of the topics covered in the pre-requisite classes. The pre-test (based on contents of Electric Circuits II) is as follows:

Assessment Pop Quiz (Closed-Book, 20 mins.)
Problem 1 *General Multiple-Choice Questions* (5 pts. each => 50pts. total)

Circle your answer. **If you do not know the answer, circle e. Please do not guess. Wrong answers will be penalized extra 2pts. which means Circle e. or No answer = - 5 pts. Correct answer = + 5 pts. Incorrect answer = - 7 pts.**
**Correct Answers are Underlined. Number of responses are indicated.**
Consider the circuit on the right where v(t) = 4cos(wt), w=2pi f, C = 30 uF.




1. When f = 0 the voltage across the capacitor is:

   4 0 5 0 1

   a. 0 b. $\sqrt{2}$ c. 2 d. $2\sqrt{2}$ e.

   ===

2. When f = $\infty$ the voltage across the capacitor is:

   7 0 1 0 2

   a. 0 b. $\sqrt{2}$ c. 2 d. $2\sqrt{2}$ e.

   ===

3. When the voltage across the capacitor is 200 v, the energy stored in the capacitor is:

   0 6 0 1 3

   a. 0 b. 0.6 j. c. 3.2 j d. 32 j. e.

   ======

4. With the output taken across the capacitor this circuit acts as a:

   7 0 0 0 3

   a. Lowpass Filter b. Bandpass Filter c. Highpass Filter d. Bandstop Filter e.

   ==============

5. If an inductor L of value (1/30) uH were placed in parallel across the capacitor the resonant frequency would be:

   0 2 4 0 4

   a. 0 b. 159 KHz c. 1 MHz d. 1 GHz e.

   ========

6. With the inductor of Problem 5 in place, the Bandwidth is:

   1 0 8 0 1

   a. 1.5 KHz b. 8.33 KHz c. 0.833 KHz d. 1.2 GHz e.

   =======

7. With the inductor of Problem 5 in place, the peak current at resonance in the 40 ohm resistor is:

| 0 | 0 | 0 | 3 | 7 |
|---|---|---|---|---|
| a. 0 | b. 0.01 | c. 0.0354 | d. 0.05 | e. |
| | | | ===== | |

8. At "high frequencies" the Bode Plot of a single-pole lowpass filter rolls off at:

| 1 | 1 | 2 | 0 | 6 |
|---|---|---|---|---|
| a. 6 dB per decade | b. 6 dB per octave | c. 20 dB per octave | d. as 1/f | e. |
| | ============= | | | |

9. A linear differential equation is given by: $\dfrac{df(t)}{dt} = 6f(t)$. Its solution is:

| 3 | 0 | 3 | 1 | 3 |
|---|---|---|---|---|
| a. $f(t) = e^{6t}$ | b. $f(t) = e^{-6t}$ | c. $f(t) = f(0)e^{6t}$ | d. $f(t) = f(0)e^{-6t}$ | e. |
| | | ========== | | |

10. The time constant of an RL circuit is given by:

| 3 | 4 | 0 | 2 | 1 |
|---|---|---|---|---|
| a. L/R | b R/L | c. 1/RL | d. RL | e. |
| ==== | | | | |

**Correct answer key is**

| Question | 1 | 2 | 3 | 4 | 5 | 6 | 7 | 8 | 9 | 10 |
|---|---|---|---|---|---|---|---|---|---|---|
| Answer | c | a | B | a | c | c | d | b | c | a |

Even though many questions had 4 multiple choice answers some students chose the 5th answer to indicate the did not know the answer. They were asked to chose (e.) if they did not understand to discourage guessing.

**Problem 2 *Laplace Transform* (50 pts.)**

Find the Laplace Transform, G(s) of the following signal, g(t).
$g(t) = e^{-2t} \sin(3wt)$
3 out of 10 gave correct responses, 3 gave incorrect responses, 5 had no clue.

