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In This Issue (p.36)
Distracted Driving: Effects of Conversation and Cell-Phone Use

Philip Weinsier, TIIJ Editor-in-Chief

Interesting! In trying to find images online of distracted drivers, easily 99% were of people texting or talking on a cell phone while driving. The only other images were of people eating or putting on makeup. The reason I started with "interesting" is because cell-phone use while driving only represents around 4-12% of crashes (depending on which study you want to quote; mine come from The Washington Post and the U.S. DoT National Highway Traffic Safety Administration, DOT HS 811 380). I am a parent with two kids just learning to drive; so of course we never miss an opportunity to tell them not to use their cell phones for any reason while driving. This concern is shared by everyone I know or have ever spoken to; we all just seem to believe intuitively that cell phones + driving = disaster. However, from all that I'm learning from studies on the subject, we should be directing our ire not at phones but at passengers in the car. The numbers from the same studies noted above, 16-57% of crashes, suggest that conversing with passengers in the car is much more dangerous and distracting. Ironically, I spend an exorbitant amount of time talking to my kids WHILE they are behind the wheel, describing scenarios and breaking down the driving styles of others...uggg!

"Believe it or not, using your phone isn't the most dangerous activity to do while driving. Chatting with your passengers is. It sounds weird, but [according to federal data], more than half of distracted driving accidents were caused by conversations with passengers." (Jacob Bogage, June 23, 2016, Washington Post).

Now, knowing more about the distractive effects of talking with passengers, I went looking for other organizations to see what they were espousing. Did you know that April is National Distracted Driving Awareness month? I did not. The National Safety Council tells us that 40,000 people were killed in motor vehicles crashes in 2018, due to "...cell phones to dashboard infotainment systems...and other in-vehicle technologies." No mention of conversations with passengers. The U.S. DoT's NHTSA also suggests that we turn off electronic devices and put them out of reach; but no mention of conversing with passengers.

The National Motor Vehicle Crash Causation Survey (NMVCCS) conducted by the NHTSA collected on-scene data on several crash factors, including driver inattention and in-vehicle and non-driving cognitive distraction sources. The analysis was based on 2,188,970 crashes involving 3,889,775 drivers. The effects of driver age (grouped as, under 16, 16 to 25, 26 to 64, and 65 and older) were also considered in the study. The percentage of drivers most distracted were in the 16-25 age group (22%). Unsurprisingly, the frequency of drivers being distracted decreases with age. No wonder insurance companies charge the highest rates for drivers 16 to 25 years of age! On the whole, the drivers in this study accounted for the following percentages of crashes: 0.2% (under 16), 29.6% (16-25), 59.1% (26-64), and 9.4% (65+). And no, gender does not seem to play a role here.

In the study highlighted in this issue (p.36), the authors collected data on 18 subjects, each of whom participated in two sessions, one involving individual driving and the other with distractive driving from passengers. The authors contend that driving is associated with various visual and auditory signals that are controlled by cognitive factors such as fatigue and distractions, which are common experiences associated with driving and are directly related to the mental workload of the driver. The authors measured the subjects' lateral variation characteristics (speed variability and maintenance of lane positioning) on a virtual 10-mile stretch of highway in Florida in order to understand their behavior during lane changes and secondary tasks. This was a pilot study performed to help identify the root cause of the high number of traffic accidents on highways.

The authors found that speed variability and mental workload was higher for younger drivers than elderly drivers for the same task. People with a higher mental load index were more distracted while driving. In this paper, the authors provide a general driving model showing the driving trends of young and elderly drivers; not surprising perhaps, the model quantifies the fact that younger drivers have a tendency to drive faster, which may add risk for highway driving in certain situations.

Editorial Review Board Members

UNMANNED AERIAL VEHICLE TRANSCEIVER MODULE SYSTEM DESIGN

Ben Zoghi, Texas A&M University

Abstract

In this paper, the author describes the design, implementation, and testing of a system using an unmanned aerial vehicle transceiver module (UAV-TRXM). The UAV-TRXM system is intended to provide a low-cost, and low-power solution enabling unmanned aerial vehicles to act as mobile relays to allow end users on the ground to communicate with each other over great distances and terrain. With the UAV-TRXM, end users will be able to receive peer-to-peer status messages from either the modules that are on the UAV or the end ground user. Additionally, the system will also allow end users to receive up-to-date information on nearby UAV details, such as ID, altitude, air speed, and squawk code. Each of the modules' parameters are configurable, depending on whether the node will be used in UAV or ground-station mode. In the event that a break in communication occurs, the end user will still be able to successfully reconnect and receive the peer-to-peer messages. The UAV-TRXM utilizes the XBee 900HP modules that allow for the meshing capability across UAV and the ground-station modules on the same network. Using the UAV-TRXM, FreeFlight Systems will be able to utilize messages functional with the field bus data link (FDL) protocol used by most UAV communication systems and relay messages through Digi International's XBee radios wirelessly over long-range distances to both UAVs and the ground-station user.

Introduction

FreeFlight Systems is an avionics company based in Irving, Texas, which supports manufacturing and development of professional-grade system solutions for private, commercial, and military aircraft. Automatic dependent surveillance-broadcast (ADS-B) is a technology that uses a GPS tracking system to periodically broadcast an aircraft's precise location (Gugliotta, 2009; Richards, O'Brien, & Miller, 2010; FAA, 2010; Commission, 2011; Davidson, 2013; Mozdzanowska et al., 2007; Deng et al., 2014; Airservices Australia, 2015). Ground stations and other aircraft can pick up this signal and use it to see all aircraft in an area more accurately than traditional radar systems. FreeFlight has been working with Texas A&M in developing the Pegasus I UAV. This unmanned aerial vehicle was created to help test autonomous flight controls, sensor systems, and video navigation.

Problem Statement

In current UAV systems, ground users rely on wireless transmissions to communicate with their aerial vehicles. If there is a break in the wireless network, due to the environment or outside the range at which a UAV is located, all communication is lost. The team is working with FreeFlight Systems to develop a communications system to bridge the gap between devices that would be unable to communicate otherwise. The unmanned aerial vehicle transceiver module will be used in the Pegasus I UAV to create a self-forming mesh network between other UAV platforms and ground devices with the same UAV-TRXM device. The XBee-PRO DigiMesh 900 embedded modules will allow for extended-range wireless connectivity and mesh network configuration across all device nodes present in the network. The design will also integrate with the ADS-B transceiver, RANGR 978, created by FreeFlight Systems to update control messages as well as obtain status and heartbeat messages. The system will transmit and receive peer-to-peer messages with specified source and destination addresses using the XBee radio module. With the use of the DigiMesh protocol, robust mesh networking capability will be established for all the device nodes within the network.

Conceptual Design

Figure 1 shows the conceptual block diagram of the UAV -TRXM system. The device marked as "prototype module" will be the UAV-TRXM, which is the focus of this paper. The transceiver module will interface with the ADS-B module, which will provide flight information. Both the prototype and ADS-B modules will be contained on one of the UAV systems provided and will not be designed. With each UAV containing both modules, this will allow for the setup of a DigiMesh-supported network provided by the prototype module. With a mesh network of UAVs, users on the ground will be able to send messages to other users with a designated address. Users on the ground will also be able to request UAV flight data and send control messages to make changes to this data.

Functional Design

The UAV-TRXM circuit board can be broken down into three major component sections. The high-level functional block diagram in Figure 2 displays the circuit modules and how they will be communicating with the microcontroller, as well as how the ADS-B module will interface with the board. The hardware design will explain how the CAN bus module will communicate between the microcontrollers, CAN bus controller, and CAN bus transceiver.

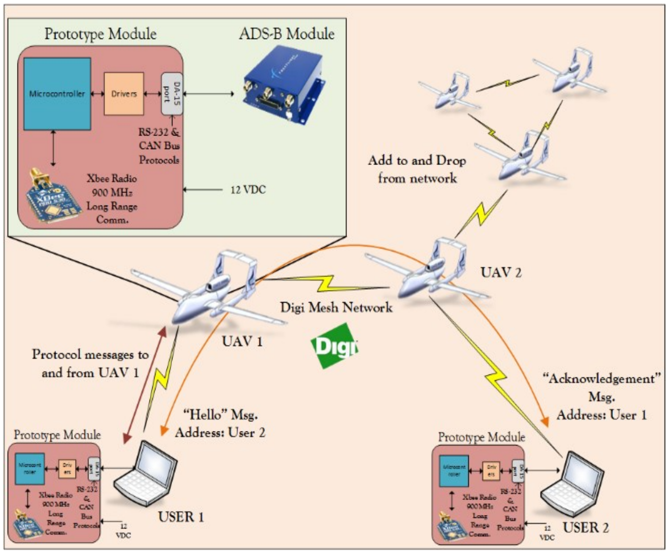

Figure 1. Conceptual block diagram.

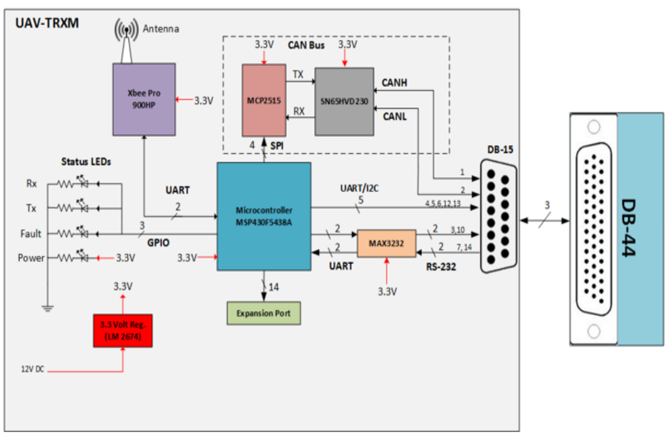

Figure 2. Functional block diagram.

Hardware Design

The hardware design for the UAV-TRXM is similar for both the UAV module and the ground user module. The system is initially powered with a DC voltage range of 8-40V, but for this case, the on-board UAV battery will use a 12V DC battery. Both sources are the input to a switching regulator that has configured circuitry to enable the regulator to output a steady fixed 3.3V output to power the UAV-TRXM board. Figure 3 shows the overall power circuit that was developed using Texas Instruments' Webench Power Design tool to produce 3.3V for the entire system. All of the major components that were selected can be powered with 3.3V, so no additional voltage regulation is needed to power the UAV-TRXM's onboard components. The LM2674 takes a range of 8V-40V and outputs a fixed constant output of 3.3V. This specific range was selected to accommodate the requirement by FreeFlight for commercial power sources that are within this selected range. Figure 4 shows the functional block diagram of the design. The microcontroller acts as the central processing unit for this device. It is the central node for all communication peripherals. All communication lines, including UART, RS-232, SPI, and CAN bus, are handled by the microcontroller, specifically the MSP430F5438A.

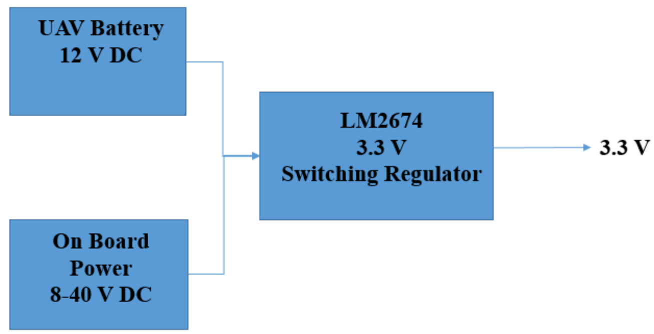

Figure 3. Power functional block diagram.

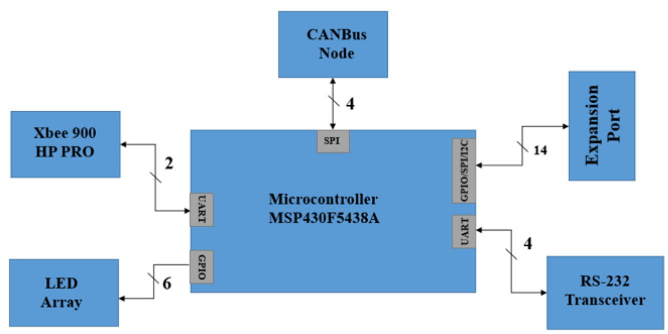

Figure 4. Microcontroller communication layout.

The sponsor, FreeFlight Systems, has requested the CAN bus standard be designed to provide support for future UAV autopilot applications using CAN bus for communication purposes. The CAN bus, as seen in Figure 5, has two main components, the CAN transceiver and the CAN controller. The CAN transceiver will receive the CAN high and CAN low signals via the DB-15 port and send these to the CAN controller over CAN transmit and receive lines. From there, the CAN controller will feed the signal to the microcontroller via SPI lines, with the microcontroller serving as master and the CAN controller as the slave.

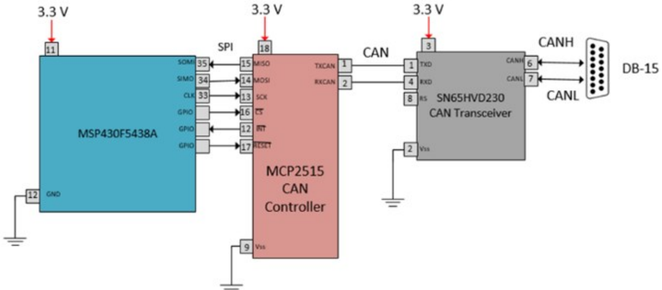

Figure 5. CAN bus functional block diagram.

RS-232 serial communications will be the main communication link by which the ADS-B device, RANGR 978, will transmit and receive data with the microcontroller. As shown in Figure 6, the RS-232 connections will be tied to a DB-15 port by which either the RANGR 978 or other UAV autopilots, such as the Piccolo II or Pixhawk, will be able to interface with the UAV-TRXM. The RS-232 transceiver will receive either the signals from DB-15 port and format them to be output to the microcontroller or signals from the microcontroller and format them to be output to the DB-15 port and the device that is connected to it. The RS-232 transceiver will communicate with the microcontroller via UART with transmit-in pins, and receive-out pins. Essentially, the MAX3232 transceiver in RS-232 serial converts the signal out to either 3.3V or 5V TTL serial that the microcontroller can interpret and use in order to acquire the actual ADS-B messages. In this case, since 3.3V is powering the MAX3232, it will output 3.3V TTL for the microcontroller to use.

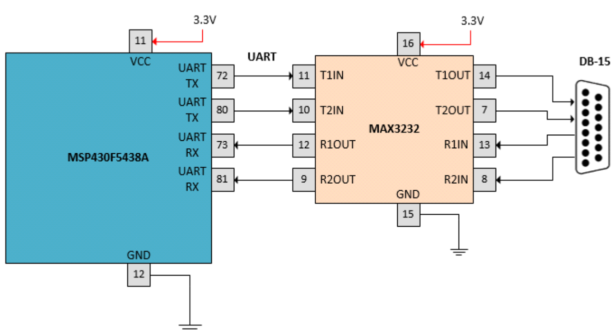

Figure 6. MAX3232 transceiver functional block diagram.

The XBee radio will be used primarily to set up the self-forming mesh network that will be able to support the main forms of communication between among UAVs or ground users. As illustrated in Figure 7, the XBee radio will be receiving and transmitting messages between users on the network, with the UAV acting as a relay. The XBee-Pro 900HP was the chosen module for the radio and communicates directly with the microcontroller via UART connections over transmit and receive pins on both devices. The XBee uses a half-wave dipole articulated antenna that operates in the 900MHz frequency spectrum. This antenna is a male RPSMA antenna, which then connects to a female RPSMA end that is already attached with the XBee radio modules themselves. This allows for faster user integrity and better quality of signal transmission.

