



## **An Experiment to enhance Signals and Systems learning by using technology based teaching strategies**

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The University of Texas at El Paso teamed with the “Signal Processing Education Network,” (SPEN), which consists of academic, industry and professional community. SPEN, an NSF-sponsored effort, is based on four technologies: Connexions, interactive simulation tools, Quadbase question/answer system and OpenStax Tutor. It seeks to develop materials that allow educators to break away from traditional textbook-lecture-homework education, and create a new framework based on an engaged community of educators, students, and industry professionals that continuously collaborate, improve and explore interactive content. The initial effort focuses on one strategic subdiscipline in electrical engineering, signal processing, but the framework can be applied to engineering education at all levels: high school, university (undergraduate and graduate) as well as continuing education.

During the Fall 2012 and Spring 2013 semesters, UTEP implemented the use of Connexions, interactive examples, Quadbase system, and OpenStax Tutor in a sophomore course on Continuous-Time Signals and Systems. We organized existing material pertinent to the course into learning modules, created problems with associated solutions in Quadbase and developed interactive simulations in Mathematica to help students more effectively learn concepts with which they had difficulties. In addition, we used the assessment system provided by OpenStax Tutor to track and evaluate students’ progress.

OpenStax Tutor facilitates the instructors’ work by automatically grading student work and exporting the grades to a spreadsheet. It also provides statistics of students’ performance, e.g., reporting the time taken to complete specific assignments. These statistics enable assessment of overall class performance as the semester progresses.

The feedback from students, gathered through a modified version of the SALG instrument, demonstrated that they enjoyed and learned the material better by using technology tools. The assessment of the learning gains of students in the Fall 2012 and Spring 2013 semester demonstrated an increase in the assessed learning outcomes compared to the Summer 2012 semester, where the tools were not used.

The use of technology tools can address multiple situations in engineering education: limited opportunity for active learning; limited opportunity for laboratory activities that are interesting or relate to students’ ideas about their “real world”; lack of interactive learning demos; textbooks providing limited connections among topics; development of textbooks and course materials limited to a small number of authors; and rising textbook costs that present a financial burden for students, especially low-income students.

### **Introduction**

Engineering job opportunities are increasing every year<sup>1</sup>; therefore, to meet the workforce needed the rate of graduates in these areas needs to be increased.<sup>2</sup> In addition, an improved teaching and learning environment is required at undergraduate engineering disciplines to prepare graduates capable of pursuing engineering related careers.

There is an existing crisis in engineering education: stagnant or decreasing student enrollment, underprepared students, and instructional methods disconnected from students' preferred methods of communication and interaction. To address these problems, we are implementing, assessing and evaluating effective teaching strategies that integrate technology-based materials intended to enhance teaching and learning. We hypothesize that by implementing the use of technology based tools into electrical engineering courses, an improved teaching and learning environment can be achieved. By using technology based teaching strategies we can improve students' learning outcomes. Consequently, leading to motivated students who will follow engineering careers or will pursue engineering graduate programs.

In our determination to improve engineering education we joined the SPEN project. The SPEN project is a partnership between the academic, industrial and professional communities focused on implementing, assessing and disseminating teaching materials with four technologies: Connexions, interactive simulations, Quadbase system and Openstax Tutor.<sup>3</sup> Connexions is an open-access "modular" repository that enables authors to collaborate and create educational materials: instructors can rapidly build custom courses from these modules and learners can explore connected content through linked modules.<sup>4</sup> Interactive simulations are demos in Labview, Mathematica and Matlab, which encourage learners to experiment in signal processing via computer simulations that encourage exploration and design.<sup>5</sup> Quadbase provides problems and solutions to help students learn and practice core topics on an individual basis. These three technologies are compiled into Openstax Tutor. Openstax Tutor is a study resource, homework and test delivery system that is aimed to improve students' learning and instructor's assessment of students' learning.<sup>5</sup>

The technologies used in our teaching and learning experiment address multiple situations in engineering education. Connexions, addressing textbooks providing limited connections among topics; development of textbooks and course materials limited to a small number of authors; and rising textbook costs that present a financial burden to students, especially low-income students. Quadbase, addressing limited variety of practicing problems; and difficulty in sharing and reusing problems and their solutions. Interactive simulations, addressing limited opportunity for active learning; lack of interactive learning demos; and limited opportunity for laboratory activities that are interesting or relate to students' ideas about their "real world." Openstax Tutor, addressing limited feedback about student's learning (to both students themselves and instructors) and assessment out of sync with course development.