**SOLUTION**
Let $f(t) = \sin(wt)$, then $F(s) = w/(s^2 + w^2)$
Apply scaling property
If $f(t) \Leftrightarrow F(s)$, then $f(at) \Leftrightarrow 1/a\, F(s/a)$
Therefore,
Let $p(t) = \sin(3wt) = f(3t)$, then $P(s) = (1/3)\, w/( (s/3)^2 + w^2)$
Also, apply frequency shift property
If $f(t) \Leftrightarrow F(s)$, then $e^{-at} f(t) \Leftrightarrow F(s + a)$

Therefore,
Let $g(t) = e^{-2t} \sin(3wt) = e^{-2t} p(t)$, then $G(s) = P(s + 2) = (1/3)\, w/( ((s + 2)/3)^2 + w^2)$

$G(s) = (1/3)\, w/( ((s + 2)/3)^2 + w^2) = 3w / (s^2 + 4s + 4 + 9w^2)$

The Summary Report of the test is shown in Table 2 below.

**Table 2: Summary Report of the Santa Clara University Linear System Pre-Test Assessment Tool**

| Total # Multiple-Choice Questions = 10, Q2 is Paper and pencil question | | | | | | | | | | | |
|---|---|---|---|---|---|---|---|---|---|---|---|
| **Question #** | **1** | **2** | **3** | **4** | **5** | **6** | **7** | **8** | **9** | **10** | **Q2(Laplace)** |
| **#Right** | 5 | 7 | 6 | 7 | 4 | 8 | 3 | 1 | 3 | 3 | 3 |
| **#Wrong** | 5 | 3 | 4 | 3 | 6 | 2 | 7 | 9 | 7 | 7 | 7 |

The first part of the test is about a given RC circuit. The following describe the questions and the student responses in more detail.

Questions 1-4

The first two questions are about the voltage across a capacitor when the frequency of the applied voltage source is f=0 and when it is f=infinity. About half of the students got both questions right.
Question 3 was about the energy stored in the capacitor.
Question 4 was about the behavior of the overall circuit as a filter: lowpass, highpass, bandpass or band reject filter? A little more than half got Questions 3 and 4 right.

Questions 5-10

Question 5 extends the RC circuit to an RLC circuit and the following questions 6 and 7 are about RLC network issues like bandwidth and peak current at resonance, etc. Four, Eight and three students out of ten got Questions 5, 6 and 7 right respectively. Question 8 asks about the Bode plot of a low-pass filter. Only one out of ten students got this question right. Question 9 is about solving a simple first-order differential equation and the last Question 10 is about the time constant of an RL circuit. Only three out of ten students got both Questions 9 and 10 right.

The second part of the test is about finding Laplace Transform of a time-domain signal using the scaling and frequency-shift properties of Laplace Transforms.

In summary, the students did the worst on Question 8 about Bode plots. This is followed by Questions 7, 9 and 10 where only 3 out of 10 got it right.

There seems to be a need to reinforce the topics covered by these questions (especially question 8) the next time this class is offered.

**The Signals and Systems Concept Inventory (SSCI) Tests**

Here follows some description of the SSCI CT Test.

Questions 1-4, 14

These questions are about Math and most of the students answered them correctly as shown in Table 1. These are not difficult questions. The concepts tested are time/frequency signal plots, time reversal, time shifts and signal transformations. Question 14 tests the recognition of the form of the solution to a LCCDE with sinusoidal forcing functions in a differential equation.

Questions 5, 23, and 24

These questions are about Linear Time-invariant (LTI) systems. Recognizing linear and time-invariance properties are important. Also, the analytical tools required such as convolution, properties of convolution are tested. Determination of the property of a system given its input and output signals tests the students' ability to synthesize these properties by reverse thinking processes.

Questions 6, 7, 9-11, 13, 15-22, 25

These questions test the transform properties with applications to pole-zero plots, Fourier series, etc. As seen from the Table 3 above, many of the students had some difficulty with these questions.
Many of the questions involve relating two or more concepts such as time-domain signals, with filtering, with pole-zeros plots. Question 22 tests Bode Plots. This problem seemed very conceptually difficult for the students. Only 3 out of 19 students got this one correctly. Bode Plots were not taught in this class but is part of the pre-requisite class; Electric Circuits II. So, it is obvious that the students did not expect this problem and must have forgotten the topic of Bode plots.

Questions 8, 15, 23

These questions test the concept of convolution and its properties when applied to a Linear, time-invariant (LTI) system.

The two parts of the SSCI Test (CT and DT) are described more fully in [2].
This reference details the multiple-choice tests and the way the test are developed and how to apply them. Our focus here is on the Continuous-time (CT) test.