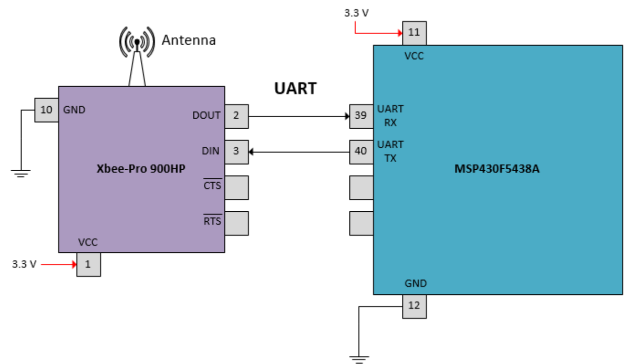

Figure 7. XBee 900 HP Pro functional block diagram.

As a requirement by FreeFlight Systems, all communication peripherals would be routed to a single DB-15 port, which would then be used to interface with the RANGR-978 ADS-B device, which will be provided by FreeFlight Systems for testing.

Enclosure

The enclosure was fabricated using a 3-D printer to quickly test the design. Figures 8 and 9 show the interior and exterior of the enclosure, respectively.

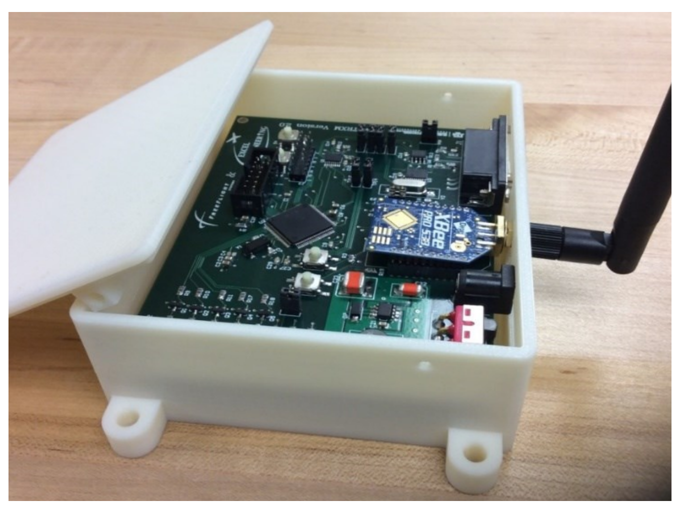

Figure 8. Enclosure interior.

Figure 9. Enclosure exterior.

Cost Analysis

The final cost analysis includes final components, manufacturing and assembly of PCB, enclosure, and mounting materials for both an individual system and 100 systems. Component costs were accumulated using current rates and shipping as ordered. Assembly costs for a single system did not incur any cost, due to the work being done in house. Enclosure costs were finalized using the rate of $5.00 per cubic inch for enclosure body and lid. Mounting materials included screw inserts needed for enclosure parts. For 100 systems, the costs for components, enclosure, and mounting materials were calculated with an increased multiplier for 100 systems calculation. For PCB board and assembly, Table 1 shows the discounted rate for a larger quantity of systems.

Table 1. Final system costs.

UAV-TRXM	1 System:	100 Systems:
Components	$465.26	$39,158.00
PCB Board	$198.00	$2,241.00 @ $7.47/Board
PCB Assembly	$0.00	$9,279 @ $30.93/Board
Enclosure	$127.50	$12,750
Mounting Materials	$37.41	$2,228
Total:	**$828.17**	**$65,656.16**

Software Design

The TRXM system will run based on the inputs from all of the different ports. The main loop will simply wait until a command or message is received on a port and then process and execute the necessary code based on the message received. The main communications ports that will be polled are the RS-232 putty port, an RS-232 RANGR port, a CAN bus port, and an XBee UART port. The putty port will accept commands from a user and, depending on the command, a certain process will occur (change squawk code, change callsign, change baud rate, etc.). The RANGR port will receive messages from the RANGR and store them until requested by a user; it can also send out commands to the RANGR. The CAN bus port is currently only going to be used for testing. If a CAN message is received, each character will be incremented by 1 and sent back out on the port to prove functionality. The XBee port is used for wirelessly transmitting and receiving messages. This will be used for connecting to another user or executing commands entered by the user.

Hierarchy Chart

Figure 10 shows the five major functions for checking whether or not there is a message that needs to be processed or sent. Beneath those major functions are the message checking and message processing functions.

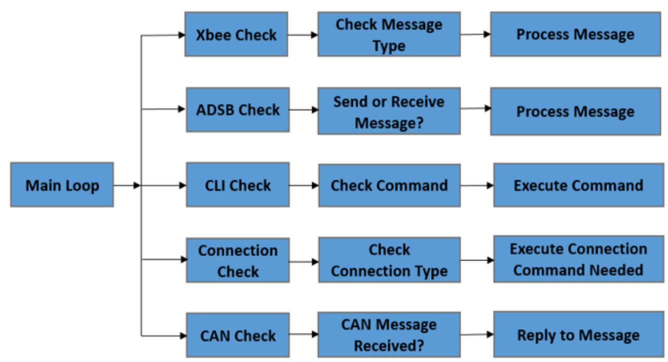

Figure 10. Hierarchy chart.

Flowcharts

The main loop shown in Figure 11 consists of five steps. It checks to see if an ADS-B message has been received from the RANGR or if a message is ready to be sent out to the RANGR. It checks to see if a full XBee message has been received, then checks for a command input from the command line and also if there is a wireless connection message to be handled. Finally, it checks to see if a CAN message has been received.

ADS-B Message Check

The ADS-B message check shown in Figure 12 performs three different checks: if a full message has been received, if the user has requested a message, or if the user is sending a message to the RANGR. If a message has been received, the CRC is checked and the message is processed. If a message has been requested by a user, the XBee message is composed and sent to the user wirelessly. If a message is pending to be sent into the RANGR, the message is composed and sent out.

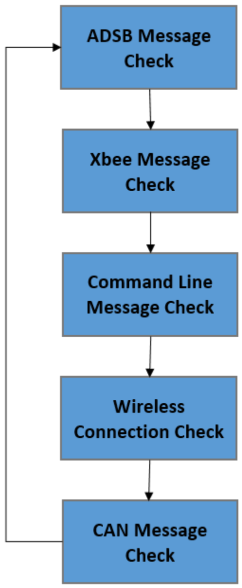

Figure 11. Main loop flowchart.

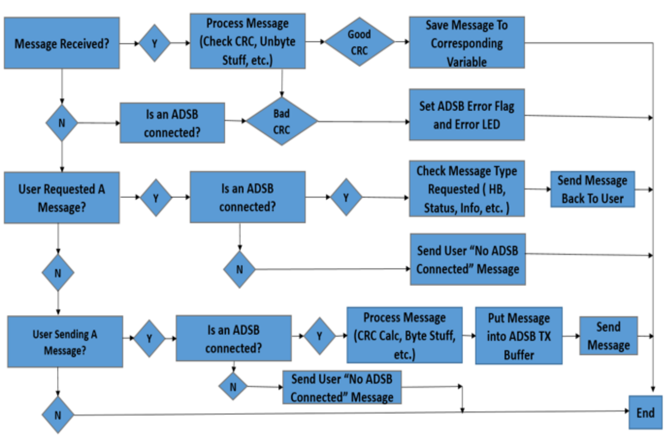

Figure 12. ADS-B message flowchart.

XBee Check

Figure 13 shows the XBee flowchart to see if a message has been received. If a full message is in the receive buffer, the message's CRC is checked. If the CRC is good, the message will be processed and the correct action will be taken according to the message type.

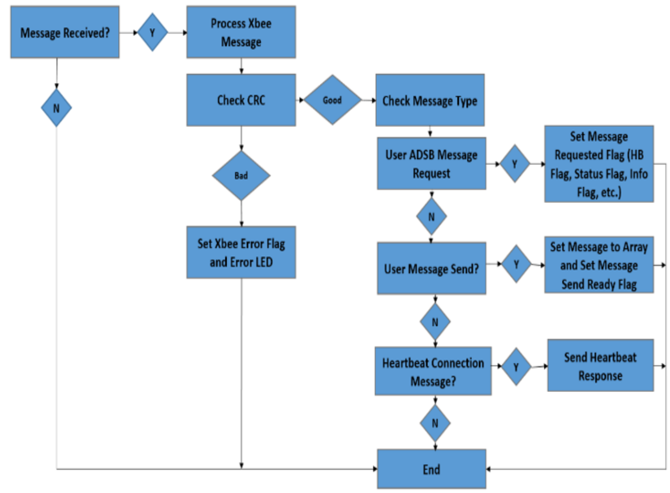

Figure 13. XBee check flowchart.

Command Line Check

Figure 14 shows the command line that has two different checks. It checks to see if the user has entered a command. If enter is pressed, the message is checked for validity and processed accordingly. The other check is to see if a message has been sent back from a connected device to be displayed in the console. If a message has been received it will be printed out.

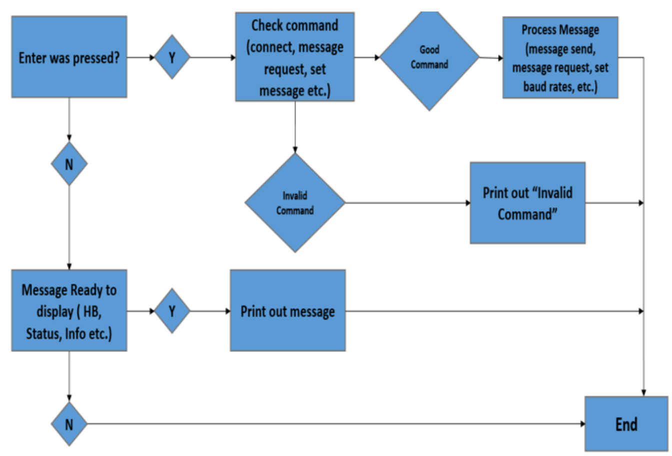

Figure 14. Command line flowchart.

Wireless Check

The wireless check is for making sure a connection is still available. Periodic heartbeat broadcast messages are sent out from any device that is on. If this message is being received by other devices then the user will know that it is available to connect to. Figure 15 shows other checks, such as heartbeat connect timers.

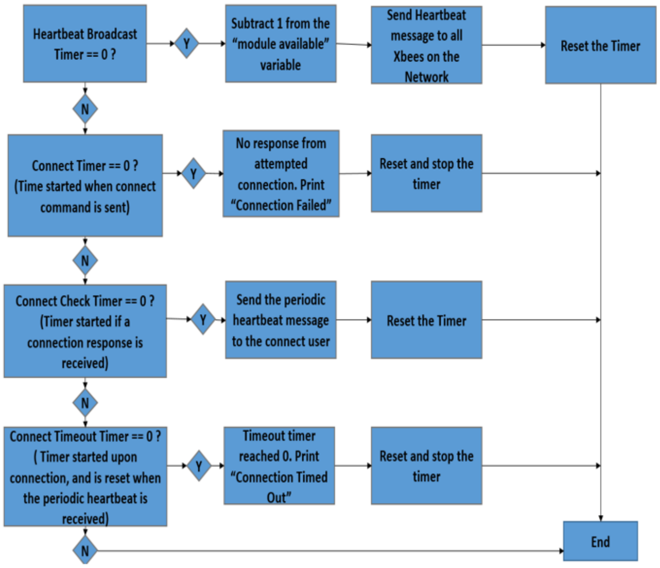

Figure 15. Wireless check flowchart.

Testing

In order to produce a successful final prototype for the unmanned aerial vehicle transceiver module, various tests were conducted to verify the functionality of the design. Table 2 shows communication and power testing for each module.

Table 2. Test matrix.

	Power Regulation	Wireless Communication	ADS-B Communication	Microcontroller Communications
DigiMesh Test		X		
Hops Test		X		
RS-232 Test			X	X
Wireless Range Test		X		
LED Array Test		X	X	X
CAN Bus Signal Test				X
3.3 Volt Test	X			
Full Functionality Test	X	X	X	X

Test Process/ Plan

Initial testing with the voltage regulator was conducted to verify that the module was receiving 3.3V to all major hardware components incorporated in the design, which included the CAN bus controller and transceiver, RS-232 transceiver, and XBee modules, which will be mounted through receptacle sockets on the board. Testing with the microcontroller was also conducted to verify that the XBee modules were able to receive and transmit through UART communication lines. In addition, the microcontroller was tested to assess states for receiving, transmitting, and fault to control the LEDs on the prototype board. Additional microcontroller testing was done to handle the CAN interrupt from the CAN controller to verify transmission signals to and from the microcontroller. The CAN bus functionality will be utilized for the prototype board for future integration with UAV autopilot applications. Wireless range testing was achieved with the XBee modules, first using USB-to-serial connections with two computers, each connecting to a module.

Test Results

With the DigiMesh and hops test shown in Figure 16, functionality of the DigiMesh protocol was verified with three hops and the XBee modules. Four XBees in varied ranges were used from 100 ft. to 300 ft., where XBee 4 cannot receive packets from XBee 1, due to interference and range. Upon setting up XBee 2, which can communicate with XBee 1 and XBee 3, the XBee 4 will be able to communicate with XBee 1. The connectivity route was tracked using the XCTU software with XBee 4 to verify the number of hops taken to reach XBee 1. The testing was done at the ground level from a few feet to a couple hundred feet.

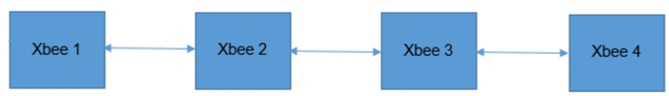

Figure 16. Hops test diagram.

The wireless range test was conducted using two XBee modules powered by serial connections to laptops taken out to test line-of-sight across fields. Using the XCTU software, the transmission between the modules running a range test sending packets continuously were ensured. In order to obtain a precise range value, Google Maps measurement tool was used to get connectivity up to four miles.

Analysis

The UAV-TRXM system was intended to provide a low-cost, low-power, solution enabling unmanned aerial vehicles to act as mobile relays to allow end users on the ground to communicate with each other over great distances and terrain. Through achieving the long-distance range of four miles of connectivity and mesh capabilities using the XBee Pro 900HP modules, the system was able to combat the problem of long-distance communication between ground-station users connected via a UAV mesh network. The UAV-TRXM successfully interfaced with the RANGR 978 ADS-B transceiver allowing users to make modifications to UAV properties and successfully reconnect where there is a break in the communication. All components of the board received power and met functionality to allow end users to receive peer-to-peer status messages and up-to-date information on nearby UAV details such as call sign, altitude, air speed, and squawk code. The UAV-TRXM used a green LED for messages that were transmitted and received properly, and a red LEF for when an error occurred in received messages. CAN messages can also be sent and received to the UAV-TRXM allowing for future use with UAV autopilots as desired by FreeFlight Systems. With the UAV-TRXM, FreeFlight will be able to utilize messages functional with the FDL protocol used by most UAV communication systems and relay messages wirelessly over long-range distances to both UAVs and the ground-station user.

Conclusions

With the fully functional UAV-TRXM prototype, the user should be enabled to wirelessly communicate between other UAV-TRXM modules over XBee radios as well as communicate between a PC or an ADS-B module over RS-232 cable on the DB-15 port. The modules will support the ability to send wireless messages to other modules as well as send ADS-B heartbeat, status, and other messages from a connected ADS-B wirelessly to other UAV-TRXM modules in range. For future development and continued work on the UAV-TRXM modules, software functionality to change the network ID of the XBee radio should be implemented, likely by setting a number of preset network IDs for the user to choose from. This would remove the need to change the network IDs manually on the XBee radios and allow the user to do so through the command line, thereby simplifying the process.

