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Improving Learning in Continuous-Time Signals and Systems Courses Through Collaborative Workshops

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The introductory continuous-time signals and systems (CTSS) course at Rose-Hulman Institute of Technology suffers from drop/failure rates that are 2-6 times greater than other required electrical and computer engineering courses. Based on conversations with faculty at numerous other institutions, the poor performance seen in this course is a typical situation for most programs. We have received NSF funding to explore the sources of difficulty in such courses and determine effective methods of helping students to learn the material. A major outcome of this project is to produce a workshop that communicates pedagogical research results, gathers different perspectives from other schools through focused discussion, and develops a broader community of interested pedagogical researchers. By June 2015, the workshop will have been offered five times, each time over a different duration from 1.5 hours to 3 days and with a varying audience [1-4]. This paper describes the contents of the workshop, the experiences of the attendees, and the results of interacting with the various attendees.

Regardless of the duration, the workshop is set up to address a series of questions: 1) Why are CTSS courses so difficult for students? 2) What can educators garner from learning theories and experimentation to make CTSS courses more accessible for undergraduate students? 3) How can we exploit conceptual learning theories to improve learning for conceptually difficult courses? 4) What approaches were utilized to improve learning? 5) How can participants use what was covered in the workshop to improve their own courses? The answers to the first three questions are sought by promoting discussions among the attendees through presentation of historical data, analysis of students' work samples, reviews of some relevant conceptual learning theories, and results from research being done to identify student misconceptions and their sources. Question 4 is addressed by demonstrating some hands-on application-oriented learning activities that are being developed at Rose-Hulman and Bucknell University to improve learning in introductory CTSS courses. Finally, to address Question 5, the attendees are given an opportunity to review the already developed activities in the context of the discussions that occurred for the first three questions.

As of September 2014, the workshop has been attended by approximately 35 faculty members from over 20 different universities, some of which were international, and several different industry representatives. By sharing similar experiences about student difficulties in learning within CTSS courses from a wide range of institutions and curricula, a more complete picture of both the difficulties and solutions to help students get past them is formed. For example, several new hands-on activities were developed by workshop attendees during the extended summer offerings. Several new perspectives with regard to conceptual learning theories were derived from offering the workshop and were used to steer a Ph.D. dissertation study [5]. Discussions have promoted and influenced a redesign of the hands-on laboratory sessions at Rose-Hulman.

Workshop Description

The workshop is presented in three major phases: analysis of student learning difficulties, examples of and experience with hands-on activities, and review of the hands-on activities with respect to the discussion about learning difficulties from the earlier part of the workshop. The amount of time spent on each of these topics varied in order to tailor the workshop for the different formats from a 1.5 hour conference session to the multi-day workshop at Rose-Hulman. The primary difference between the multi-day workshop and the shorter conference workshops is the amount of time allotted for hands-on activities. In the multi-day workshop, attendees are eventually able to develop and present their own new hands-on activities while the shorter workshops are more of an introduction to the topic.

In order to motivate the workshop and focus discussion, the workshop begins with a description of historical data that was collected at Rose-Hulman. The data includes examples of student work that provides a general sense of the difficulties that students encounter when trying to learn the concepts. Historical data is used to show that the difficulty is due primarily to the course content and not anything that the students or faculty are doing. During the first offerings of the workshop this presentation led to many discussions, which in turn generated new questions for analyzing the historical data. A preliminary summary of this analysis that includes answers to many of these questions was published at the 2014 ASEE Annual Meeting [6]. Discussion questions focused on asking the attendees to describe the aspects of the course that they find most difficult to teach and to ponder why they think students have so much difficulty learning those aspects.