**Results of the Fall 2005 SSCI CT Post-Test as a Post-Assessment Tool**

On the last day of class, we tested all the 20 students in the class using the SSCI CT Test.
The results are discussed and analyzed as follows in Tables 3 and 4:

**Table 3: Details of the Results of the Fall 2005 SSCI CT Post-Test**

| Question Number => | 1 | 2 | 3 | 4 | 5 | 6 | 7 | 8 | 9 | 10 | 11 | 12 | 13 | 14 | 15 | 16 | 17 | 18 | 19 | 20 | 21 | 22 | 23 | 24 | 25 |
|---|---|---|---|---|---|---|---|---|---|---|---|---|---|---|---|---|---|---|---|---|---|---|---|---|---|
| Student Number | | | | | | | | | | | | | | | | | | | | | | | | | |
| 1 | 1 | 1 | 1 | 1 | 0 | 0 | 1 | 1 | 1 | 1 | 1 | 1 | 1 | 0 | 1 | 1 | 1 | 1 | 1 | 0 | 0 | 1 | 0 | 0 | 1 |
| 2 | 1 | 1 | 1 | 1 | 0 | 1 | 0 | 0 | 0 | 1 | 1 | 1 | 1 | 1 | 0 | 0 | 0 | 1 | 0 | 0 | 1 | 1 | 0 | 1 | 0 |
| 3 | 1 | 1 | 1 | 1 | 0 | 1 | 1 | 1 | 0 | 1 | 0 | 1 | 1 | 1 | 0 | 1 | 0 | 1 | 0 | 0 | 0 | 0 | 1 | 0 | 1 |
| 4 | 1 | 1 | 1 | 1 | 0 | 0 | 1 | 0 | 0 | 0 | 1 | 1 | 1 | 0 | 1 | 0 | 1 | 1 | 1 | 0 | 1 | 0 | 0 | 1 | 0 |
| 5 | 1 | 1 | 1 | 1 | 0 | 0 | 0 | 1 | 0 | 1 | 1 | 1 | 1 | 0 | 1 | 0 | 0 | 1 | 0 | 0 | 1 | 1 | 0 | 0 | 1 |
| 6 | 1 | 1 | 1 | 1 | 0 | 1 | 0 | 1 | 1 | 1 | 1 | 1 | 1 | 1 | 1 | 0 | 1 | 1 | 0 | 0 | 0 | 1 | 0 | 1 | 1 |
| 7 | 1 | 1 | 0 | 0 | 1 | 0 | 0 | 0 | 1 | 1 | 1 | 1 | 1 | 0 | 0 | 0 | 0 | 1 | 0 | 0 | 0 | 0 | 0 | 1 | 1 |
| 8 | 1 | 1 | 1 | 1 | 1 | 1 | 0 | 0 | 0 | 1 | 1 | 1 | 1 | 1 | 1 | 1 | 0 | 1 | 0 | 1 | 1 | 1 | 1 | 0 | 0 |
| 9 | 1 | 1 | 1 | 1 | 1 | 1 | 0 | 0 | 1 | 1 | 1 | 0 | 1 | 1 | 0 | 1 | 0 | 1 | 0 | 0 | 1 | 1 | 1 | 0 | 0 |
| 10 | 1 | 1 | 1 | 1 | 1 | 1 | 0 | 0 | 0 | 1 | 0 | 1 | 1 | 1 | 0 | 1 | 0 | 1 | 1 | 0 | 0 | 1 | 1 | 0 | 0 |
| 11 | 1 | 1 | 1 | 1 | 0 | 1 | 1 | 1 | 0 | 1 | 1 | 1 | 0 | 1 | 1 | 1 | 0 | 1 | 1 | 0 | 0 | 1 | 0 | 0 | 1 |
| 12 | 1 | 1 | 1 | 1 | 0 | 1 | 0 | 1 | 0 | 1 | 0 | 1 | 1 | 1 | 0 | 1 | 1 | 1 | 0 | 0 | 1 | 0 | 1 | 0 | 1 |
| 13 | 1 | 1 | 1 | 1 | 0 | 1 | 0 | 1 | 0 | 1 | 0 | 1 | 1 | 1 | 0 | 1 | 1 | 1 | 0 | 0 | 1 | 0 | 1 | 0 | 0 |
| 14 | 1 | 1 | 1 | 0 | 1 | 0 | 0 | 0 | 0 | 1 | 1 | 1 | 1 | 0 | 0 | 0 | 0 | 1 | 0 | 0 | 1 | 0 | 0 | 0 | 1 |
| 15 | 1 | 1 | 1 | 1 | 1 | 1 | 0 | 0 | 1 | 0 | 1 | 1 | 1 | 1 | 1 | 1 | 0 | 1 | 0 | 1 | 1 | 0 | 0 | 0 | 0 |
| 16 | 1 | 1 | 1 | 1 | 1 | 1 | 1 | 1 | 1 | 1 | 1 | 1 | 1 | 1 | 1 | 1 | 0 | 1 | 0 | 0 | 0 | 1 | 0 | 0 | 1 |
| 17 | | | | | | | | | | | | | | | | | | | | | | | | | |
| 18 | 1 | 1 | 1 | 1 | 1 | 1 | 0 | 1 | 1 | 1 | 1 | 1 | 1 | 0 | 1 | 1 | 1 | 0 | 1 | 0 | 1 | 0 | 1 | 1 | 1 |
| 19 | 1 | 1 | 1 | 1 | 1 | 1 | 0 | 0 | 1 | 1 | 1 | 1 | 1 | 1 | 0 | 1 | 0 | 0 | 0 | 0 | 0 | 0 | 1 | 1 | 1 |
| 20 | 1 | 1 | 1 | 1 | 1 | 1 | 0 | 0 | 0 | 1 | 1 | 1 | 0 | 1 | 0 | 0 | 1 | 0 | 1 | 1 | 0 | 0 | 1 | 0 | 0 |