## Background

New methods for enhancing students' learning have been studied by the education psychology and pedagogical community at large.<sup>2,6</sup> In the traditional paradigm of higher education, the professor transmits information to students and expects them to capture this information, commit it to memory and apply it with guided practice limited to laboratory experiments. Cognitive scientists tell us that people can retain information in long term memory by actively participating in their learning experience.<sup>7</sup> Slowly but steadily the passive approach is being substituted by a learner-centered paradigm in which the educator creates a transformative experience in the classroom, guiding students in a process of discovery that simulates scientific research. Thus, an optimal learning experience is one that provides an engaging environment where students fine tune critical thinking skills. Instructional technology (including hardware, teaching platforms and

software) is impacting higher education as a way to transform learning. New methods that include instructional technology are being used, assessed and evaluated to enhance student learning.<sup>8,9</sup> Incorporating technology based tools into the teaching strategy can transform the learning environment to a learning centered approach, where students take action and actively participate in their learning. Taking advantage of technology resources can transform teaching and learning from the textbook-lecture-homework method to an engaging learning environment where students actively participate in their learning.<sup>5</sup>

In the traditional teaching style, a reference textbook is assigned as the primary resource for the class. With the expansion of the web we can improve the learning environment by using open source educational materials such as Connexions.<sup>10</sup> Connexions was founded in 1999 by Richard Baraniuk. It is organized into small modules that can be compiled into courses. In Connexions, instructors can rapidly use, customize and contribute to modules. Students can access the online resources anytime, anywhere, at no cost.

Another way to incorporate technology into the teaching style is by using interactive simulations. Software such as MATLAB, Mathematica and LabView has helped to reorganize learning around simulation activities. The use of visualization tools improve student learning and motivate students to pursue engineering related careers.<sup>9</sup> The incorporation of interactive simulations into the class can encourage students to actively participate in their learning experience.

Students learn electrical engineering by practicing outside the classroom what they learned in the classroom. A good approach to teaching is to include graded homework into the teaching style. However, the traditional paper homework can be substituted by Quadbase for assessment of students' learning. Quadbase is a free online repository of questions where professors can create, share and use free-form, multiple choice, matching and multi-step questions. There are many disputes in using multiple choice answers (MC) or constructed response (CR). A disadvantage of using MC answers is that each multiple choice answer needs to be carefully chosen. Distracters or wrong answers need to be included in the multiple choice answers so that students cannot just easily guess the answers instead of solving the problems.<sup>11</sup> In addition, for each homework problem the instructor can create a complete solution that is given to students to learn from their mistakes. From the point of view of the instructor this is time consuming; however, by creating online homework instructors can improve students' learning. Students can access and solve the homework at their best time and learn from the feedback provided by each homework problem.

Significant efforts to improve signal processing education can be found in literature.<sup>12, 13, 14</sup> Some of these efforts include the assessment of different teaching strategies such as problem based learning that are intended to help students learn the material.<sup>6</sup> Other efforts include the incorporation of hands-on or laboratory experiments to the course to help students learn from real world experiments.<sup>12,13,15</sup> In addition, we can find efforts to improve signal processing where they use online tools demonstrations to help students to visualize the concepts.<sup>14</sup> However, each of these efforts is targeting one deficiency of students' learning. In this project, we implemented the use of Openstax Tutor which is a powerful learning tool that incorporates principles from cognitive science that have been proven to increase long term retention and transfer of learning.

Openstax Tutor includes homework, study resources, interactive simulations and the assessment system to improve the teaching/learning environment.

### Experimental Method

Based on the analysis of how technology based instruction can improve learning environment, we implemented the use of SPEN tools to investigate how it can improve students' learning. We conducted an experiment in successive semesters where the sample population was taken from a sophomore level undergraduate electrical engineering course: Continuous-Time Signals and Systems. All electrical engineering students are required to take this course. The prerequisites for this course are Differential Equations, Calculus 2 and Introduction to Electrical Engineering.