Acknowledgements

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Improving STEM Recruitment through a Theme-Based Summer Residential Camp Focused on Sea Level Rise

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Abstract

In this paper, the authors present an enrichment program that focuses on Science, Technology, Engineering, and Math (STEM) concepts. The program is named Building Leaders to Advance Science and Technology (BLAST) and is held each summer at three universities across the Commonwealth of Virginia: Old Dominion University, the University of Virginia, and the Virginia Polytechnic Institute. BLAST is sponsored in partnership among these three universities and the Virginia Space Grant Consortium (VSGC), and is funded by the General Assembly of Commonwealth of Virginia. Its main purpose is to expose high school students to topics related to different STEM fields through engaging hands-on activities so that more high school graduates will choose to pursue STEM careers. The program stems from the first session that was held at Old Dominion University in June of 2016 and was named ODU BLAST 2016. Two additional sessions followed in the summers of 2017 and 2018. Each year, eighty rising ninth- and tenth-grade students from across the state participated in this summer enrichment program. The program is residential and lasts three full days, Sunday to Wednesday, with an overarching theme focused on resilience to climate change and sea level rise. It includes faculty and students from various colleges and STEM fields. The main program has four rotating daily sessions, with additional sessions held on each of the three evenings that students spend on the ODU campus.

Introduction

Sitting between two tidal rivers, the threat of tidal storm flooding is nothing new to Old Dominion University (ODU, 2018). The university frequently has to consider recurring flooding: 1) when deciding whether to cancel classes because of the potential safety threat; 2) when considering where to build new buildings or raze old ones; or, 3) when having to make myriad other daily decisions by an institution that is open 360 days a year. Hampton Roads is located in the southeast region of the U.S., in southeast Virginia, on the cusp of the Chesapeake Bay, an area that represents one of the world's largest metro areas vulnerable to flooding from tidal storms related to climate change. Climate change and resilience has been identified as one of the main research focuses of Old Dominion University, supported by the university's administration and local government. Research efforts focus on various climate-change issues, such as its causes, but also how more resilient communities can be designed and improved to adequately resist future climate changes and sea-level increases (Marfield, 2017).

Due to this initiative, several new programs, centers, and courses have been implemented at the university (Tomovic & Jovanović, 2016). Building Leaders to Advance Science and Technology (BLAST) is an educational program funded by the General Assembly. Its main objective is to increase the number of high school students that will pick STEM as their future career. BLAST programs are administered and funded by the Virginia Space Grant Consortium (VSGC) in the Commonwealth of Virginia (2018). These programs are currently offered at three Virginian universities. The program structure is similar across all locations. VGGC advertises and accepts students based on academic performance, teacher recommendations, and gender; they strive for equal numbers of boys and girls. For this current study, over the course of two days and three nights, eighty students were divided into eight gender-specific groups of ten students that rotated through four, three-hour STEM workshop sessions and three specially designed STEM evening events.

The special events were organized to complement the workshop sessions. In these evening sessions, high school students were introduced to the deans of each participating college, who then introduced their respective colleges and research efforts related to climate change and sea level rise. Program offerings, as well as the individuals involved, are different among the locations. The ODU BLAST 2016 program had four main workshop sessions that were designed and implemented by the faculty from the College of Science and the College of Engineering and Technology. Evening events were designed and implemented by faculty from the College of Sciences, the College of Education, and the College of Arts and Letters.

Opening Night Session: Questioning Climate Change and Sea Level Rise

Faculty: C. Tomovic and V. Jovanović

ODU BLAST 2016 began at the Pretlow Planetarium. In this session, students were introduced to the administration team and participating faculty. Students were asked to reflect on the connections between STEM careers and tackling important challenges that are happening to the communities, due to climate change and sea level rise. High school students then watched a full-dome film, called *Our Living Climate* (2009), which addresses the historical and recent causes for slow, rapid, and sometimes violent changes in earth's climate. The film focuses on how the earth's atmosphere is a dynamic system that has changed many times throughout history. It explains how the atmosphere formed from some of the earliest organisms; how it was altered by super-volcanic eruptions, such as Toba; the methods for directly measuring the past composition of the atmosphere; and, atmospheric changes, due to the extensive use of fossil fuels. While the movie focuses on the history of the earth's atmosphere, and how the atmosphere changes slowly over hundreds of thousands of years or longer, it also discusses the rapid climate changes that are currently being caused by humans. Portions of the film discuss some of the current technology being developed to help fight climate change. After the film, a healthy discussion on whether the causes of climate change were natural or man-made was facilitated by faculty from the College of Science.

Using the planetarium for the ODU BLAST 2016 opening night allowed faculty to start the week's events in a unique, interactive environment. Full-dome planetarium movies are an immersive and inspiring atmosphere, and the goal was to start ODU BLAST with enthusiasm. After the film and the discussion, the director of the planetarium showed some of the current stars and planets visible in the night sky above Norfolk. The evening's events were concluded with everyone having the opportunity to look at Jupiter, Saturn, and Mars through several of ODU's telescopes. Over two days, students attended four hands-on intensive workshop sessions (Tomovic & Jovanović, 2016). These sessions were focused on science and engineering topics regarding solutions to mitigating the effects of climate change and sea level rise. A description of each workshop in greater detail follows.

Session 1: Our Home Planet and Its Place in the Cosmos

Faculty: C. Tomovic, V. Jovanović, B. Terzić, and J. Mason

Faculty, staff, and students from the Department of Physics designed a session with the main goal of showing and teaching the basic physics behind climate change, as well as taking a larger look at why humans should be protecting the planet.

Part 1: The Greenhouse Effect

The activity started by having high school students set up a simple model that demonstrated the greenhouse effect. For each session, the twenty high school students were divided into four groups of five students and given two, 20-oz. bottles filled about a third of the way with water. In one of the bottles, they added two tablets of Alka-Seltzer. When Alka-Seltzer is mixed into the water, it releases carbon dioxide (CO_2). The caps to both bottles had been drilled with holes into which a thermometer was fastened. The caps were then screwed onto the bottles. Both bottles were placed close to a desk lamp with a 75-watt light bulb. During the subsequent 30-40 minutes, in three minute intervals, the students recorded the temperature of the air in both bottles. At the conclusion of the experiment, each group plotted, in different colors, the temperature versus the time for each bottle. Each person was given colored pencils and a pre-made piece of graph paper with "temperature" on the y-axis and "time" on the x-axis. Having the high school students graph their data by hand, rather than using a software program such as Microsoft Excel, reinforced basic math skills that the students already knew. Figure 1 shows a typical graph of temperature versus time.

Once all of the groups had prepared their graphs, one of the graphs was projected onto the wall and a discussion was held on how the presence of CO_2 could be observed in the bottle with the Alka-Seltzer tablets. Typically, the air in the bottle with the extra CO_2 from the Alka-Seltzer tablets becomes several degrees warmer than the bottle without the Alka-Seltzer tablets. The CO_2 inside the bottle with the Alka -Seltzer tablets simulates and acts as a greenhouse gas, meaning that it traps more heat. This demonstration allowed the high school students to create and observe the greenhouse effect in a simple, inexpensive, and effective manner. One important point to note during this experiment, however, is that one group in five typically has difficulties, due to the simplicity of the equipment and issues such as the CO_2 escaping rather than remaining within the bottle. Another issue observed during this study was that the bubbling from the Alka-Seltzer deposited water droplets on the thermometer and cooled it.

Part 2: Waves

Taking temperature data for 40 minutes alone would not be very exciting for the students, so during the same time, the groups performed the greenhouse experiment, an experiment to learn about waves and wave motion. Since photons

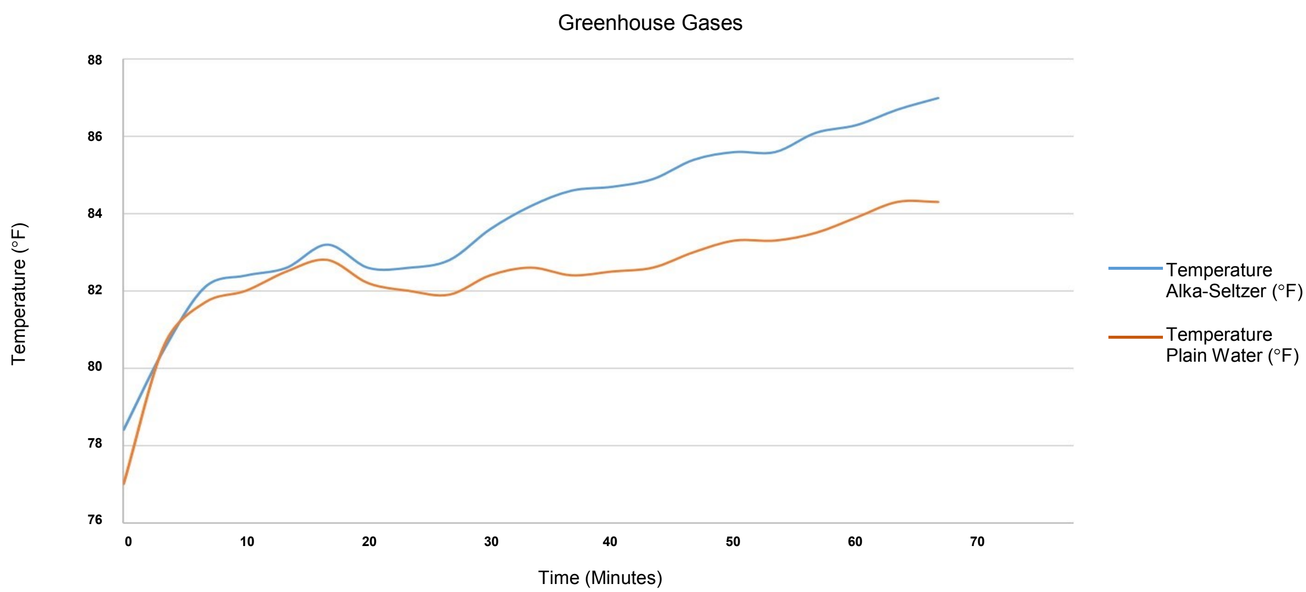

Figure 1. Graph of temperature versus time for greenhouse gases.

interact with our atmosphere and can act as waves, high school students were introduced to the concept of waves, wavelength, wave speed, and frequency. This session needed to be set up in advance so that the timing for the experiment fit into the given workshop time. The main setup had an elastic string stretched across the table and mounted over a pulley. A 400g weight was suspended on the string. A frequency generator was then attached to a speaker and the string was run through the top of the speaker. The speaker then vibrated the string at various frequencies and created standing waves, such as those shown in Figure 2.

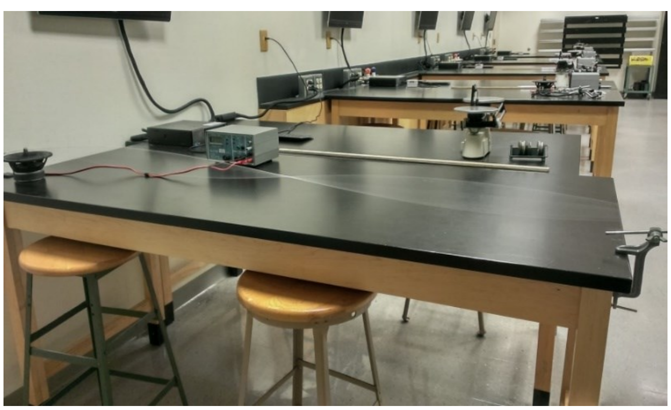

Figure 2. Experimental setup for the waves and wave motion.

The high school students were tasked with finding multiple harmonics of the standing waves, measuring their wavelengths, and calculating the velocity of the waves of the string. After all of the students had time to thoroughly investigate standing waves, they were given a 10-minute challenge to see who could produce the most harmonics on the string. This challenge was well received by all groups, as it was a chance to compete amongst themselves. The record set by one group was 23 full waves over just two meters of string. The only drawback to this challenge was that some of the groups wanted to continue to go back to this part of the workshop rather than move forward to the next experiment. This was typically only a problem with the boys' groups, and not observed with the girls' groups.

Part 3: Infrared Light

The third portion of the workshop allowed the groups to explore different forms of light, and demonstrated that there are forms of light that cannot be perceived by the human eye. By this point, students had been introduced to the nature of waves and light, and how they can interact with the atmosphere. Now, the goal was to show the high school students that light can come in different forms. In order to qualitatively show different forms of light, the high school students were given a solar panel that was connected to an oscilloscope. The students were then given three different kinds of flashlights: 1) a normal, visible-light flashlight; 2) an ultraviolet flashlight (UV); and, 3) an infrared flashlight (IR). The students were given 15-20 minutes to investigate the different types of light and how each influenced the power output of the solar panel. They were encouraged to shine the light on the solar panel repeatedly, flicker the power switch, put pieces of paper between the flashlight and the solar panel, and, given time, investigate the solar panel on their own. The normal flashlight produced expected rises in the solar panel's power output. The UV flashlight also produced rises in the power output of the solar panel. The students were somewhat interested in this flashlight, because it produced the novel "black light" glow. However, many of the students were interested in the IR flashlight, because the infrared light could not be seen, yet it produced the largest power output of the solar panel. The students were particularly interested in this flashlight when they found it had strobe capabilities and could produce both red and blue flashes. They then examined whether the IR and UV lights produced the same effect on the solar panel. The students liked this portion of the workshop, because the directions were less rigid, and they were given the equipment and free reign to explore how all of it interacted.

At the conclusion of this section on infrared light, an IR camera was connected to the projectors in the room so that everyone could see themselves in infrared light. The students enjoyed the activity with the infrared camera, how they measured light emitted by the heat of their bodies, and shared multiple images of it on various social networks. They could see themselves in the dark, as they continued to glow in the infrared, even if they could not easily see each other with their own eyes. The students were shown how their bodies give off infrared light and how that light could, or could not, pass through various everyday objects. For example, the infrared light was blocked by a piece of glass (normally transparent to visible light), but it passed through a trash bag (normally opaque to visible light). The students were then allowed to have fun and encouraged to get in front of the camera to see themselves and their friends in infrared light. Figure 3 shows some of the groups with the infrared camera.

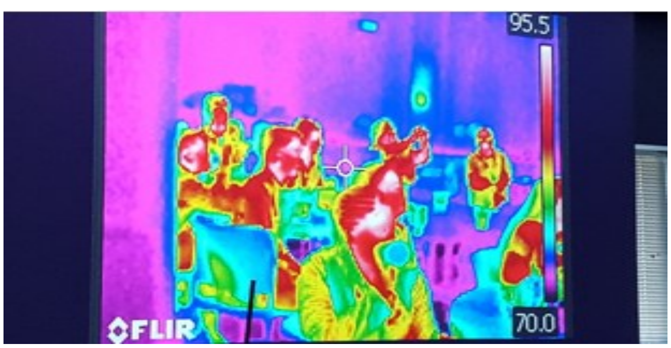

Figure 3. Infrared camera activity during Our Home Planet workshop.

Part 4: Life in the Universe

Finally, after covering topics like the greenhouse effect, waves, and different forms of light, the workshop took a step back to look at the bigger picture of Earth and its climate. Two, 5-minute videos were shown to the students. The first video (Dudnik, 2013) covered the Drake equation (Drake, 2015) and the statistical likelihood of life in the universe. The second video was about the Fermi paradox (2016) and possible reasons why humans have not seen or had contact with alien lifeforms. After the videos, a discussion was conducted with the students, who were asked about their thoughts as to why humans have not found any evidence of aliens or their existence. This discussion allowed the faculty to focus the students' thoughts towards the idea of taking care of, and protecting, the planet. The students arrived at the conclusion that if the only known life form in the universe exists on Earth, then they should be addressing climate change to protect our planet.