| | | | | | | | | | | | | | | | | | | | | | | | | | |
|---|---|---|---|---|---|---|---|---|---|---|---|---|---|---|---|---|---|---|---|---|---|---|---|---|---|
| #Right | 19 | 19 | 18 | 17 | 10 | 14 | 5 | 9 | 8 | 17 | 15 | 18 | 17 | 13 | 9 | 12 | 7 | 16 | 6 | 3 | 10 | 9 | 9 | 6 | 11 |
| #Wrong | 0 | 0 | 1 | 2 | 9 | 5 | 14 | 10 | 11 | 2 | 4 | 1 | 2 | 6 | 10 | 7 | 12 | 3 | 13 | 16 | 9 | 10 | 10 | 13 | 8 |
| Mean | 1 | 1 | 0.95 | 0.9 | 0.5 | 0.7 | 0.3 | 0.5 | 0.4 | 0.9 | 0.8 | 0.9 | 0.9 | 0.7 | 0.5 | 0.6 | 0.4 | 0.8 | 0.3 | 0.16 | 0.53 | 0.47 | 0.47 | 0.32 | 0.58 |
| **Question** | **1** | **2** | **3** | **4** | **5** | **6** | **7** | **8** | **9** | **10** | **11** | **12** | **13** | **14** | **15** | **16** | **17** | **18** | **19** | **20** | **21** | **22** | **23** | **24** | **25** |

Student number 17 dropped the class in the first or second week so he did not take the test. The overall mean score for all the 19 students is Sum / 19 = 14.85/25. The maximum score is 20/25. The minimum score is 11/25 for the 19 students taking the exam.

Comparing the class rankings in the standard exams and in the SSCI CT Test (see Table 4), it is easy to see that there's a correlation between students who do well in the standard exams and those who do well in the conceptual tests. The students whose score are not correlated suggest that they may be good at solving design and mechanistic problems, requiring step-by-step procedure but not good at conceptual understanding. The reverse is also true. This suggests that the instructor should be able to present the material to suit the varying learning styles of the students [14].