A summary of learning theories is then presented in order to get different perspectives of what could be causing the concepts to be so difficult to learn. This part of the workshop has changed substantially as the Principle Investigator (PI) and his collaborators continued their research into this area. In the first workshop, a survey of different learning theories was presented: phenomenological primitives [7], ontological categorization [8], knowledge in pieces [9], framework theory [10], advanced mathematical thinking [11], Bloom's taxonomy [12], Kolb's theory of experiential learning [13], and deep versus surface approaches to learning [14]. As part of this NSF grant, we conducted student interviews to gain a better understanding of students' thought processes as they work through signal processing problems. The problems are phrased in such a way that they force students to apply their conceptual understanding of the material to solve the problems instead of being able to apply a standard procedure to get an answer. As the research was conducted and completed, the coverage of these topics morphed from a survey of learning theories to our current understanding of what we think is happening with the students.

When presenting the summary of learning theories, discussion questions focused on asking attendees to apply one or more of these learning theories to try to explain some of their students' learning difficulties. The feedback that we received from the attendees about this portion of the workshop is that it did help them to see the problem from perspectives that they hadn't thought of previously. However, they also said that, while valuable, there wasn't enough time to truly digest all of this material. This part of the workshop is continually being revised in order to make it more effective.

The next phase of the workshop is focused on presenting hands-on activities that can help students to overcome some of the learning difficulties that they face. The fundamental CTSS concepts are very mathematical and theoretical, but research indicates that most engineering students prefer to learn by doing something with the material and seeing how it is used [14]. Furthermore, one of the stages in Kolb's experiential learning cycle is to have some sort of engaged physical experience with the material. Many decades ago, electrical engineering students were drawn into electrical engineering because of their experiences with amateur radio or taking apart electronic devices, so they had some prior experience on which to build. However, most modern students do not have these types of experiences because modern technology makes it much more difficult to take systems such as cell phones apart, and the recent generations are listening to streaming audio over the internet instead of radio broadcasts. In order to address some of the students' current lack of experience, the PI and his collaborators have been developing hands-on activities to provide such experiences with the CTSS concepts. At Rose-Hulman, the introductory CTSS course is taught with a dedicated 3-hour laboratory session each week. However, at most institutions, the course is taught without a laboratory component. The activities presented at this workshop can be easily adapted for quick demonstrations in class or even for use as homework assignments or mini-projects.

The hands-on activities are done with an analog circuit platform that was developed at Rose-Hulman and the Digilent Analog Explorer platform that provides portable electronic instrumentation such as power supplies, oscilloscopes, and function generators [15]. The attendees need only to bring their laptop with the free software that controls the Digilent platform installed. The analog circuit platform was designed to be very easy to set up so that it doesn't take long to begin an experiment. It can also be easily reconfigured to perform a large variety of experiments in order to cover a wide range of course topics. An introduction to this hardware is required because none of the attendees are familiar with it. The hands-on activities were then performed after this introduction during the first workshops. It was later discovered to be more effective to introduce the equipment while walking the attendees through the first hands-on activity.

The hands-on portion of the workshop is what varied most when offering the workshop in the different formats. The goal of the multi-day workshop is to provide each attendee with enough hands-on experience that they can begin developing their own activities that are tailored to their specific course when they return to their institutions. During the multi-day workshop, the afternoon of the first day was used to introduce the hardware platforms and making sure that the attendees knew how to use the hardware. During the second day, they were able to work through several different activities that utilize all of the different parts of the analog circuit platform. They also begin developing new hands-on activities during the afternoon of the second day. The morning of the third day is used to finalize the design of the activities that they develop and to present it to the other attendees.

The goal of the conference workshops is just to introduce participants to the idea of using hands-on activities and provide a limited experience with how they can help to improve student learning of CTSS concepts. During the 3 hour pre-conference workshop, the equipment was set up ahead of time for each participant to do experiments with the hardware so that they only had to connect their laptop. At least 2 hours of the workshop were allotted for hands-on activities, so the participants were able to experience a few different activities that covered different topics. During the 1.5 hour conference session, a few hands-on activities were presented by the facilitators as demonstrations because there was insufficient time for the participants to perform them. However, the participants were asked for which concepts they wanted to see activities performed. This format would be similar to a demonstration during a normal lecture session of the course.