Session 2: Water, Water Everywhere and No Place to Go

Faculty: C. Tomovic, V. Jovanović, and M. Erten-Unal

The main objective of this session was to introduce students to civil and environmental engineering. Students learned about the green infrastructure and low-impact development technologies. The main purpose of these activities was to showcase one of the engineering solutions frequently used to alleviate flooding issues that occur as a result of storm waters and the negative effects of sea level rise. After being introduced to these natural and innovative storm-water management strategies, the students built and tested the performance of bioretention cells. Bioretention cells contain different media, including top soil, sand, pea gravel, mulch, and geotextile material to enhance infiltration and improve water quality. They explored how bioretention cells slow and treat storm-water runoff to alleviate flooding and improve water quality. The reactors to simulate and house the media for the bioretention cells were constructed from Plexiglas and had an inlet type of drain and gutters that fed them.

The students were provided the materials and media, including sod, sand, gravel, mulch, and topsoil to build their own bioretention cells. Students then brainstormed, as each group designed their own mix media configuration. They recorded the types of media and the ratios of each material added to the Plexiglas containers. Figure 4 shows the students using two parallel units, one of which they built as a bioretention cell that was designed to reduce flow volume and velocity and pretreat the applied water. The other unit did not have a bioretention cell but did have a Plexiglas surface that simulated an impermeable surface, much like pavement. Figure 4 also shows how the students observed the differences between the two containers when they applied equal flow rates to the two alternatives.

(a) Unit with a mixed-media bio retention system.

(b) Unit without a bio retention system.

Figure 4. Students observing the differences between the two containers when they applied equal flow rates to the two alternatives.

Both systems required a water connection and a water distributor made up of perforated pipes, which simulated a rain event. The students measured and compared the amount of runoff collected from parallel units with and without bioretention cells. Water quality parameters were also introduced, as were the concepts of engineering design through the redesign activity of improved bioretention cells. Their redesign included different configurations, all for the purpose of better design performance. They compared the mixed-media characteristics (the materials and their thickness) of the two bioretention cells and determined the travel time of the water within the media and shared their results between groups. Through this experiment, students developed an understanding of the concepts of infiltration rate, percolation, runoff, and storage capacity. They learned about properties of different media and, additionally, how they affected the movement of water within each media.

Session 3: Changing Oceans and Exploring Acidification and Albedo

Faculty: C. Tomovic, V. Jovanović, and V. Hill

A faculty member from the Department of Earth, Ocean, and Atmospheric Sciences designed this session. Albedo and acidification were chosen as the focus of this session, because these two phenomena produce prominent impacts on climate change in the ocean environment. The aim of this workshop was to introduce students to the principles of climate change in the ocean and to stimulate their interest by providing them with experiences in collecting data and subsequent analysis and synthesis. Both parts of this workshop session were structured to take students from simple to more complex experiments.

Part 1: Albedo

The main part of this ODU BLAST 2016 educational program was to focus on the reflective properties of materials and how these properties play a role in light absorption and heating. The Arctic was used as a case study. The session started with a 10-minute presentation that demonstrated the albedo effect (the fraction of light reflected back from an object), an important concept to convey when discussing the warming of the ocean and why the melting of sea ice and terrestrial snow cover impacts temperature. The students were encouraged to participate by asking them questions about their knowledge of changes in the Arctic and its impact on ecology and local residents. After the presentation, students were presented with two cans filled with water, one black and the other silver. Students used their new knowledge to predict which can would result in greater heating of the water inside. Figure 5 shows the experimental setup in which students observed and recorded the temperatures inside the two cans at an interval of two minutes, once the lamp was switched on.

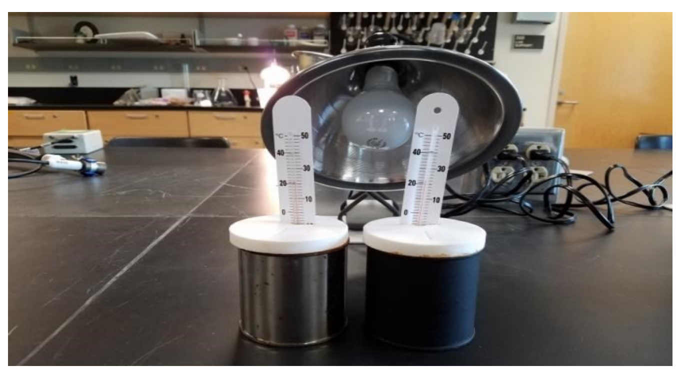

Figure 5. Experimental setup for the albedo session in which each can contained the same volume of water and was capped by a foam disk with a thermometer inserted into the water. The lamp was switched on after the time zero temperature was recorded.

After 20 minutes, the students plotted the temperature data from both cans. They were provided with a graph on which tick marks on the axis were already made. Students had to decide which variables should go on to each axis and then plotted the data. They then drew a best-fit line by eye. The rate of temperature increase for each can was calculated in order to determine in which can water heated more rapidly. The students were introduced to the main concepts of scientific research through hypothesis testing, and by presenting their results. The students then went outside, where they used a light sensor to measure the reflectance of various objects, including a white plaque that was used to stimulate sea ice, a pond surface, soil, grass, and other objects of their choosing. Students calculated the percent of incident light that was reflected and discovered that darker surfaces, such as soil and water, absorb more light than white objects; thus, simulating the high reflectivity of sea ice and snow. In the conclusion of the experiment, the students discussed how to apply this knowledge to the impacts of climate change in the Arctic and more locally.

Part 2: Acidification

In acidification, students learn that burning fossil fuels increases CO_2 in the atmosphere, which is absorbed by the ocean. Increasing CO_2 in the ocean causes the water to become more acidic, thereby impacting coral, bivalves, and certain phytoplankton. This session started with a 10-minute presentation explaining the process of ocean acidification and its impact on organisms. Students were asked to identify which kinds of animals are affected by acidification. The students then moved to testing substances for vulnerability to acidification. They were provided with samples of coral, carbonate sand, silicate sand, oyster shell, and granite. After writing down their predictions, students placed several drops of weak hydrochloric acid on the samples and recorded their observations through the experimental setup (see Figure 6).

The students were then asked if they knew why some substances fizzed under the acid, and then the explanation was shared with them (release of CO_2 gas). Students then used a Bromothymol blue (BTB) solution, a pH indicator, to demonstrate that CO_2 affects the pH of seawater. When blowing into the tubes of the solution, CO_2 in their breath caused a reduction in pH, which was shown by a change in the color of the BTB solution from blue to yellow. This pH indicator has a range of colors from green to yellow, which correspond to the changes. Figure 6 shows how, in the last experiment, students used CO_2 gas bubbled through seawater to observe and record changes in pH as CO_2 concentration increased through the setup. This session used the setup demonstrated by the University of Hawaii C-MORE outreach (2016).

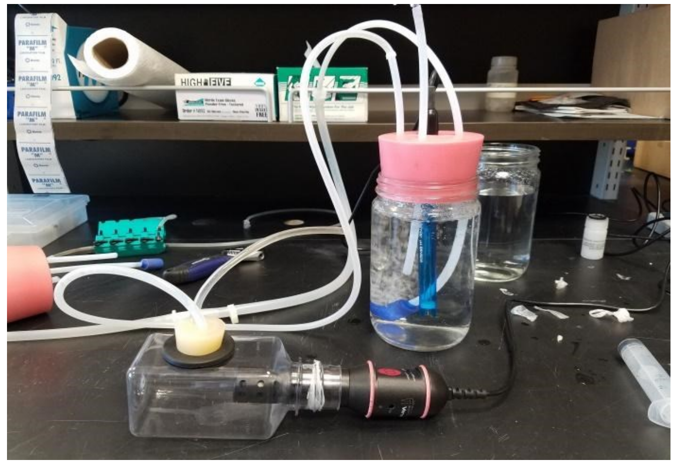

Figure 6. Experimental setup for the acidification session, including a pH probe inserted through a stopper into a glass jar into which CO_2 was allowed to flow, and a CO_2 sensor that measured CO_2 concentration in the air that was displaced from the glass jar.

Students recorded pH and CO_2 using sensors connected to a Vernier Labquest mini; they then plotted the data to look at how pH changes with CO_2 concentrations. They were asked to discuss what they had learned with respect to their understanding of ocean acidification. The aim of both sessions was to expose students to concepts that they may not have been introduced to before, to provide an opportunity for hands-on experimental experience, as well as provide an opportunity to analyze and plot data and calculate rates and percentages. By finishing each session with a discussion and synthesis portion, the aim was to have students solidify their new knowledge and see that even small laboratory experiments could provide them with an understanding of the larger ocean environment. By starting each session with simple demonstrations of concepts and then building on them with more complex experiments, an increasingly challenging environment was provided to the students with a wide range of abilities.

From the albedo part of the session, students learned that as ice and snow melt in the arctic, lower albedo surfaces were exposed, which resulted in more energy absorption and heating. Due to this phenomenon, the loss of snow and ice in the Arctic impacts climate change. In regards to acidification, points for discussion included an explanation of the changes in pH that were used in the experimental setup, and whether it will exceed what is expected in the ocean over the next 100 years. Also, it was used to demonstrate the relationship between CO_2 and pH, and to demonstrate that even small changes can have detrimental impacts on marine organisms; in particular, that even when just one species is affected, it can have cascading impacts on marine ecology, as other organisms rely on them for habitat and food.

Session 4: Satellites, Lasers, and Drones From Sci-Fi to Studying the Impacts of Climate Change and Sea Level Rise

Faculty: C. Tomovic, V. Jovanović, G. McLeod, and D. Smith

The main objective of this workshop was to introduce students to the technologies used for mapping the effects of climate change on sea level rise.

Part 1: Introduction to GIS
This session conveyed the critical importance of geospatial tools and technologies in recording, understanding, and communicating the impacts of sea level rise and storm surge flooding. Figure 7 shows how the high school students were introduced to a 4-step geographic information systems (GIS) problem-solving cycle, as a framework for how geospatial scientists tackle the problem of flooding.

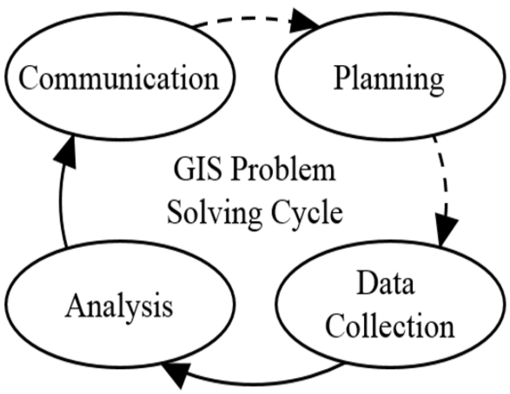

Figure 7. GIS problem-solving cycle.

Using this framework, students were tasked with answering the fundamental question, “How will flooding from sea level rise impact my community?” They conducted the following four primary tasks, as they worked towards developing their answer: Task # 1: Develop a plan fir collecting pictures of locations, buildings, and areas impacted by flooding; Task # 2: Collect simulated flood damage data using GPS, tablets, and digital cameras; Task # 3: Perform visual overlay, analysis, and synthesis of flood hazard data; and, Task # 4: Communicate their findings by creating an interactive “live” Esri Story Map website (2018). At the inception of this session, the students were divided into four, 5-person teams. A graduate student was assigned to guide each team through the process of geospatial discovery and the communication of their results. As the focus of their study, each team was assigned a specific flood-prone neighborhood area within the city of Norfolk (see Figure 8).

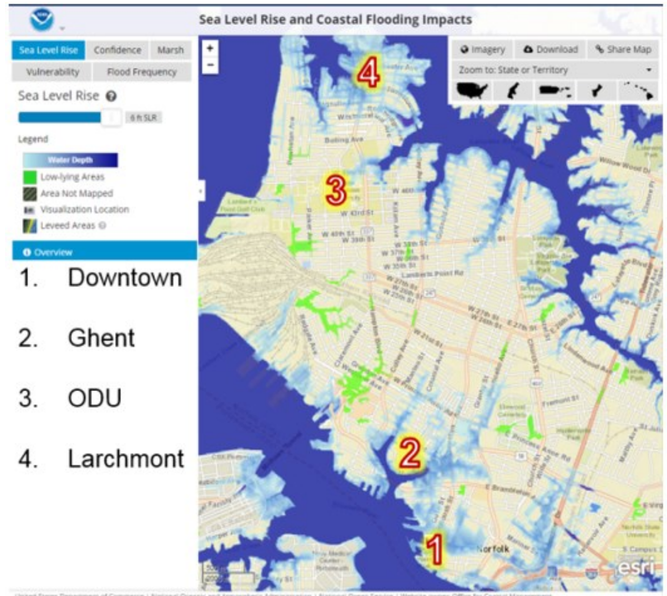

Figure 8. Flood-prone study areas in Norfolk: (1) Downtown, (2) Ghent, (3) ODU, (4) Larchmont.

Part 2: Data Collection
After a brief classroom introduction to the nature of geospatial data and technologies, students were taken outside to a natural area surrounding the ODU science pond. A demonstration was presented on how researchers use small unmanned aerial vehicles (sUAS) to collect data more quickly and efficiently than traditional means. Students were shown how UAS were capable of rapid acquisition of imagery, video, and other data that provide critical information for emergency responders and recovery operations after major storms and flooding events. After the UAS demonstration, the student teams split up to perform a hands-on exercise simulating the collection of flood damage data. Two different collection technologies, stand-alone GPS and web-connected tablets, were presented to the student teams. The main purpose of these activities was to discuss the positive and negative sides of using these different technologies. The other goal was to explain why it is sometimes necessary to have redundant data collected from various sources for scientific research. Students were instructed in the fundamentals of global positioning system (GPS) technology, GPS receiver operations, and conditions of optimal GPS data recording. The differences between capabilities of ruggedized GPS receivers, smartphones, and tablet devices were highlighted and explored. The student teams spent approximately 45 minutes on data collection, learning how to create and generate hazard damage assessment data that were output directly to a “live” website. These simulated data described the condition of a flood-impacted property with an attached photo of the actual damage. Upon completion of their data collection, the teams regrouped in a central loca-

tion to engage in a 10-minute discussion about their findings and their experiences with using multiple data collection platforms to collect redundant data.

Part 3: Synthesis and Communication

Students returned to the GIS computing laboratory to learn more about sea level rise and begin the data synthesis process. A 15-minute instructor-led presentation was delivered to introduce students to the regional and local-scale impacts of sea level rise in Hampton Roads and Norfolk. Students resumed work in their 5-person teams with two objectives: 1) to learn more about the impacts of flooding in their assigned areas, and 2) to effectively communicate this information to diverse high school students. Towards these goals, the teams engaged in web research and group discussions regarding the history and issues specific to their study areas. They were led in the discovery of a variety of flood mitigation and adaptation strategies, which were available for communities dealing with the challenges of persistent and recurrent flooding. Prior to the development of their communication piece, students were required to engage in organizational planning, and to divide up and execute the tasks necessary to complete their communication piece in a compressed time frame. Student teams worked together to use data collected in the field and information acquired online to build multi-page Story Map websites that explained the flooding conditions and impacts of their study areas. Esri Story Maps are web applications that let authors combine GIS data, maps, narrative text, images, and multimedia. Students were tasked with considering the best format and flow for factual and effective communications of their data synthesis and research. Near the end of the session, the student teams were required to present their Story Map to the entire class. They were asked to discuss the greatest risks posed by sea level rise to the specific group's study area; the most interesting and challenging part related to the creation of a story map and some potential solutions for migration of problems identified in the area of their group. Figure 9 shows the high school students' final Story Maps, which were made public on live web URLs so that the students could share them with their teachers, friends, and family upon completion of the ODU BLAST program.