**Table 4: Comparing Fall 2005 Class Exam and SSCI CT Test Rankings**

| Student Number | Rank in Class Exams | Rank in SSCI CT Test |
|---|---|---|
| 1 | 1 | 3 |
| 2 | 7 | 14 |
| 3 | 12 | 11 |
| 4 | 15 | 14 |
| 5 | 16 | 14 |
| 6 | 2 | 3 |
| 7 | 19 | 18 |
| 8 | 14 | 3 |
| 9 | 18 | 7 |
| 10 | 9 | 11 |
| 11 | 3 | 6 |
| 12 | 5 | 7 |
| 13 | 13 | 11 |
| 14 | 6 | 19 |
| 15 | 11 | 7 |
| 16 | 4 | 2 |
| 17 | 20 | 20 |
| 18 | 10 | 1 |
| 19 | 17 | 7 |
| 20 | 8 | 14 |

Also, from our results, we are able to determine the concepts which the students have had difficulty understanding so that there may be more emphasis on those concepts the next time the course is offered. For example, the concept of graphical convolution and Bode plots. Also, student had difficulty with  SSCI CT Test problems that synthesize more than one topic (so-called synthesis problems). This shows a lack of student ability to relate two or more aspects of the course together.

Next we address the performance of students on their ability to relate pre-requisite course material (in Electric Circuits) with the new material in the Linear Systems course. The data here is not enough to make any specific judgments.

We also recommend alternate pedagogical methods for presenting the material in the Linear Systems course based on the results of our study. Such alternatives include using an index of learning style approach [14], active and cooperative learning styles, [15], etc.

**Results of the Fall 2006 SSCI CT Post-Test as a Post-Assessment Tool**

On the last day of class, we tested all the 33 students in the class using the SSCI CT Test. The results are discussed and analyzed as follows in Tables 5 and 6:

**Table 5: Results of the Fall 2006 SSCI CT Pre- and Post-Tests**

| | Pre-Test | 25/25 | Post-Test | 25/25 | Post-Test |
|---|---|---|---|---|---|
| Class ID | #Questions missed | Grade | #Questions missed | Grade | Rank |
| 1 | 15 | **10/25** | 17 | **8/25** | **31** |
| 2 | 11 | **14/25** | 8 | **17/25** | **8** |
| 3 | 13 | **12/25** | 13 | **12/25** | **29** |
| 4 | 13 | **12/25** | | | **N/A** |
| 5 | 13 | **12/25** | 4 | **21/25** | **1** |
| 6 | 13 | **12/25** | 12 | **13/25** | **26** |
| 7 | 15 | **10/25** | 9 | **16/25** | **9** |
| 8 | 17 | **8/25** | 17 | **8/25** | **31** |
| 9 | 14 | **11/25** | 11 | **14/25** | **20** |
| 10 | 15 | **10/25** | 5 | **20/25** | **4** |
| 11 | 9 | **16/25** | 10 | **15/25** | **13** |
| 12 | 12 | **13/25** | 5 | **20/25** | **4** |
| 13 | 13 | **12/25** | 13 | **12/25** | **29** |
| 14 | 12 | **13/25** | 11 | **14/25** | **20** |
| 15 | 17 | **8/25** | 12 | **13/25** | **26** |
| 16 | 13 | **12/25** | 9 | **16/25** | **9** |
| 17 | 14 | **11/25** | 10 | **15/25** | **13** |
| 18 | 17 | **8/25** | 12 | **13/25** | **26** |
| 19 | 18 | **7/25** | 10 | **15/25** | **13** |
| 20 | 12 | **13/25** | 11 | **14/25** | **20** |
| 21 | 9 | **16/25** | 4 | **21/25** | **1** |
| 22 | 9 | **16/25** | 6 | **19/25** | **6** |
| 23 | 17 | **8/25** | 9 | **16/25** | **9** |
| 24 | 14 | **11/25** | 11 | **14/25** | **20** |
| 25 | 13 | **12/25** | 9 | **16/25** | **9** |
| 26 | 11 | **14/25** | 7 | **18/25** | **7** |
| 27 | 13 | **12/25** | 11 | **14/25** | **20** |
| 28 | | | | | **N/A** |
| 29 | 15 | **10/25** | 4 | **21/25** | **1** |
| 30 | 18 | **7/25** | 10 | **15/25** | **13** |
| 31 | 16 | **9/25** | 10 | **15/25** | **13** |
| 32 | 14 | **11/25** | 10 | **15/25** | **13** |
| 33 | 15 | **10/25** | 10 | **15/25** | **13** |
| 34 | 18 | **7/25** | 17 | **8/25** | **31** |