The last part of the workshop is devoted to reviewing the hands-on activities within the context of the learning theories and student challenges that were presented at the beginning of the workshop. In the multi-day workshop, some of this discussion is done while the participants are designing their own hands-on activities. When each participant presents the activity that he/she designed to the other participants, the whole group is exposed to ideas that may not have been part of the individual activity. This final discussion provides an opportunity to think critically about what makes a hands-on activity effective and which topics in the course could most benefit from having a hands-on activity. At the conference sessions, each participant is asked to describe how the workshop might have changed their opinions about why students struggle so much in this course. This final discussion serves to summarize the workshop and gives each participant a chance to think critically about the challenges that the students face and how hands-on activities might help with some of those challenges.

Participants' Experiences

This section provides first-hand experiences of participants that were self-written. All of these participants attended the multi-day workshop. Each of their experiences is described in the first person in their respective subsections in order to explicitly relate the experiences that are described to that particular participant. The identity and location of each participant is provided as the heading of each subsection.

Jay Wierer from Milwaukee School of Engineering (MSOE)

The experiment that I developed at the summer workshop at Rose-Hulman in June 2013 focused on visualizing the impulse response of a system and the corresponding convolution with an input signal. The experiment was designed to show how the step response – that is, the convolution of a step input and the impulse response – is built up from the sum (integral) of weighted and shifted impulse responses.

Students were instructed to create a product of two rectangular pulse trains as the input signal. One pulse train models the step input and has a 50% duty cycle and longer period. The other pulse train models an impulse train with short 1% duty cycle pulses and a much shorter period. When these two signals are multiplied together with the hardware it is similar to approximating the step input with high frequency impulses that turn on and off with the step up or down.

In the first part of this experiment, the frequency of the impulse train input is increased, while the pulse width is kept constant. This effect allows the students to visualize the step input as a sum of closely spaced rectangular pulses and correspondingly to visualize the step response as a sum of closely spaced pulse responses. This follows the development of the superposition integral for fixed, linear systems in Ziemer, Tranter, and Fannin, which is the textbook that is used at MSOE for this material [16].

In the second part of this experiment, the duty cycle of the impulse train input is increased, while the amplitude-duty cycle product is kept constant. This similarly follows the development of the superposition integral but offers a different perspective. As the width of the pulses is increased to full width, adjacent pulse responses merge together, forming a rough approximation of the step response.

This experiment was first implemented in the Spring 2014 offering of the signals and systems course. Because this course is offered without a laboratory component at MSOE, the experiment was included as part of a mandatory homework assignment, and a laboratory room was reserved during one class period in order to allow students to perform the experiment while the instructor was available for questions. Although no numerical data was collected, students commented that they were able to see “abstract math in action [in] the convolution lab”.

The workshop inspired me to continue to develop new mini-laboratory exercises and to modify existing exercises developed by Drs. Simoni and Aburdene as part of a redevelopment of the signals and systems curriculum at MSOE. Because individual laboratory instrumentation platforms such as the Digilent Analog Discovery board are becoming more readily available to students and will be required for purchase by students in the EE curriculum at MSOE, these experiments can be more easily completed outside of a laboratory, whether in the classroom or at a student’s home. Hence these new exercises are being developed as modules to be completed in class with the instructor’s guidance.

Wenli Huang from the U.S. Military Academy at West Point (USMA)