The course learning outcomes are

1. Determine characteristics of continuous time signals and systems such as linearity, time invariance, period, frequency, power and energy.
2. Apply convolution and its properties to solve linear time invariant systems.
3. Use Fourier series, Fourier transforms and its properties to analyze continuous-time signals and systems.
4. Compute impulse and frequency responses of linear time invariant systems.
5. Use the Laplace transform to analyze continuous time invariant systems.

Two experiments were performed to compare the learning outcomes resulted from using technology based instruction to traditional instruction.

Experiment 1. The first experiment was performed in the Summer 2012 where the instructor gave five lectures per week, each lecture of 130 minutes. The lecture was devoted to explaining the material and problem based teaching. Students were assigned several assignments outside the class such as reading and homework. The reading assignments were chosen from the primary book for the class. The homework structure was aligned with the traditional method (paper and pencil). Each session, students were assigned specific problems from the book used in the course. The homework was related to the topics covered in the classroom. The instructor of the course was responsible for grading the homework and students used the graded homework as feedback for them to prepare for the exams. The data collected for this experiment was based on 27 students taking the course.

Experiment 2. The second experiment was performed in Fall 2012 and Spring 2013 where the instructor gave two lectures each week, 80 minutes long each, for each semester. The lecture was devoted to lecture and problem based learning teaching strategy. Students were assigned several assignments outside the class such as reading, interactive simulations and homework. Specifically, students were assigned a set of problems each week to be completed in Openstax Tutor.

For both experiments students' learning was assessed by using homework and course exams. In addition, students from the second experiment were surveyed to know about their perception on the use of technology teaching tools. The survey was conducted at the end of the semester.

## Procedure

The technology based instruction consists in the implementation of the online technologies: Connexions, interactive simulations, Quadbase and Openstax Tutor. The preparation for the course included the customization of the material in Connexions, the creation of interactive simulations, the creation of questions to be used to assess students' learning and finally the incorporation of the tools into the platform Openstax Tutor.

The Connexions repository was used to build the online course resources. The topics covered in the class were used as a base to create the course online material for Continuous-Time Signals and Systems.

Based on our previous knowledge of common students' deficiencies in Continuous-Time Signals and Systems, we created interactive simulations on the topics students commonly have more difficulties. The interactive simulations were created by using Mathematica. Three main interactive simulations were created for this experiment specifically on complex numbers, complex exponential and convolution. These interactive simulations allowed students to explore a topic using a hands-on approach. An example of interactive simulation is shown in Figure 1. In this interactive simulation, developed in Mathematica software, students were able to play with the topic of linear convolution in a linear system. The graphical user interface (GUI) in Figure 1 allows the student to select both the input waveform  $x(t)$  and the impulse response  $h(t)$  of the linear system among a set of pre-defined waveforms: pulse, triangle, sawtooth, exponential, bell and the derivative of bell (first column on the GUI). Then, by sliding a cursor on a time scale (top of second column) students can change the time variable and observe both operations  $x(t) h(t)$  (third column) and  $h(t) x(t)$  (fourth column) taking place, as well as the corresponding result of these equivalent operations being plotted (bottom of second column) for each position of the sliding cursor.