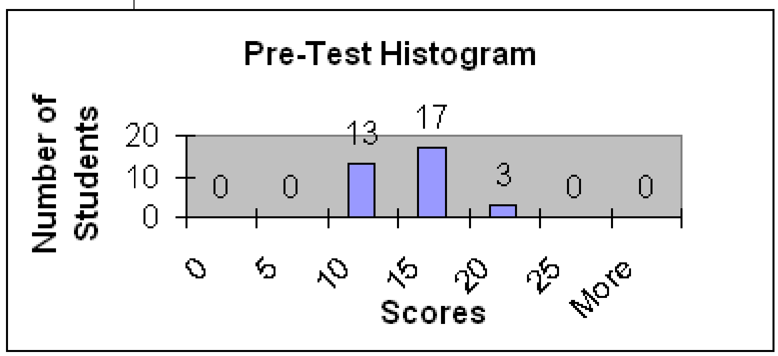
Student #4 did not do the Post-Test. Student #28 dropped the course early in the term.
The overall mean score for all the 33 students is Sum / 33 = 15.09/25. The maximum score is 21/25. The minimum score is 8/25 (for the 33 students taking the exam).

In Table 5, the details of the student performance in the individual questions are not included. Instead, the overall results are summarized.

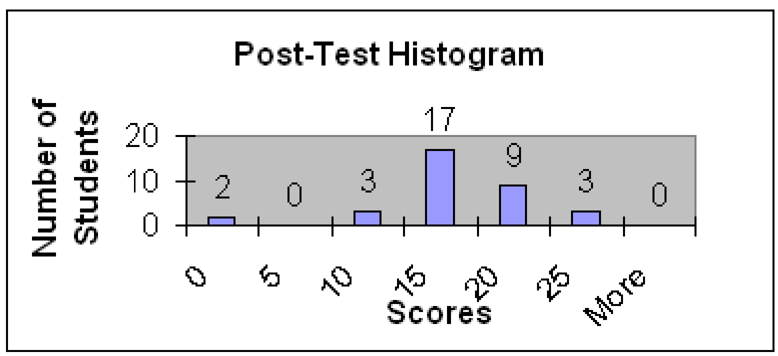
It is expected that Post-Test grades will be higher than Pre-Test grades. This is true except in few cases. Also, there's some direct correlation between the Overall Class Rank and the Rank in the SSCI CT Post-Test. SSCI measures conceptual understanding while the class exams measures mastery of the class subject and the overall ability to solve problems.

Here's the histogram for the pre-test and post-test data for Fall 2006:

| *Bin* | *Frequency* |
|---|---|
| 0 | 0 |
| 5 | 0 |
| 10 | 13 |
| 15 | 17 |
| 20 | 3 |
| 25 | 0 |
| More | 0 |




| *Bin* | *Frequency* |
|---|---|
| 0 | 2 |
| 5 | 0 |
| 10 | 3 |
| 15 | 17 |
| 20 | 9 |
| 25 | 3 |
| More | 0 |




We also display below the normalized gain as defined and used in [2].

| **Student** | **1** | **2** | **3** | **4** | **5** | **6** | **7** | **8** | **9** | **10** | **11** | **12** | **13** |
|---|---|---|---|---|---|---|---|---|---|---|---|---|---|
| <g> | -0.13 | 0.272 | 0 | N/A | 0.692 | 0,076 | 0.4 | 0 | 0.214 | 0.667 | -0.11 | 0.583 | 0 |
| **Student** | **14** | **15** | **16** | **17** | **18** | **19** | **20** | **21** | **22** | **23** | **24** | **25** | **26** |
| <g> | 0.083 | 0.294 | 0.307 | 0.285 | 0.294 | 0.444 | 0.083 | 0.555 | 0.333 | 0.470 | 0.214 | 0.307 | 0.363 |
| **Student** | **27** | **28** | **29** | **30** | **31** | **32** | **33** | **34** | | | | | |
| <g> | 0.153 | N/A | 0.733 | 0.444 | 0.375 | 0.285 | 0.333 | 0.055 | | | | | |

It is clear from these histograms that the performance of the students improved at Post-test compared to Pre-Test. The <g> parameter (defined as <g>=(post-pre)/(100-pre)) helps us quantify student learning during the course. A positive <g> indicates performance improvement. The value of 100<g> % shows student incremental learning or gain in knowledge during the course as a percentage.