Signals and Systems is a required course taught during the Fall semester of junior year for electrical engineering majors at the USMA. The course is known to be one of the most challenging courses in electrical engineering major because it is highly mathematical and it deals with many abstract concepts that students find difficult to relate with their daily lives. To motivate and to inspire students to learn, a set of MATLAB exercises was created to help students understand the concepts, which they can then apply to create or to manipulate signals such as sound or music. Although these exercises are generally helpful, it must be noted that they are only simulations where mathematical operations of the signals are performed. On the other hand, the multi-day workshop at Rose-Hulman exposes attendees to various hands-on-activity ideas with the use of a signal board developed at Rose-Hulman. The signal board provides an easy way to implement the MATLAB exercises into hands-on hardware based experiments. The Digilent Analog Explorer platform used in the workshop can be replaced by the National Instrument ELVIS board that is available at the USMA. The board provides portable instrumentation and interfaces with the computer. Therefore, all the experiments introduced in the workshop are easily adapted. My plan is to change two of the MATLAB exercises into hands-on activities for the fall term of the 2015-2016 academic year. Since the majority of the electrical engineering students enjoy hands-on building exercises, this change will further help in stimulating their learning.

In particular, the two hardware labs that will be developed are (1) Sampling and (2) AM modulation and demodulation. In the case of sampling, the purpose of the exercise is to verify the sampling theorem and observe what happens after signal reconstruction when the signal is sampled at rates above and below the Nyquist rate. There are three main steps to this experiment:

(1) Create a band-limited signal. This can be done using the arbitrary signal generator on ELVIS. For example, the signal can be a weighted sum of ten sinusoidal functions with a maximum frequency of no more than 5000Hz.

(2) Sample the signal. This is done by using the sample and hold circuit on the signal board. The sampling rate is controlled by a clock signal generated from ELVIS. Alternatively, the sampling can also be realized by multiplying the input signal with a periodic low duty-cycle pulse function.
(3) Reconstruct the original signal from the sampled signal by applying a low pass filter. Students can design a low pass filter based on the sampled spectrum and build the circuit on the signal board. The board provides circuit space for filters ranging from 1st order to 6th order.

The sampling rate is chosen so that one is at a rate higher than Nyquist frequency, e.g. 10000Hz, and the other is lower, e.g. 5000Hz. Students can visualize that the sampling rate needs to be at least at the Nyquist frequency in order to successfully reconstruct the original signal. At each step, students observe signals in the time and frequency domains simultaneously, and they can simultaneously compare the original signal to the sampled and reconstructed signal. From the frequency domain representation of the sampled signal, students can clearly understand why low pass filter is needed for reconstruction and why oversampling can reduce the requirement of the low pass filter. Thus, the concepts taught in the lecture are illustrated and reinforced.

The second hardware lab covers AM modulation and demodulation. The goal is to help students understand the principles of communication. During this lab, students create a message signal from a sample of voice or music. This can be done by directly using the microphone input on the signal board. It can also be realized by taking an output from a device's earphone port and connecting it to the input of the signal board. The signal is then modulated using DSB-SC modulation technique. For demodulation, the modulated signal is connected to the input of the second signal board where coherent detection is used. Figure 1 illustrates the block diagram of the exercise. Two hardware signal boards are needed for this exercise, one for modulation, and the other for demodulation. Two students can work together to complete this lab. Students will observe the frequency spectrum of the message signal, the modulated signal, the demodulated signal before filtering, and the demodulated signal after filtering. The students will better understand some basic principles of a modern wireless communication system as they watch the message spectrum shifts to a high carrier frequency by amplitude modulation and shift back to low frequency by demodulation.