This special evening event was designed by staff in Student Advising, by faculty in the Department of STEM Education, and faculty in the Department of Theatre and Communications. The purpose of Part 1 - STEM IT! was to provide students a foundation about college life, what it takes to be successful in STEM majors, and opportunities that they should take advantage of during their time in college. The purpose of Part 2 - STEM IT! was to allow students to experience the opportunities and challenges that scientists and engineers experience when working together as a team.

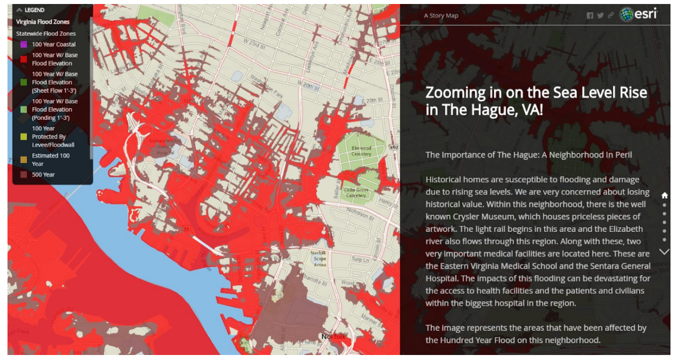

Figure 9. Front page of the Story Map created by BLAST students (Esri, 2018).

Special Evening Event 2: Preparing for College STEM Career—STEM IT!

Faculty: C. Tomovic and V. Jovanović

Part 1: STEM-related Advice and Panel

STEM IT! was introduced by the Dean of the College of Education. The high school students were given a brief presentation about how to be successful in college and in STEM majors, from the perspective of an academic advisor. In the remaining hour, a panel of two female students and two male students, representing biology, modeling and simulation, chemistry, and mathematics, presented their perspectives on what it was like to be a STEM major and afterwards invited high school students' questions. The outcomes the facilitator wanted to accomplish during the workshop included familiarizing the high school students with college life and the differences between high school and college expectations; understanding what it means to pursue a STEM major and how to take advantage of on-campus opportunities to expand their professional growth; seeing and hearing what it is like to major in a STEM field from other students who have been through the college experience; and, finally, introducing students to success strategies specific to STEM majors.

Part 2: Rockets to the Rescue!

Faculty: C. Tomovic and V. Jovanović

This activity led students through a scenario after a disaster. Students discussed issues related to the logistics needed by the emergency responders to the people affected by the flooding. In severe storms, for example, roads, bridges, ports, and runways may not be usable; thus, citizens become isolated. In this interactive session, students built and flew paper rockets, which were used to simulate an alternative means of transportation. Each team of five students was provided plain and colored paper, string, tape, a bottle stopper, and cotton balls (Dunbar, 2016). All teams were assigned the same goals, requirements, and constraints under which to work. In all cases, teams experienced design challenges when building and testing their rockets. After about 1½ hours, teams competed with each other to determine which team had built the rocket that could fly the furthest, and land in designated areas marked by hula-hoops. Propulsion for the rockets was built from tubes and coke bottles in which air was forced from the bottle, through the pipes, and into the rockets for liftoff. During the debriefing sessions, all of the students indicated that they had enjoyed the exercise, but that working together was challenging. Thus, the major purpose of this activity was demonstrated, in particular the challenges associated with team building and resolving conflict in order to achieve a purposeful goal.

Special Evening Event 3: Closing Night Adventures at the North Pole

Faculty: C. Tomovic, V. Jovanović, and V. Hill

This special evening event was conducted by one of ODU BLAST's workshop faculty, who is an Arctic scientist. In this closing event, the high school students were regaled by fun-filled stories about living and working in −40° Arctic conditions. Following a picture-packed PowerPoint presentation, the faculty member entertained a multitude of questions by students who, afterwards, could be heard saying that they wanted to become a science explorer. This special evening was capped off by a challenge between the girls and boys, which was designed to test which one of them could dress the quickest in sub-zero clothing and get into a specially designed sleeping bag before the other. At the end of this special event, each student was called to the front of the room and awarded their personalized ODU BLAST 2016 Certification of Completion. After leaving the auditorium, students were invited to "chill-lax" in the student union, where they played ping-pong, pool, chatted with each other, and topped the night off with some refreshments.

Demographics and Evaluation

Seventy-four students participated in the survey. Eight students were 13 years old, 43 students were 14 years old, and 24 students were 15 years old. Forty students were rising 9th graders, and 35 students were rising 10th graders. When asked about their tentative major in college, the students responded as indicated in Figure 10 (pre-ODU BLAST) and Figure 11 (post-ODU BLAST). While there was likely a selection bias as to who would want to attend a STEM-related event like ODU BLAST, even with this group it was clear, based on the results of the pre/post ODU BLAST 2016 surveys, in the short run, ODU BLAST was effective at changing the attitudes of many of the high school students. A number of students who voiced responses of "don't know" or "definitely not" to their level of interest in majoring in science, technology, engineering, or math increasing moved their responses to "maybe" or "probably" interested in majoring in science, technology, engineering, or math.

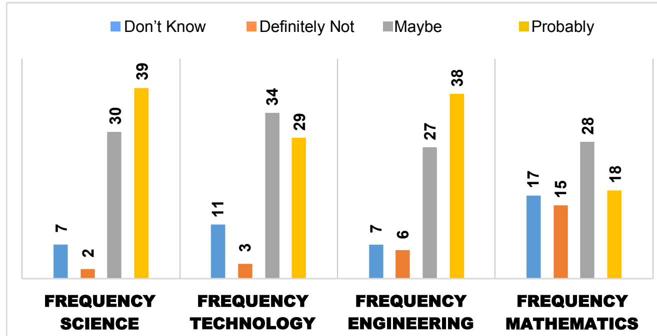

Figure 10. Frequency table for a question related to the students' choice of major (pre-activity).

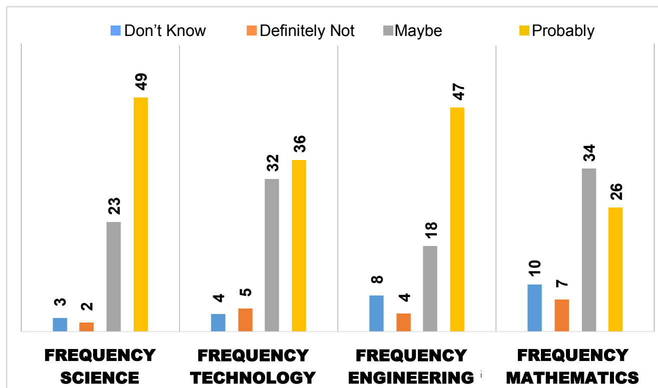

Figure 11. Frequency table for a question related to the students' choice of major (post activity).

The main focus of NASA's Space Grant program through the VSGC is to develop and deliver aerospace-related programs aimed at sparking interest in high-tech professional and educational fields across the Commonwealth of Virginia. The sessions described in this study were related to two of the main NASA missions, sea level change (NASA, 2018a) and Earth (NASA, 2018b). Students in this program were exposed to four different sessions related to STEM areas. The activities focused on interdisciplinary learning and not simply on specific majors offered in each of the colleges. Administration faculty who organized the program were from the Department of STEM Education and Professional Studies, the College of Education, and the Department of Engineering Technology, and the Batten College of

Engineering and Technology. The main workshop sessions in ODU BLAST 2016 were designed and delivered by faculty, staff, graduate, and undergraduate students from the College of Sciences and the Batten College of Engineering and Technology.

Conclusions

ODU BLAST 2016 was the first session that was delivered to high school students on the Old Dominion University campus. Since then, in June of each year, the university has held another session (in 2017 two were held). Various collaborations were formed among the participating faculty. The funding agency supported the overarching theme approach, designed as a residential educational program. Many undergraduate student researchers became graduate students in the following year. Faculty, staff, and students continuously wanted to participate in this community outreach and deliver the program to additional high school students interested in STEM careers. Feedback from students and the funding agency was very constructive, leading to various improvements in subsequent sessions.

Nomenclature

Alka-Seltzer	A pain reliever that contains three active ingredients: aspirin (acetylsalicylic acid) (ASA), sodium bicarbonate, and anhydrous citric acid.
BLAST	Building Leaders to Advance Science and Technology
BTB	Bromothymol blue is a pH indicator
CO_2	Carbon dioxide
Esri	Environmental Systems Research Institute
GIS	Geographic Information System
GPS	Global Positioning System
IR	Infrared
NASA	The National Aeronautics and Space Administration
ODU	Old Dominion University
pH	A logarithmic scale used to specify the acidity or basicity of an aqueous solution
STEM	Science Technology Engineering Mathematics
sUAS	Small Unmanned Aerial Vehicles
URL	Uniform Resource Identifier
UV	Ultraviolet
VSGC	Virginia Space Grant Consortium

Acknowledgements

Faculty and staff who participated in this program acknowledge the support from the Virginia Space Grant Consortium (VSGC). In addition, they acknowledge additional support from Old Dominion University and its Darden College of Education, College of Sciences, Batten College of Engineering and Technology, and all university administration who participated in the program.

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Creating Custom E-Learning Applications for Engineering Technology Using the Shareable-Content Object Resource Model

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Abstract

Online educational content provides students with extended access to course resources and augments traditional delivery methods. Online resources are now an integral part of all education and training. Providing interactive and relevant content is particularly challenging for engineering and technology programs, especially those that are laboratory intensive. Learning management systems have a wide selection of built-in assessment tools, but often lack effective methods for evaluating student lab work or testing student performance with complex, multi-step computational problems. Existing alternative methods that address these assessments typically require time-intensive manual grading. In this paper, the authors introduce the shareable-content object resource model (SCORM) standard and demonstrate its use in engineering education applications. The authors also provide a review of the SCORM model, examine the necessary technologies and skills required to produce custom content, and describe two examples of applications that automatically assess and grade student laboratory work. The modules provide students with direct feedback and reduce grading efforts by automatically populating grades in the learning management system.

Introduction

Computer-based educational and training resources evolved from stand-alone content contained on individual personal computers to complex learning management systems (LMSs) that can deliver multimedia content worldwide via the internet. These systems include student tracking, communication, grade management, and many forms of student assessment. LMSs include a variety of assessments and commonly include quizzes that support a number of question types. These quiz development tools include provisions for questions that involve simple calculations along with multiple-choice, true/false, matching, and fill-in-the-blank-style questions. Other assignments allow students to submit written work and calculations electronically using dropboxes. Although these tools provide great utility for most academic coursework development, they are not well suited for some types of engineering and engineering technology course assignments delivered in online or hybrid formats. Currently available quiz development tools do not allow computational questions that must be solved with multiple equations. For example, problems that require solutions of systems of equations, such as nodal and mesh circuit analysis, can only be created using static values as multiple-choice questions. This does not offer the test security found in testing-tool arithmetic questions that randomly assign problem parameters based on instructor-assigned ranges.

There are limited options for evaluating laboratory work using the embedded tools of most LMSs. Students can submit completed lab work by completing lab reports that include data and measurements to assignment dropboxes. Students can also upload short videos of experiment demonstrations that validate their knowledge of lab concepts and procedures. Both of these methods limit student interaction with faculty and do not provide timely feedback on collected data, measurements, or other results. This is very important for online and hybrid lab course delivery.

Dropbox electronic report submission of laboratory work requires extensive grading effort. Laboratory activities with many data tables that require validation and design experiments that allow students to select components from a range are examples of time-intensive grading assignments. Timely and meaningful feedback is import when conducting labs in a distance-learning format. Equipment now exists that gives students acceptable alternates to the suite of electronic instruments commonly found in campus electronics labs (Digilent, n.d.; National Instruments, n.d.). Students need a method of determining if the measurements and calculations produced during a lab procedure are correct within tolerances as they progress through the lab procedure.

Learners in online programs or in on-campus programs with limited laboratory supervision can benefit from an integrated presentation of lab procedures using multimedia and interactive data entry using web delivery. Faculty can benefit from the integration and storage of student interactions and automated grading. These features are typically not included in most LMSs, due to the specialized nature of laboratory work.

Standards and programming tools exist that give course developers the ability to produce custom course content modules that can link to any supported LMS. Using these standards, instructional designers can selectively deliver content based on individual student progress, log student responses for later analysis, and automate the grading process. One of these standards is the Shareable Content Object Resource Model (SCORM). This standard has three versions: SCORM 1.2, SCORM 2004 3rd edition, and SCORM 2004 4th edition (SCORM 2004 4th Edition Content Aggregation Model [CAM], 2009; SCORM 2004 4th Sequencing and Navigation [SN], 2009; SCORM 2004 4th Edition Run-Time Environment [RTE], 2009; SCORM Users Guide for Programmers, 2011; SCORM Users Guide for Instructional Designers, 2011). These standards, when included in an LMS that supports them, provide a platform for integrated custom content.

There are three levels of integration possible between a lab activity and an LMS. The lowest level of lab activity integration with the LMS is to simply provide a link pointing to a web page outside the system. This only uses the LMS as a protective shell that restricts others from accessing the content. No communication is possible between the LMS and the external e-learning content. The next level of integration has the LMS as the lab content host. At this level of integration, the LMS can identify users that login to the system and track time on the topic. SCORM-based content gives the highest level of integration. Learner access can be tracked and directed and, based on student performance, data can be saved between student sessions; automatic assessment and results archiving is also possible (Ruamo, Cano, Gamez, & Gomez, 2016).

Online laboratory activities served with a browser interface are known generically as “WebLabs” (Ruamo, Cano, Gamez & Gomez, 2016). A virtual lab (VL) simulates real systems using mathematical models of actual equipment. This is ideal for labs that require large, heavy and expensive equipment, such as electric machines. Commercial development of these applications gives those developing online content practical options (LabVolt, n.d.). Students using real equipment remotely perform remote labs (RL). This activity can be the remote control of campus-based equipment or students utilizing compact instrumentation systems outside of the campus setting to make measurements. Virtual/remote labs combine elements of both the VL and RL activities. In all cases, the learner interacts with the activity through a web interface (Bencomo, 2004; Gomes & Bogosyam, 2009; Chacon, Vargus, Farias, Sanchez & Dormido, 2015). In this paper, the authors focus on enhancing learner interactions in RL-type labs, where students construct and measure electrical quantities using solderless experimenter boards. Both online and on-campus courses currently use these applications in student labs. In this paper, the authors also provide an overview of the SCORM standard, discuss the software tools and techniques required to develop SCORM e-learning content, and present two e-learning lab modules that give students immediate feedback on their responses. Finally, the authors give a collection of best practices derived from these development experiences along with a discussion of future SCORM project work.

The SCORM Standard

The U.S. Department of Defense developed the SCORM standard as computer-based training and learning transitioned from PC-based content to online delivery through LMSs. The goal was to create a model that allowed the greatest interoperability between LMSs and reusability of content between courses. Many SCORM resources are available from the Advanced Distributed Learning (ADL) Initiative website (Advanced Distributed Learning, n.d.). These resources include documents, software templates, and development tools for producing SCORM-based content. The SCORM standard evolved through several versions: V1.2, 2004 3rd edition, and 2004 4th edition. The 2004 version supports extensive data communication between the LMS and e-learning content, and is used for the examples that will be presented here. Five sections comprise the 2004 SCORM standard. These are the Content Aggregation Model (CAM) (SCORM 2004 4th Edition Content Aggregation Model [CAM], 2009), Sequencing and Navigation (SN) (SCORM 2004 4th Sequencing and Navigation [SN], 2009) and the Run-Time Environment (RTE) documents (SCORM 2004 4th Edition Run-Time Environment [RTE], 2009). The standard documentation also includes a programmer’s guide and a guide for instructional designers that explain the standard’s details in both contexts (SCORM Users Guide for Programmers, 2011; SCORM Users Guide for Instructional Designers, 2011). These are all available from the ADL website.