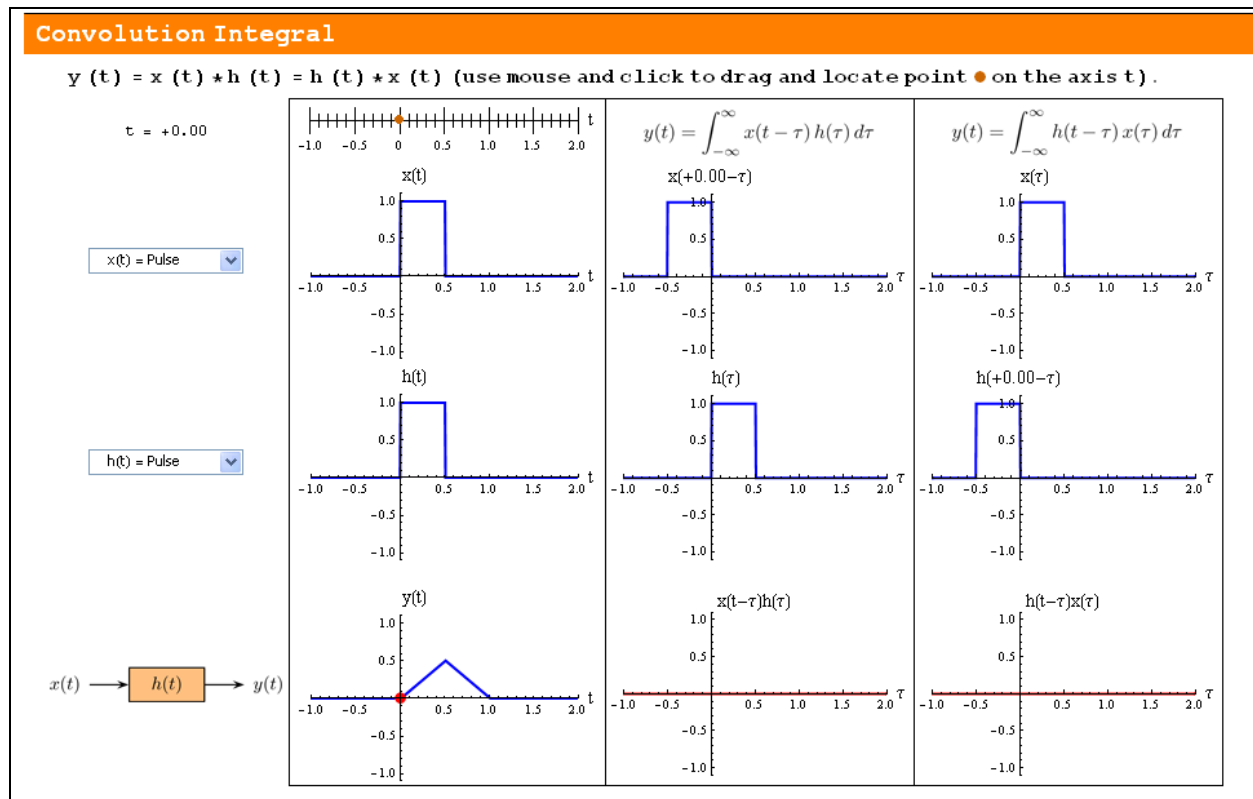


Figure 1. Interactive simulation on convolution integral.

After being exposed to each new topic through discussions in the classroom, a simulation and content in Connexions, the Quadbase system was used to assess students' learning based on homework and course exams. Around 300 questions were created for this experiment. A set of problems was assigned each week to students as homework. The homework was designed to assess students' learning on topics covered in the lecture for that week. Students had one week to complete the homework set (around 10 problems per week). For each question we created multiple choice answers, including distracters.<sup>11</sup> In addition, each question included a feedback. Feedback for each problem included the correct solution and a detail procedure to solve the problem. The given procedure included first a general way to solve the problem narrowing down to the specific solution. On this way students could learn the process needed to solve the problems related to the same topic, not just that specific problem. Students received feedback from each homework problem and had the opportunity to find out their mistakes and deficiencies about a specific topic, ultimately, improving their learning experience. An example of a homework problem assigned to students on Laplace Transform is shown in Figure 2.

Find the unilateral Laplace transform  $V(s)$  of  $v(t) = tu(t-1) + (t-2)e^{-3(t-2)}u(t-2)$ , where  $u(t)$  is the unit step function.

a)  $V(s) = \frac{1}{s+1}e^s + \frac{1}{s+3}e^{2s}$

b)  $V(s) = \frac{1}{s^2} + \frac{1}{s}$

c)  $V(s) = \frac{1}{(s+1)^2} + \frac{1}{s+2}$

✓ d)  $V(s) = \frac{1}{s^2}e^{-s} + \frac{1}{s}e^{-s} + \frac{1}{(s+3)^2}e^{-2s}$

e)  $V(s) = \frac{1}{s^2}e^{-s} + \frac{1}{(s+3)^2}e^{-2s}$

Figure 2. Homework problem given to students in the Quadbase system.