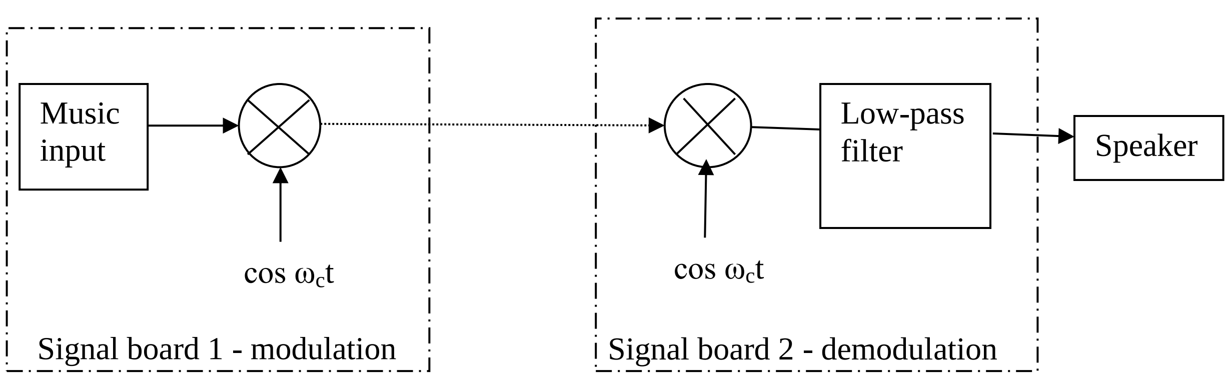

Fig. 1. A conceptual block diagram for AM modulation and demodulation lab exercise.

Vladimir Labay at Gonzaga University

The course I am modifying is EENG 311: Signals and Systems. It is currently taught during the fall semester (15 weeks) of the Junior year and is worth 4 semester credit hours (lectures). In other words we meet for 4-50 minute lectures per week. In the past the grade has been based on assignments, some require the use of MATLAB (10%), two term tests (40%), closed book final exam for which Laplace and Fourier tables are provided (40%) and weekly 10 minute class quizzes (10%). The course covers linear time-invariant systems and continuous-time signals in the time domain, impulse response and convolution, Laplace transforms, Fourier series and transforms, and sampling. We currently offer a follow up course EENG422: Discrete-Time Signal Processing (DSP), which is a 3 credit technical elective that is typically taken during the fall semester of the Senior year.

I plan to convert the 4 credit lecture course into a three credit lecture course plus a one credit lab course. Thus, we will meet for three hours in the classroom plus three hours in the lab each week. I have modified many of the experiments we were exposed to at the workshop to fit with the course content of EENG311. I have enhanced the 'design your own experiment section' on each of the lab exercises that requires the students to develop and demonstrate some signal or system principle. This was one of my take-aways from the Rose-Hulman multi-day workshop that I attended in June 2014. I noticed that this was a required component of each lab that was given to us and I thought it was a great idea. I believe students will achieve a deeper understanding if they are required to demonstrate a principle or a mathematical identity by example in the lab. So in my lab manual for EENG311 I have fewer step-by-step procedures than I would have in my other lab courses, thanks to your workshop.

Another change I am making is to have the students assemble the hardware platform (which is the same one we used during the Rose-Hulman workshop) themselves during the first couple of weeks of the semester. I am not sure how many of the parts I will have them solder onto the board but this will give me the opportunity to describe the various components and sub-circuits on the board as we assemble it. It should help them understand the functionality of the hardware, or at least recognize some of the components (besides resistors). The students will then be able to keep the board at the end of the semester.

Finally, I would like to comment on a discussion I had with one of the workshop facilitators during the presentation about student learning during the Rose-Hulman workshop. The discussion revolved around how students begin to learn and understand CTSS. Why do some students ' get it ' from the lectures and mathematical derivations, some from MATLAB simulation, and others from laboratory experimentation. We discussed a theory about learning styles that may explain this phenomenon, but I find it fascinating how different students solve a problem (i.e. mathematically, numerically, or experimentally) and how they resolve or consolidate these various approaches in their minds. It reveals an interesting thought process that I would like to learn more about. This is why I am excited to introduce this lab to EENG 311. It will be an interesting experience to add this third dimension to the course and I truly hope it will aid the students in their understanding of CTSS related concepts.

Feedback from workshop participants

Written feedback was collected from the participants at the end of each workshop. This feedback was used to improve the content and structure of each subsequent workshop. The formal assessment was given to the participants in the form of the following open-ended questions

1. How has your perspective of learning difficulties in introductory CTSS courses changed as a result of this workshop?
2. What do you see as the biggest obstacle to using the technology that you learned about in this workshop?
3. What aspects of the workshop did you find most useful to you?
4. What aspects of the workshop could be improved?