The CAM document explains the SCORM structure. The goals of the standard were to produce e-learning content that is LMS platform-independent for all systems that fully implemented the standard and to create reusable stand-alone learning modules. A SCORM-compliant LMS is able to serve and communicate with e-leaning content developed with the standard. The standard defines the smallest unit of content as a Shareable Content Object (SCO) (SCORM 2004 4th Edition Content Aggregation Model [CAM], 2009; Ostyn, 2007). Web pages, developed using HTML, CSS, and Javascript code, realize most SCOs in practice. The SCO must include all other resources such as images, videos, and graphics to be strictly compliant. Content designers can collect and organize individual SCOs into groups to create e-leaning activities called content packages. The SN document describes how SCOs may interact and be released to a student. The interactions may involve learner performance on assessments, objective attainment rules, tracking, and attempt limits (SCORM 2004 4th Sequencing and Navigation [SN], 2009). Each content package must contain an XML file called a manifest that holds all sequencing and navigation information and defines the SCO resources used in the content package. A SCORM-compliant LMS reads the manifest to determine how, what, and when SCOs are delivered to the learner.

SCORM content differs from ordinary web pages developed for e-leaning in that they establish communication with the LMS using a SCORM application programming interface (API). This API consists of eight fundamental functions that can be divided into three groups: session communication functions, data transfer functions, and helper functions (Ruamo, Cano, Gamez & Gomez, 2016). The RTE standard defines supported data types and formats. The SCORM 2004 V4 version has 24 high-level data elements, while RTE has 69 elements. These data types provide learner performance tracking with typical interactions being question responses and SCO status information (pass/fail, completed or not, etc.). The RTE data types can pass scoring information to an LMS that will automatically populate its grade book. SCORM wrappers consist of augmented code that encapsulates the SCORM API and make code development easier.

The content designer must program all interactions with the LMS in the SCORM standard. The simplest SCO consists of a single web page with all associated formatting and media resources, and Javascript code that establishes communication with the LMS using the appropriate API functions. When the leaner dismisses the web page, Javascript code must exist that terminates the SCORM session (Ostyn, 2007). More complex interaction requires the use of the data -retrieval and storage functions of the SCORM API with associated interactions in the web page. Figure 1 shows the structure of a SCORM package. The SCORM package includes all SCOs and their resources. These resources are HTML code, CSS code, and Javascript code, along with any media files associated with web pages. Every SCORM package requires a manifest. The manifest defines the SCO resource structure and its delivery from the LMS. It also determines learner progress through the content, based on learner performance and other limitations such as number of attempts. E-learning authoring tools, such as Captivate (Adobe, n.d.), produce this file automatically. Developers also have open source tools available for small projects (RELOAD Project: Editor, n.d.) that create manifest files from individually developed SCOs. Compressing all SCO resources and the manifest into a zip file completes the package preparation process.

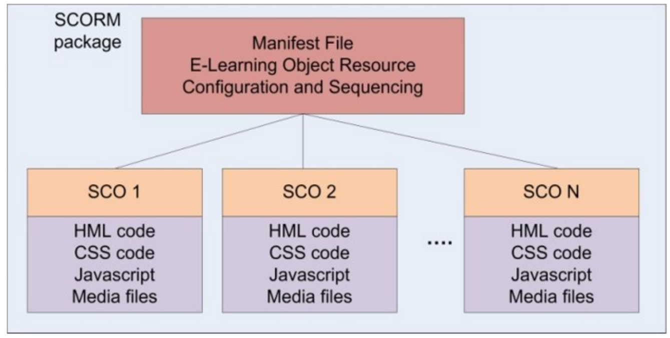


Figure 1. Typical SCORM package structure.

Figure 2 shows the LMS SCORM lesson interaction for a learner session. The manifest file contents interact with the LMS, giving the overall content structure and navigation through the SCORM content. Note that each LMS has a unique method for handling SCORM object navigation. If a package includes navigation, an LMS may superimpose its own scheme along with that developed by the designer. The standard provides a way to deactivate this with commands located in the manifest file, but not all LMS implementations may directly support this function.

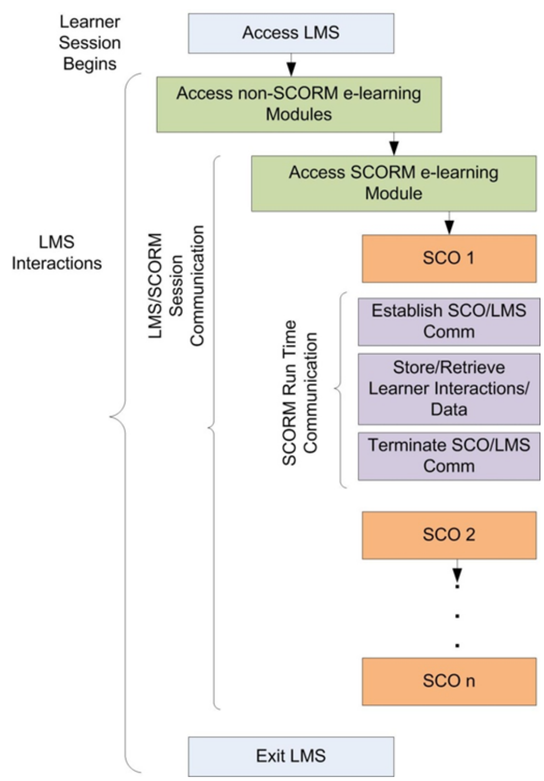


Figure 2. SCORM/LMS interactions with runtime environment.

Figure 2 shows that after learners access an SCO, a communication session with the LMS's implementation of the SCORM API takes place. Students interact with the SCO and data are stored or retrieved from the LMS as coded by the content developer. If the student leaves an SCO, the code of the SCO should save all required data to the LMS and terminate its SCORM communication session. The remaining SCOs are made accessible to a learner through sequencing and navigation commands located in the manifest. Figure 2 assumes that there is a sequential structure with a learner able to navigate forward and backward through the content.

Development Tools and Techniques

Creating a SCORM object requires instructional design and software programming skills at varying levels, depending on the development tools available. A SCORM object design project should begin with traditional instructional design methodologies. The SCORM standard allows designers to implement traditional design strategies and complex simulations in an LMS platform-independent way (SCORM Users Guide for Instructional Designers, 2011). It does not specify a particular teaching method or prescribe a content format. The developer is free to specify these design elements. The content developer should always start with a set of desired learning outcomes as they begin content development. The SCORM standard supports developer-defined learning objectives. Student performance on embedded assessments or demonstrated completion of content modules can trigger student achievement of defined learning objectives. Performance on assessments can trigger branching in the content that is not "hardwired" into the individual SCOs, but rather set in the sequencing instructions of the manifest.

The content designer should define these elements at the development stage of a SCORM project. The instructional designer should also identify what student interactions are stored in the LMS and what data the SCO must retrieve while open. This will determine the level of RTE interaction the package has with the LMS. Since SCOs are implemented practically using web pages, developers should consider including multimedia content that enhances the learning experience and engages learners. The HTML 5 standard provides simple methods for embedding this type of content into a web page. This includes tags for video and audio files supported by most modern browsers. An e-learning developer must also account for multiple platforms and browsers. Desktop computers, tablets, pads, and smartphones can all now provide learners with platforms for e-learning content. A developer should at least indicate to the student what the preferred and tested platform is for custom content.

SCORM Software Tools

The type of SCORM software tool a developer chooses depends of the level of control and customization they require in the SCOs of the e-leaning content. Many e-learning author tools exist that can produce SCORM packages using a "drag and drop" construction method or by converting existing presentations into e-learning content (iSpring, n.d.). The website cited here gives a listing of many authoring tools, as well as both commercial programs and freeware (eLearning Atlas, n.d.). These packages allow a designer to create standard assessments and interactions without extensive knowledge of HTML, CSS, or Javascript coding. A developer also needs a test bed for debugging RTE interactions with the LMS and checking the sequencing and navigation defined in the manifest. ADL hosts a software download that implements a SCORM 2004 server for checking interactions with an LMS offline. This can be installed on a computer for testing data transfer. They also provide software templates for developing commonly used packages (Advanced Distributed Learning GitHub-adlnet/SCORM-2004-4ed-SampleRTE, n.d.). A browser-based SCORM 2004 API simulator exists and is available on the web (JCA Solutions, n.d.). This software is called a SCORM wrapper, which should not be confused with software libraries produced by third-party developers that expand the function of the basic SCORM API.

The package logs API calls and responds back with appropriate messages, as though the SCO were operating on an LMS. This software is no longer supported by the developer and has limited documentation. It also does not operate correctly on certain modern browsers. A commercial website developed by Rustici Software has a free testing and development area, but is limited to packages that are 100 Mb or less (SCORM Cloud, n.d.). It provides a no-cost way to test SCORM content, RTE interactions, sequencing, and navigation. Although this site supports the SCORM standards, content may display differently in a developer's LMS, due to their system's treatment of SCORM objects. This is especially true of navigation controls that seem to be unique to each LMS implementation. Faculty developing SCORM objects with limited coding experience should use authoring tools that encapsulate as much of the low-level programming as possible. eXeLearning developed an open source browser-based tool that allows educators at all levels to author web content (ExeLearning, n.d.). This gives a no-cost entry into custom content development. The software can export content as a SCORM package that allows learner tracking or as a collection of web pages that have a uniform style and navigation. A developer using this package may still require knowledge of Javascript to produce the necessary RTE data storage and auto-grading functions.

Developers with a high level of web coding experience can use HTML/CSS/Javascript software-editing packages. Web page editors give the highest level of development control but require the most knowledge of the coding processes. This type of tool is useful when minor format changes are necessary or the e-learning content requires a strong interaction between the page elements and the user. In this paper, the authors provide examples for electrical engineering technology laboratories that require this level of learner/LMS interactions, which were created using an integrated editing and display package. Content developers using this tool set should create templates for common functions to speed content development and reduce code debugging time.

Software Structure of Shareable Content Objects (SCOs)

The most basic SCORM package consists of a single SCO that can communicate with the LMS. Figure 3 shows the relationships between the web page coding and the structure of an SCO, as defined in SCORM. HTML objects comprise the user interface of the SCO on a webpage. This can include data input tables for laboratory measurements, equations, figures, simulations, and demonstration videos. Any HTML-supported media can exist on the user interface page. The cascading style sheet (CSS) code determines the look and location of all HTML objects on the interface page. Javascript functions can modify both the page objects and the CSS code, based on learner interactions and input values. The SCORM API communicates with interface page objects and the LMS using Javascript functions that utilize API function calls.

Special functions developed using Javascript can reset page formatting and previous page interactions whenever a page reloads or when using form objects such as buttons or checkboxes. Javascript functions interacting with objects on a page allow a developer to create unique computational problems that load different parameters on each student view. A solution function can then compute the correct answer based on the current parameters and check student inputs against the computed value. The developer can assign scoring at this stage that will be communicated to the LMS by the API before the learner navigates away from the page.

SCORM Examples in EET Labs

Custom SCORM objects that communicate with an LMS give course developers tools for automating laboratory assessment, providing timely learner feedback, and integrating other media into laboratory procedures. This is especially important when developing content for hybrid and online course delivery. Students in online programs with lecture/lab courses need timely feedback, since they are without a lab instructor, who can determine if measurements are correct or are within expected tolerances. This section shows two examples of custom SCORM objects developed to give students online feedback and then automatically score their work. The e-leaning content design includes a collection of student interactions and storage in the LMS for archival and assessment purposes.

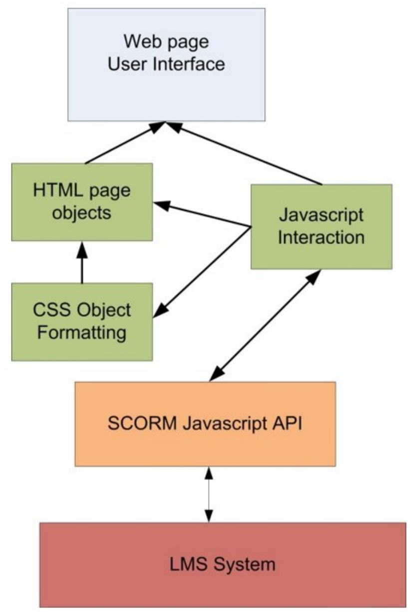


Figure 3. Coding relationship to SCO structure.

Learning the Resistor Color Code

Students in an introductory EET course learn the resistor color code by determining the value of 20 randomly selected 0.25w resistors. On campus, a lab instructor pulls a large number of resistors from a grab bag and randomly selects 20 for each student in the class. Online students select their own specimens from a grab bag in their parts kits. Each student must identify the nominal resistor value from the color code, compute the high and low resistor values based on the coded tolerance, and measure the component value with a DMM. Each student records all of these observations and measurements into a table and submits it for grading. In the past, this was done using a hard copy of a table that was then scanned to a pdf file and submitted to the LMS by both on-campus and online students. The lab instructor had to review each submission individually and assign points based on each student's readings. Figure 4 shows the SCO developed to automate this process and collect student interactions for later analysis.

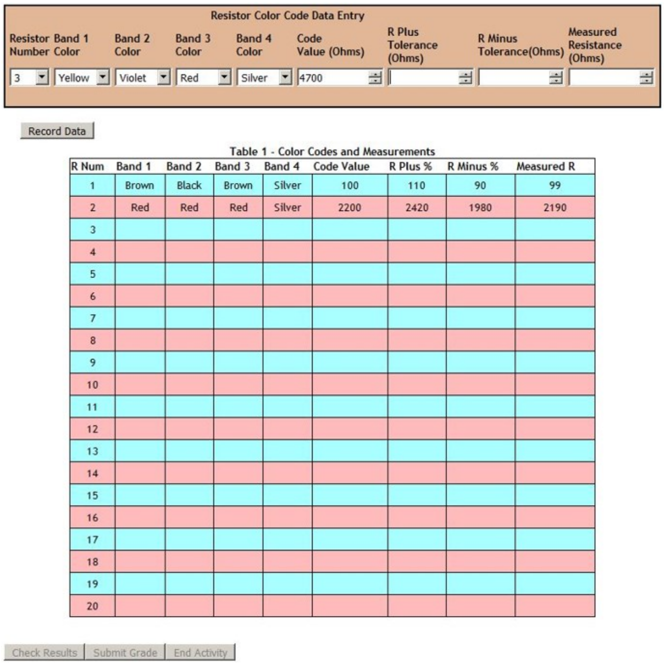


Figure 4. SCO for recording and assessing resistor color code proficiency.

The SCO consists of three sections, text of instructions on table completion, a data input area, and the table of recorded values. The instructions are not shown in this figure in order to improve clarity. Three buttons, located on the bottom right, become active as a student completes each stage of the assignment. Students use dropdown selector boxes to enter each color band on their resistors. This includes the tolerance band. The remaining input boxes hold the color code value, tolerance limits, and measured resistance values. The student clicks the Record Data button to populate the corresponding row of the table. Students may check their entries after completing the entire table. Incorrect entries are highlighted and a learner may make modifications. The entire table is assessed automatically when a user presses the Submit Grade button and the End Activity button closes the SCO. The SCO sends scores to the LMS course grade book along with the status of this page. This activity allows students three attempts. The SCO saves the score of the most current attempt. Table 1 shows the basic information an LMS reports for this SCO. This report lists student completion status, raw score as a fraction, number of student attempts, total time in the SCO, average time spent, and time/date of last learner access of the object.