The three technologies (Connexions, Quadbase and interactive simulations) were then combined into the Openstax Tutor platform. In Openstax Tutor we organized the course material into learning topics, each topic corresponding to one week of the course. The material organized in Openstax Tutor would include reading assignments from Connexions, interactive simulation on the topic being covered, and the corresponding homework problems. The learning plan for the first five weeks of classes is shown in Figure 3. For each topic, we assigned resources chosen from modules in Connexions and interactive simulations.

**Learning Plan: EE2353: Continuous Time Signals and Systems**

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Topics ?

- Background: Complex Numbers, Derivatives, Integrals, Sinusoid's, Euler's, Partial Fraction**  
5 Resources, 15 Exercises
- Laplace Transform, ROC, Properties of Laplace Transform**  
4 Resources, 15 Exercises
- Properties of LT, circuit analysis using LT**  
1 Resource, 14 Exercises
- Inverse LT**  
1 Resource, 16 Exercises

Figure 3. Learning plan in Openstax Tutor.

The instructor was able to track (in real-time) the response given by each student to each problem, and the time taken to solve each problem (time between opening the problem and



inputting an answer). In addition, Openstax Tutor provides the analytic option which allows the instructor to assess students' performance on each topic, as a percentage of correct, incorrect and incomplete answers per topic. In this way, the instructor is then able to reinforce specific topics where students show more deficiencies. An example of the Openstax Tutor analytic option for our course on Continuous-Time Signals and Systems is shown in Figure 4.

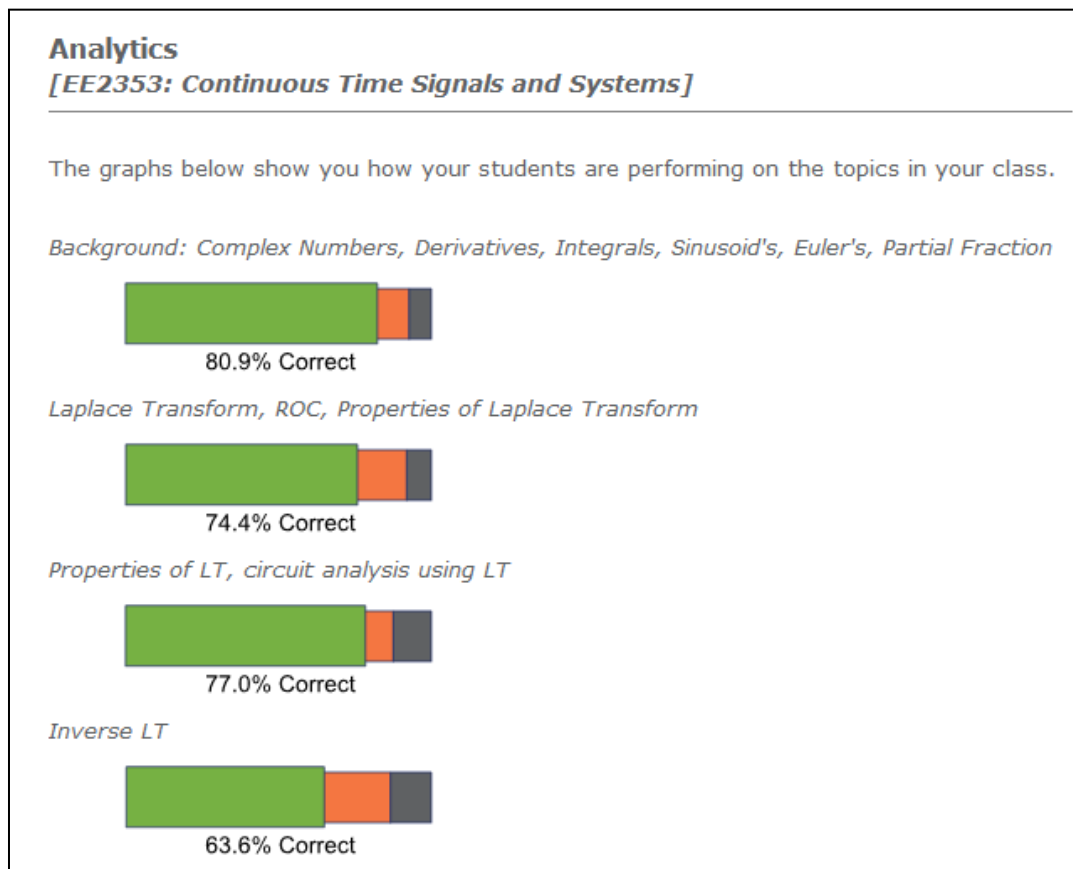


Figure 4. Analytics of homework performance.