In response to the first question, many faculty walk into the workshop thinking that the reason students struggle so much with this course is the lack of mathematical skills. The discussion about learning theories and analysis of historical data helps to shed more light on the problem. Participants walk away from the workshop with a deeper understanding of the challenges that students face when trying to learn these concepts and new perspectives for ways to help their students. However, some of the feedback from the participants indicates that there was insufficient time to digest all of the learning theories and that it was difficult to process how the learning theory can be applied to change the way they teach.

The PI and collaborators are adopting the workshop material and format in response to this feedback. The research that was done to better understand student thought processes will help to focus the discussion at the beginning of the workshop. Instead of covering general learning theories, the presentation can focus more on specific challenges that students are having while learning the material. Hypotheses to describe why students are having these challenges can be developed based on learning theories and the participants' experiences with their students.

In response to the second workshop assessment question, many participants indicated that they do not have a specific laboratory component to their course and that it might be a challenge for them to build and/or buy the hardware that they used in the workshop. Each of the participants was allowed to take the single analog circuit platform that they used in the workshop with them. These same participants indicated a desire to develop interactive demonstrations using this platform that they can show to their class or have the students perform experiments using the equipment that they currently have in the labs. The PI is also exploring ways to provide the hardware in a pre-assembled and less expensive platform.

The aspects of the workshop that participants found most useful were thinking about the difficulties students face from new perspectives and seeing how hands-on activities can help the students to overcome these difficulties. The participants of the multi-day workshop thought that there was sufficient time to learn about the analog circuit platform and the hands-on activities presented. Many of them wanted to go back to their host institutions and make changes to their signal processing courses. The participants also stated a significant benefit to simply sharing experiences from different schools and different engineering disciplines. A growing community of educators who are interested in CTSS education is developing from the relationships formed at these workshops. The PI is still in correspondence with many of these participants and is planning to develop an online presence to facilitate any future correspondence between current and future participants.

Because the PI changed the workshop in response to feedback after each offering, the parts of the workshop that the participants thought could be improved changed with each offering. At the end of the first multi-day workshop, the participants indicated that, based on the workshop announcement, they were expecting the whole workshop to be an advertisement for the analog circuit platform. By the end of the workshop, these participants were happy that it was only the announcement that was misleading. While they did enjoy using the hardware, they were also able to discover many new ideas from the workshop that were not necessarily related to the hardware. The announcement for the following year was changed to be more consistent with the true focus of the workshop, which is to gain a better understanding of the difficulties that students face and how best to help them. Subsequent offerings of the workshop did not get this same complaint.

The workshops offered at conferences were shorter, and the participants wanted more time to get acquainted with the hands-on activities. For these shorter workshop formats, it might be possible to get the participants started with the hands-on activities at the very beginning and gradually introduce learning theories when describing the primary focus of the hands-on activities. Even if the content of the 3-hour workshop is reorganized, the limited amount of time may still just be too short to give the participants an in-depth and thorough experience. The results of the student interview experiments will also help to present the learning theories in a much more concise and focused effort, which should take less time.

Conclusions

The PI and his collaborators have developed a workshop to provide participants with new perspectives and experiences to improve learning in CTSS courses. The participants benefitted significantly from 1) sharing their experiences with colleagues, 2) discussions that explored different perspectives of the students' learning difficulties, and 3) learning about and developing hands-on activities that can be easily adapted for their particular program. Because this material is a foundation for many engineering disciplines, the improvement of learning in these courses can have a significant impact on engineering education.

The workshop has been offered in different formats from a multi-day workshop to shorter conference mini-workshops. The multi-day workshop has been the most effective at helping participants make lasting changes to their courses. The conference workshops have introduced a broader range of participants to the problems that students face and opened the possibilities for future collaborations. Several of the participants of the multi-day workshops have already begun to develop active learning activities for the courses at their host institutions, which is an indication of the success of these workshops.

Acknowledgements

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