The SCO automatically decodes the resister value based on learner input of the band colors after they record the data by clicking on the Record Data button. The SCO then computes the correct responses based on the given color bands. This includes determination of the coded resistor value and the possible range of measured values based on the tolerance band. The correct response column of the report tabulates these calculations for documentation of student input and to provide correct answers for later viewing. SCORM objects can implement extensive tracking of student interactions. The LMS records all student input for each table entry row. The first number in this entry indicates the row index and corresponds with the "R" index of an interaction ID. The entered color bands follow, indicating the resistor value and tolerance a student selected. The next three numerical values are the learner inputs for resistor code value, expected high and low values as determined by the tolerance value, and the measured resistor value. The SCO automatically credits the student one point for each correct entry of these values. The entire assignment is worth 80 points. The LMS also implements results and weighting columns as part of its SCORM standard, but are not used in this SCO. A final column indicates the time the student spends on each row interaction.

Table 2 shows a condensed report generated by the LMS hosting the resistor color code SCO. The unused columns described above are eliminated. In this LMS implementation, the system records the interactions of each learner attempt. The first column of the report is the interaction identifier. In most cases, this would be the number of a question on a quiz of a testing application. In this case, the identifier indicates the table row and the date that the student interacted with the table on each attempt. The first two entries in this column indicate that the student attempted the table twice on consecutive days.

Table 1. Resistor Color Code Basic Interaction Report

Progress	Status	Score	Attempts	Time spent	Average Time Spent	Last Accessed
Incomplete	x	--	3	0:09:43	0:03:14	9/23/2018 11:30 AM
Completed	✓	0.8	4	0:22:32	0:05:38	9/26/2018 11:04 PM
Completed	✓	1	3	0:21:27	0:07:09	9/19/2018 12:54 AM
Completed	✓	0.9875	1	0:06:09	0:06:09	8/22/2018 10:41 AM

Table 2. Resistor color code lab input SCO report of learner interactions.

Interaction ID	Type	Correct Response	Learner Response	Time Spent
R1_2018_09_27	Other	200, 210, 190	1. Red, Black, Brown, Gold, 200, 210, 190, 240	0:01:48
R1_2018_09_26	Other	200, 210, 190	1. Red, Black, Brown, Gold, 200, 10, 190, 240	0:05:37
R2_2018_09_27	Other	91000, 95550, 86450	2. White, Brown, Orange, Gold, 91000, 95550, 86450, 90100	0:03:28
R2_2018_09_26	Other	91000, 95550 ,86450	2. White, Brown, Orange, Gold, 91000, 4500, 4500, 90100	0:06:33
R3_2018_09_27	Other	91, 96, 86	3. White, Brown, Black, Gold, 91, 95.55, 86.45, 91.5	0:04:20
R3_2018_09_26	Other	91, 96, 86	3. White, Brown, Black, Gold, 91, 4.55, 4.55, 91.5	0:07:11
R4_2018_09_27	Other	5100000, 5355000, 4845000	4. Green, Brown, Green, Gold, 5100000, 5355000, 4845000, 5290000	0:05:31
R4_2018_09_26	Other	5100000, 5355000, 4845000	4. Green, Brown, Green, Gold, 5100000, 255000, 255000, 5290000	0:08:39
R5_2018_09_27	Other	15, 16, 14	5. Brown, Green, Black, Gold, 15, 15.75, 14.25, 18.4	0:06:18
R5_2018_09_26	Other	15, 16, 14	5. Brown, Green, Black, Gold, 15, 0.9, 0.9, 18.4	0:09:56

The LMS places attempt interactions in the report consecutively. The first two entries in the table are then the corresponding row 1 data for the first and second attempts. This is a function of the LMS implementation of SCORM interaction reporting and out of the developer's control. Adding a SCORM package into an LMS includes attaching a grade item to it, if the developer desires assessment. This SCO can automatically send the student score to the course grade book. Javascript functions that are part of the SCO structure establish the communication with the LMS and store assignment interactions and grades. The developer is responsible for writing the code that provides this functionality.

Recording and Verifying Circuit Measurements

The previous application shows how a custom SCO gives learners feedback and reduces grading effort when each assignment submission has unique solutions based on random component selections. This example will show how to provide students with interactive error checking for laboratory measurements as a student progresses through a circuit design and testing activity. Students in an analog controls course perform a lab activity that requires that they design a multistage operational amplifier (op amp) circuit that simulates the mathematical operations of averaging and subtraction. They must also construct a circuit that shifts voltage levels to a desired output span. The EET program offers both an on-campus and online section of this course. Students document their work, in part, by entering computed and measured values into three data tables. Each table verifies the operation of the circuit in a unique way. The tables are part of a larger custom e-learning project that converted the static laboratory procedure used in the on-campus labs to a multimedia online format. This online document included typical op amp circuits and their gain formulas, videos detailing the assembly of each circuit on a simulated breadboard, and a detailed example showing a scalar circuit design.

The developer used the authoring tool eXeLearning V2.1.3 for the general layout and structure of the e-learning content. Custom Javascript code embedded in the resulting web documents established communication and data storage for the interactive data tables. Using a function library developed for the color code SCO described previously reduced the development time for this project considerably. The instructional design goals of this project were to provide both on-campus and online students a unified location for accessing lab resources, to give immediate feedback to students as they computed values and entered measurements, to record student interactions, and to automatically populate a grade item in the LMS after a learner had completed their calculations and measurements on this activity. Figure 5 shows the opening page of this document with the topic menu partially expanded. Only the tables of this project are implemented as SCOs.

These are standalone topics in the LMS. The LMS hosting these SCOs displayed redundant navigation menus that would confuse students, so the other content is loaded as standard web pages. The final goal of this project will be to implement the entire procedure as a SCORM object with full tracking capabilities. Figures 6-8 and Table 3 show the interactive input tables that students use to enter and check their computations and measurements. The table entry will indicate if a computed or measured value is incorrect by highlighting the input field in red after the student leaves it.

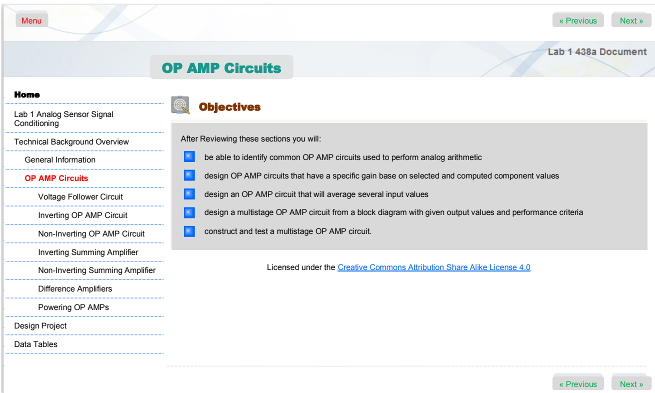


Figure 5. E-learning object for a controls lab showing format and content structure.

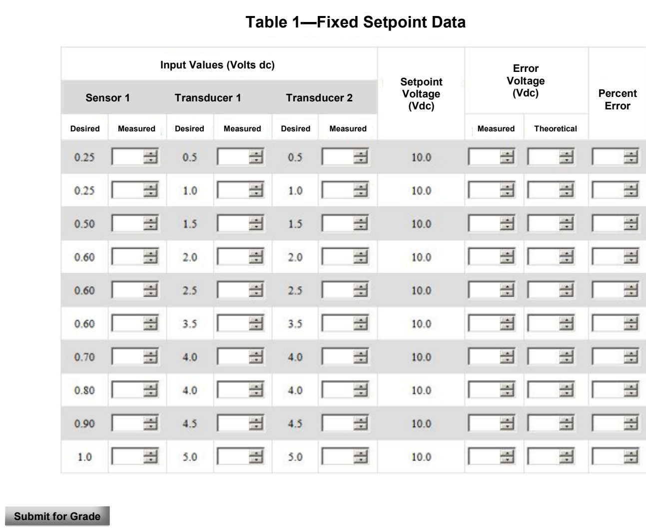


Table 1—Fixed Setpoint Data

Input Values (Volts dc)						Setpoint Voltage (Vdc)	Error Voltage (Vdc)		Percent Error
Sensor 1		Transducer 1		Transducer 2					
Desired	Measured	Desired	Measured	Desired	Measured		Measured	Theoretical	
0.25		0.5		0.5		10.0			
0.25		1.0		1.0		10.0			
0.50		1.5		1.5		10.0			
0.60		2.0		2.0		10.0			
0.60		2.5		2.5		10.0			
0.60		3.5		3.5		10.0			
0.70		4.0		4.0		10.0			
0.80		4.0		4.0		10.0			
0.90		4.5		4.5		10.0			
1.0		5.0		5.0		10.0			

Submit for Grade

Figure 6. SCO data table for op amp controls laboratory.

Figure 7 shows this behavior for a table entry. A Javascript function associated with each input field on the page compares the learner input to a predefined tolerance and changes the input field format accordingly. The error tolerance can be set globally or individually, based on previously computed or instructor-obtained lab values. Figure 8 shows a completed table that is ready to be submitted for a grade. Clicking on the button shown determines the grade for the data entry and stores the student interactions in the LMS. The course instructor can then review the values as necessary. This also provides a record of lab performance.

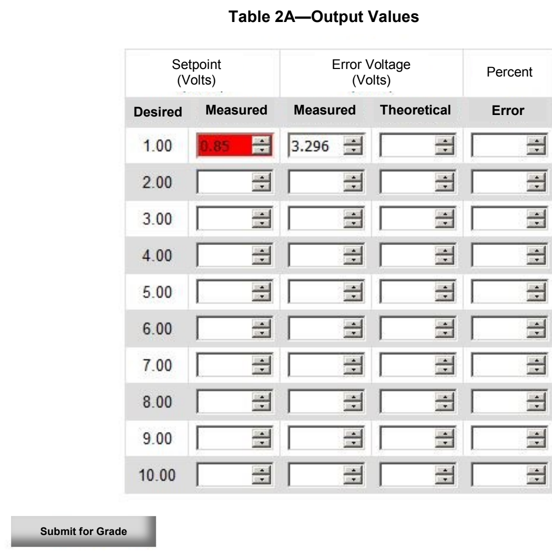
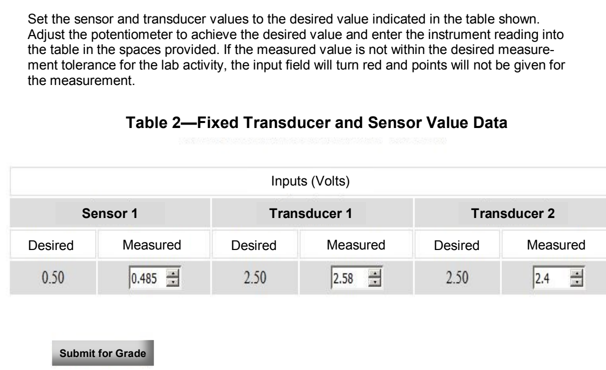


Table 2A—Output Values

Setpoint (Volts)		Error Voltage (Volts)		Percent
Desired	Measured	Measured	Theoretical	Error
1.00	0.85	3.296		
2.00				
3.00				
4.00				
5.00				
6.00				
7.00				
8.00				
9.00				
10.00				

Submit for Grade

Figure 7. Interactive data table with out-of-tolerance input.



Set the sensor and transducer values to the desired value indicated in the table shown. Adjust the potentiometer to achieve the desired value and enter the instrument reading into the table in the spaces provided. If the measured value is not within the desired measurement tolerance for the lab activity, the input field will turn red and points will not be given for the measurement.

Table 2—Fixed Transducer and Sensor Value Data

Inputs (Volts)					
Sensor 1		Transducer 1		Transducer 2	
Desired	Measured	Desired	Measured	Desired	Measured
0.50	0.485	2.50	2.58	2.50	2.4

Submit for Grade

Figure 8. Interactive data table with correct measured values.

Table 3. Recorded student interaction-row 1 fixed set-point data.

Input Values (Volts dc)			Error Voltage		% Error
Sensor 1	Transducer 1	Transducer 2	Measured	Theoretical	
0.25	0.52	0.488	9.20	9.29	0.96

Table 4 shows the SCORM interactions report provided by the hosting LMS for the Table 1 entries of Figure 6. This report records data similar to the color code activity. The first column identifies the table row and the latest date of the student interaction. The correct response field is not implemented in this application and is blank. The learner response consists of the student-entered values on each table row. These are the final values that the learner entered when the table was submitted for grading. The learner response in row 1 of the SCORM report shows that the student entered the following values in the corresponding table row. Interactions for these tables do not include time spent entering each row of data like the first example. As in the first example, Javascript functions and the SCORM interface save and store the student interactions and assessment score to the LMS. The content developer is responsible for determining what student interactions are recorded in the LMS.

Lessons Learned and Wisdom for Aspiring SCORM Developers

The SCORM standard provides e-learning developers with a well-documented framework for creating educational content that meets unique needs. Engineering lab interactions is one such area. Those wishing to experiment with this standard and the associated programming tools need to be aware of certain aspects of SCORM discovered during the development of the activities described above. As with any programming project, development tools are important to successful and timely project completion. A developer should select tools that encapsulate the coding details without limiting feature development. E-learning authoring tools mask most of HTML code development behind a simpler graphical design interface. The tools can also provide content structure and some SCORM scripting capabilities. Only hand code web pages, when authoring tools do not provide features or activities required for a learning object.

Javascript functions are what distinguish ordinary web pages from SCORM objects in an LMS. A developer must have tools for writing and debugging Javascript code to create a successful e-learning SCO. Best practices of web development suggest that a separate file holds all Javascript code and be linked into the file holding the web-page interface. A simple text editor is all one needs to get started producing Javascript functions. A web-development package usually has a more advanced code editor with features that speed production and reduce code syntax errors. Anyone interested in creating a SCORM e-learning object should use a code library called a SCORM wrapper. Several sites host these libraries (Pipwerks, n.d.). This code expands the functionality of the basic SCORM API with functions that facilitate LMS communications, error checking, and data storage. The developer must select the proper SCORM wrapper for the version used in the project: 1.2 or 2004. A Javascript debugger is absolutely necessary. Modern web browsers have this functionality built in. The debugger lets a developer step through code, view variable values, and check for logical errors in functions. The debugger will not allow a developer to check LMS interactions when calling SCORM API functions.

A SCORM LMS simulator gives developers a test bed for determining if the SCORM API calls operate correctly. The ADL website hosts downloadable software for checking SCOs. Use this or the other resources listed in the previous section for checking the SCORM package manifest, se-

Table 4. Control lab data table student interactions report.

Interaction ID	Type	Correct Response	Learner Response	Time Spent
Table_row_0_2018_09_20	Other		0.25 0.52 0.488 9.20 9.29 0.96	0:00:00
Table_row_1_2018_09_20	Other		0.24 1.02 0.98 8.62 8.63 0 .115	0:00:00
Table_row_2_2018_09_20	Other		0.523 1.5 1.461 6.70 6.81 0.016	0:00:00
Table_row_3_2018_09_20	Other		0.60 2.0 2.09 5.68 5.70 0.003	0:00:00
Table_row_4_2018_09_20	Other		0.61 2.45 2.585 5.01 5.1 0.017	0:00:00
Table_row_5_2018_09_20	Other		0.60 3,40 3.631 3.68 3.73 0.013	0:00:00
Table_row_6_2018_09_20	Other		0.731 4.02 4.162 2.65 2.63 -0.007	0:00:00
Table_row_7_2018_09_20	Other		0.82 4.05 4.174 2.09 2.19 0.045	0:00:00
Table_row_8_2018_09_20	Other		0.92 4.52 4.572 1.07 0.97 -0.10	0:00:00
Table_row_9_2018_09_20	Other		1.025 5.25 5.149 -0.15 0.16 -0.06	0:00:00

quencing, navigation, and data storage actions. Use development templates and code snippets as much as possible. The ADL site hosts downloadable files that include templates for some basic SCO structures. These provide examples for unique applications or can be used directly. Web searches will usually find Javascript solutions for page modifications necessary for creating interactive SCOs. These include embedding video/audio and changing the characteristics of web-page objects. Each LMS that claims SCORM compliance will have unique ways of implementing SCOs in practice. Developers cannot be assured that a SCORM package will display correctly in the LMS until it is installed. Some anomalies can include redundant navigation schemes, sequencing issues, invisible manifest files, and difficulties in linking and unlinking grade items associated with the SCORM objects. It is best to thoroughly research an LMS's SCORM implementation and quirks before attempting a custom project.