**Table 6: Fall 2006 Comparing Class Exam and SSCI CT Test Rankings**

| Class ID | Rank in Class | Rank in SSCI CT Post-Test | SSCI CT PT Grade 25/25 |
|---|---|---|---|
| 1 | *22* | 31 | 8/25 |
| 2 | *5* | 8 | 17/25 |
| 3 | *32* | 29 | 12/25 |
| 4 | *N/A* | N/A | N/A |
| 5 | *21* | 1 | 21/25 |
| 6 | *12* | 26 | 13/25 |
| 7 | *2* | 9 | 16/25 |
| 8 | *16* | 31 | 8/25 |
| 9 | *24* | 20 | 14/25 |
| 10 | *17* | 4 | 20/25 |
| 11 | *20* | 13 | 15/25 |
| 12 | *3* | 4 | 20/25 |
| 13 | *19* | 29 | 12/25 |
| 14 | *11* | 20 | 14/25 |
| 15 | *30* | 26 | 13/25 |
| 16 | *13* | 9 | 16/25 |
| 17 | *6* | 13 | 15/25 |
| 18 | *10* | 26 | 13/25 |
| 19 | *7* | 13 | 15/25 |
| 20 | *25* | 20 | 14/25 |
| 21 | *1* | 1 | 21/25 |
| 22 | *8* | 6 | 19/25 |
| 23 | *23* | 9 | 16/25 |
| 24 | *15* | 20 | 14/25 |
| 25 | *14* | 9 | 16/25 |
| 26 | *4* | 7 | 18/25 |
| 27 | *28* | 20 | 14/25 |
| 28 | *N/A* | N/A | N/A |
| 29 | *15* | 1 | 21/25 |
| 30 | *26* | 13 | 15/25 |
| 31 | *27* | 13 | 15/25 |
| 32 | *18* | 13 | 15/25 |
| 33 | *9* | 13 | 15/25 |
| 34 | *31* | 31 | 8/25 |

## Conclusions

In this paper, we presented and analyzed the results of assessment tests in a Linear Systems course at Santa Clara University. Two specific tests are discussed. The results of both tests are analyzed. Some suggestions for future offerings of the course are also presented.

Our sample sizes are quite small. First, the first internal test had 10 students, the first SSCI test had 20 students and the second SSCI Test had 34 students. The statistical distribution of the results may be less than expected due to this small sample size but the trends are as expected. We intend to keep up doing these pre- and post-assessment tests for future offerings of the class. This will increase our sample sizes and we will then be able to accumulate the results over time so that the statistical analysis of the results will become better reflective of the sample space, the student population at Santa Clara University.

One of the major lessons learnt from this exercise is that the presentation of the material needs to be done conceptually as well as mechanically. The regular exams take care of determining the students' capability in the mechanistic methods of solving the problems. The assessment tests (especially the SSCI CT test) help us determine if the students have an understanding of the concepts of linear systems, signals and transforms. Through these assessment tests, we have been able to determine how much conceptual understanding the students have developed by the end of the class.

We also note that the SSCI Tests did not discourage guessing by penalizing it in anyway. This means students can guess answers and score well on these tests even if they did not understand the concepts. An ideal test should penalize guessing to accurately determine students' understanding of the concepts taught in class.

Finally, we have used the results to recommend alternate pedagogical methods for presenting the material in the Linear Systems course.

In summary, we met the goals of our study:
(1) We were able to determine how much conceptual understanding the students have developed by the end of the class compared to the beginning of the class.
(2) We were able to correlate the performance on the end-of-term exam with the performance on the SSCI Post-Test which is designed to test the conceptual understanding, but not necessarily the steps of problem solving and system design.
(3) We were able to determine the concepts which the students have had difficulty understanding so that there may be more emphasis on those concepts the next time the course is offered.
(4) We were able to relate the performance of students on their ability to relate pre-requisite course material (in Electric Circuits) with the new material in the Linear Systems course. Also, we were able to adequately prepare the students for follow-up courses in the "Systems" area.
(5) We were able to recommend alternate pedagogical methods for presenting the material in the Linear Systems course based on the results of our study.

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