## Results and Discussion

After implementing the aforementioned technologies into Continuous-Time Signals and Systems for two consecutive semesters, we feel confident to report a significant improvement in students' learning outcomes.

The metric used to measure the learning outcomes for the three semesters (Summer 2012, Fall 2013 and Spring 2013) was the percentage of students obtaining score of at least 70% on a given topic. The results summarized in Table 1 indicate a significant improvement for those semesters in which Openstax Tutor was adopted. It is important to realize that Experiment 1 was performed during the summer semester. Learning outcomes in Experiment 1 are very low compared to Experiment 2. The low performance could be influenced by other external factors such as the short duration of the summer semester. In typical summer semester, students have less time to study and to do homework. Because of the low performance in learning outcomes during the

summer semester, a makeup exam at the end of the semester was administered to students to reassess the learning outcomes.

Table 1. Assessment of Learning Outcomes.

Learning Outcome	Summer 2012	Fall 2012	Spring 2013
1	51%	70%	77%
2	56%	92%	70%
3	61%	77%	88%
4	35%	85%	92%
5	20%	88%	100%

In addition, a modified version of the SALG instrument was used to survey students about their perception of the use on the aforementioned technologies in the course. The results are summarized in Table 2 to 5. Table 2 summarizes the students' responses to the survey question on the effectiveness of the use of Openstax Tutor homework to help them learn the course material. Seventy-seven percent of the students indicated that assigned homework problems helped them to learn the course material.

Table 2. Students' perception on homework.

Answer	% Students
Excellent	45%
Good	32%
Fair	18%
Poor	5%
Not applicable	0%

Table 3 summarizes the students' responses to the survey question on the effectiveness of the feedback of the homework solutions provided in Openstax Tutor to help them learn the course material. A high score of ninety-five percent of the students indicated that the feedback of the homework solution helped them to learn the course material.

Table 3. Students' perception on feedback.

Answer	% Students
Excellent	43%
Good	33%
Fair	19%
Poor	5%
Not Applicable	0%

The response to the survey question on the effectiveness of the use of the learning resources in Connexions to help students learn the course material is summarized in Table 4. Eighty-six

percent of the students answered that the online resources helped them to learn the course material.

Table 4. Students' perception on online learning resources.

Answer	% Students
Excellent	33%
Good	24%
Fair	29%
Poor	14%
Not Applicable	0%

Finally, Table 5 summarizes the students' responses to the survey question on the effectiveness of interactive simulations to help them learn the course material. Ninety percent of the students indicated that the interactive simulations also helped them to learn the course material.

Table 5. Students' perception on interactive simulations.

Answer	% Students
Excellent	29%
Good	43%
Fair	19%
Poor	10%
Not Applicable	0%

## Conclusion

Based on our experience in teaching Continuous-Time Signals and Systems we realized that students taking this class were not achieving the expected learning outcomes for the course. An intervention was required where an improved teaching and learning environment could be achieved. For that reason, the University of Texas at El Paso joined the SPEN project led by Rice University and implemented the technology-based instruction for two consecutive semesters. Students taking the course were able to actively participate in their learning by using four technologies: Connexions, Quadbase system, interactive simulations and Openstax Tutor. Students used the modules in Connexions to study at their own place and time. They were able to reinforce their knowledge in specific topics by the course from the homework feedback by using the Quadbase system. A significant improvement on the learning outcomes was observed when implementing technology-based instruction compared to the traditional instruction. The use of these technologies tools facilitate the instructor's work by tracking performance of students on real time and exporting grades to excel worksheets. Students' survey responses indicate that they were benefited with the use of technology-based instruction by helping them to learn the material better. The results from this experiment indicate that the use of the technology-based instruction can improve the teaching and learning environment. We were able to create an engaged teaching and learning experience: students actively participating in their learning and instructors more effectively delivering content and assessing students' learning.

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