The examples presented in this paper are part of a three-year internally funded grant project to convert an existing EET program into a parallel online program complete with lab activities. Two associate professors and several graduate students worked on the overall conversion effort. The work reported in this paper was done primarily by a single associate professor with support from graduate assistants in both computer science and electrical engineering. This professor also received support from instructional designers/developers that serve the entire university community. This professor estimates that the resistor color code SCO took approximately 60 hours to complete and the interactive data tables 20 hours. This included a steep learning curve, as the faculty member was learning various programming tool and techniques while developing the applications. The faculty member was also teaching and acting as program coordinator while this work was in progress. This, to some readers, may seem too large a time investment, given the amount of content created.

The developers of these applications and of the entire online conversion process were given the time and resources to complete the project. The project team then worked to produce the highest quality content and improve instructor/student interactions, especially when lab support is not readily available, as with online labs. Both on-campus and online students use the same activities, so both aspects of the program benefit. Individuals not able to devote time to this type of work should consider these SCOs as examples of what is possible for the future of STEM education. Faculty can express their desires for better support materials and interactive learning tools to textbook publishers, who can then produce the content that will both reduce faculty work load on teaching support and give students a better learning experience.

Conclusions and Future Work

The SCORM standard gives e-learning developers a framework that can ensure interoperability and reusability, regardless of the LMS platform. It also provides a means for expanding and extending course content beyond the capabilities provided in an LMS platform. It enables developers to integrate many media types in order to produce more engaging course content. It also provides extensive tracking and scoring functionality through its run-time environment data structures. In this paper, the authors reported applications of this standard to laboratory activities in an EET program. Both online and on-campus versions of the EET program used these applications to give students timely feedback on lab calculations and measurements, and to automatically grade student entries. Reports generated by the hosting LMS show student interactions with the SCORM objects, thereby providing instructors with a record of student performance and completion status.

E-learning authoring software gives novice developers the best software tools for creating a SCORM package. More specialize applications may require extensive knowledge of HTML, CSS, and Javascript web development. A SCORM developer programming a very specialized application should also have a set of software tools that allow them to create and test the communication of student interactions between the SCOs and the LMS. These tools include online or offline LMS SCORM simulators and a Javascript debugger. The SCORM standard does not prescribe or dictate learning pedagogy; it only provides the technical framework for e-leaning objects. A content developer must have clear educational objects in mind when creating e-leaning content or consult with instructional designers who have experience in this type of development. This standard does provide a means for integrating all types of media into lessons and activities and has the necessary student-tracking and sequencing capabilities to record learner progress.

As the reported projects in this paper undergo further field testing, another project is under development. This future work will reproduce currently utilized on-campus tests using SCORM. These tests require multi-step mathematical calculations and are not currently supported by available quiz authoring tools. The test will incorporate random problem parameter selection, student feedback after test submission, and automatic grade item scoring. A future paper will report those results. After the SCOs in this project are fully field tested, the authors intend to examine the efficacy of these applications in student learning. The total number of students in the courses using these activities is too small at this time to draw any meaningful data. When enrollment increases, the authors will craft a study to see exactly how students are utilizing the SCOs. This will be especially important in tracking the success of online students.

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EFFECT OF CONVERSATION ON DRIVING: TOWARDS INCREASED MENTAL LOAD AND VIRTUAL LATERAL VEHICULAR VARIATION

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Abstract

Using virtual reality on a driving simulator is a very important technique for detecting driver behavior. It is a very common method for studying driver behavior, because it provides a safe research environment. This provides an opportunity to design a virtual world that can closely replicate the real world to help researchers collect data from subjects in order to understand their driving behavior in certain situations. Driving is associated with various visual and auditory signals that are controlled by cognitive factors. Fatigue and distractions are common experiences associated with driving and are directly related to the mental workload of a driver. In this study, the lateral variation characteristics (speed variability and maintenance of lane positioning) were measured on a virtual 10-mile stretch of Florida highway, Interstate 10 (Exits 199 to 209 A/B), to understand the drivers' behavior during lane changes and secondary tasks. This was a pilot study performed to help identify the root cause of the high number of traffic accidents on highways.

Data were collected from 18 healthy subjects. Each subject participated in two sessions, one involving individual driving and the other with distractive driving from passengers. Results imply that speed variability in the second session is much higher than during the first session, for the case of younger drivers. Also, lane maintenance was poor while driving with passengers. Mental workload was also estimated for each subject, using NASA TLX. Mental workload was higher for younger drivers than elderly drivers for the same task. People with a higher mental load index were more distracted while driving. In this paper, the authors include a general driving model that shows the driving trends of young and elderly drivers. The model quantifies the fact that younger drivers have a tendency to drive faster, which may add risk for highway driving in certain situations.

Introduction

Driving is an unavoidable task in most of the parts of the United States, and US highways are shared by drivers of different age groups, ranging from 16 to 75 years of age (Wang & Knipling, 2004). Florida, especially, has many elderly drivers. Records from the National Highway Traffic Safety Administration (NHTSA) indicate that 37,486 people were killed in 34,436 motor vehicle crashes in 2017, an average of 102 people each day (Bengler, Dietmayer, Farber, Maurer, Stiller, Winner, 2014). Florida has more accidents than any other state. Since the authors reside in Florida and have access to information that can examine these statistics (Ohn-Bar, Tawari, Martin, & Trivedi, 2015), it is reasonable that this work would focus on statistics that impact Florida drivers. But, the interesting point to note is that driving is a task which itself is associated with a lot of multitasking of our body parts. Table 1 lists the most important tasks while driving.

Table 1. Basic tasks associated with driving.

Physical Demands	Cognitive Demands
Vision	Attention
Hand, Leg Muscle Movements	Quick decision ability
Hearing	Quick response to stimuli

Florida is a large state, yet smaller than California, so population is not the reason for an excessive amount of accidents. Road design, driver age, and the rate at which people drive can be contributing factors to high crash percentages. Among total crashes, according to the NHTSA, 40% are due to improper lane maintenance, and almost 95% of those are fatal. Figure 1 shows factors for accidents (Shantinath, Ramdas, Hanumant, & Sudhakar, 2015). Accidents occur during lane changes, due either to speeding or slow driving. Speed variation can be due to driver distraction, an aspect of driving that needs further exploration in order to achieve a solution for safer lane changes. Further review of the literature reveals a very high number of accidents at the I-10 region in Tallahassee. The ramps of the exit are 360º circular for this region. A rapid decrease in speed from 75 mph to 36 mph in a circular path can be difficult for many drivers, especially the elderly. It might be a primary cause of crashes (Mogelmose, Trivedi, & Moeslund, 2012). It is clearly evident that most of the accidents in Florida are due to improper lane maintenance. Hence, this factor needs some serious attention in order to check the crash rate on state highways (Wilson-Jones, Tribe, & Appleyard, 1998).

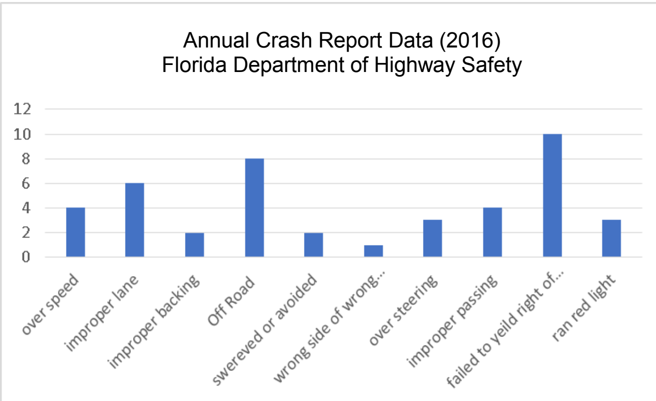

Figure 1. Statistics showing factors responsible for road accidents.

It is important to know which age group is facing the highest number of crashes in order to study the behavioral differences in the drivers' age groups. Male and female drivers usually have different response and reaction times to stimuli. The Florida Department of Highway Safety and Motor Vehicles also published a study that shows the age groups that are highly exposed to accidents on highways (Trivedi, Gandhi, & McCall, 2007). As Figure 2 indicates, young and elderly drivers have more accidents than other age groups.

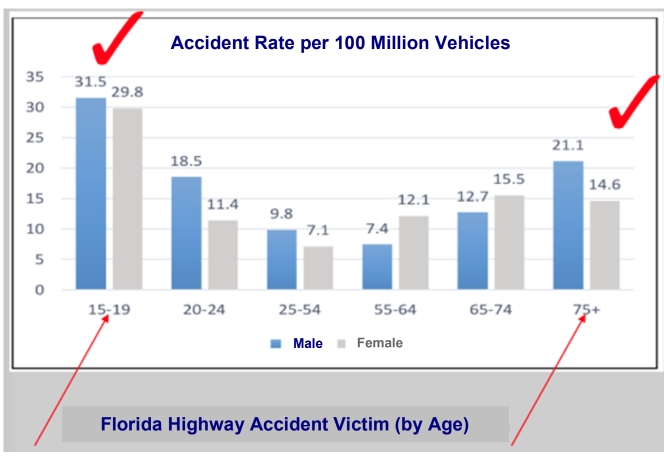

Figure 2. Florida highway accident statistics.

The 15-19 age group usually has good eyesight, whereas drivers aged 75 and up may have deteriorating eyesight, but both are prone to accidents. This implies that eyesight is not the reason for accidents, and distraction or reaction time might be a possible reason for crashes in these age groups (Cheng & Trivedi, 2010). Driving is a task that demands mental attention. A few seconds of distraction might cause a fatal crash. Using a cell phone has been the main focus of recent research as the most distracting task in fatalities (Peng, 2002), but a 2017 NHSTA accident report notes other factors that seem to cause more accidents (Hess & Modjtahedzadeh, 1990). Figure 3 shows the various factors that can distract a driver on the road, and the most dangerous distractive task is interacting with passengers (Yakub & Mori, 2015). Talking to other passengers about topics that elicit the driver's emotion to a great extent (like anger or depression) can distract the driver and, as a result, cause fatal highway accidents (Pentland & Liu, 1999). These kinds of emotions might add to the mental load of the driver (Hart & Staveland, 1988).

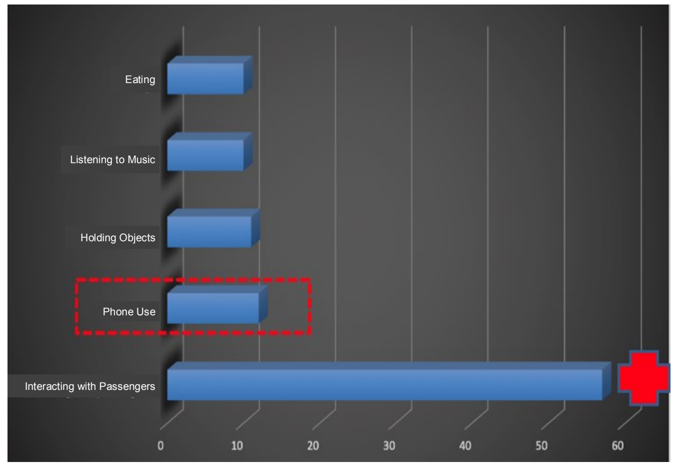

Figure 3. Different secondary tasks causing driver distraction.

To investigate and validate this problem, this study was conducted with two age groups of drivers, 20-35 years and 55-60 years, driving in two scenarios: alone in the car and with two to three passengers discussing emotional topics. Driving data can be obtained in two forms, real-time driving or data from a driving simulator. Most researchers prefer to collect the initial data on a simulator, as it provides an inherently safe atmosphere for research, and it is easier to control experimental conditions on a simulator (Wilson-Jones, Tribe, & Appleyard, 1998). But both are usually linked to a computer for online data processing and storage of data for further analysis. On the other hand, the driving simulator environment is virtual, which might affect driving behavior (Hart, 2009). Hence, there is an issue of reliability when using a simulator. After collecting data from a simulator, researchers typically validate the results with real-time data to modify the driving scenario for accuracy and precision (Cao, Chintamani, Pandya, & Ellis, 2009).

In this current study, the authors used a driving simulator to collect data. The study involved lane maintenance and speed variance in these two scenarios, monitoring from the simulator with some statistical analysis to analyze the general driving behavior on a highway. Also, the mental load of the drivers was analyzed with NASA TLX after the first session to understand the mental work demand on a driving simulator (Salvucci & Liu, 2012). Each participant completed a questionnaire for data collection and to store driving history. All drivers were trained on the simulator before the actual data collection, and they signed a waiver before their participation in this research.

System Design

System design in this experiment involved scenario design on the driving simulator. The scenario was designed based on local intersections in Tallahassee, Florida, along I-10 (Exit 209A/B) that were known to have a higher-than-average rate of roadway incidents (Salvucci, 2004). The environment was designed to replicate the I-10 209A/B exit as closely as possible. The scripting language for controlling the traffic in the virtual world was TCL, a scripting language used in Hyperdrive (Kuge, Yamamura, Shimoyama, & Liu, 2009). The scenario started from merging onto the highway from an exit with flowing traffic and then driving on a three-lane highway with various curves. There were two exits designed with ramps mimicking the 209A/B. This exit was a one-lane, circular road. Figure 4 shows the simulated 3D design.

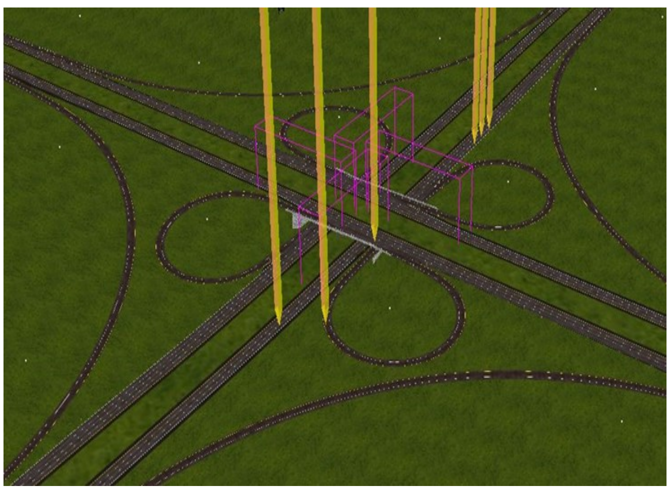

Figure 4. 3D Simulated design of Exits 2019A/B.

The scenario was programmed to include location triggers (yellow lines in Figure 4). Hyperdrive supports TCL scripting, which is a high-level machine language; the simulated cars, then, were introduced into the scenario by writing code in TCL (Salvucci, 2006). Figure 5 shows an example of this scripting. Thirty-two vehicles of different makes and models were used as well as commercial vehicles such as buses and 18-wheeler trucks. When the participant's car approached the location trigger to merge onto the highway, all 32 cars would be generated one after another to form the highway traffic. Eighteen subjects participated in this study, and everyone completed the entire task successfully. All subjects who participated in this study had been driving for at least two years in the U.S. None of the participants had a history of any major or minor accidents within the last two years. Before the experiment started, participants completed a questionnaire to assess their driving history and typical driving behavior. The survey had 23 questions, ranging from specific demographics to decision-making questions such as the ones listed here (Salvucci, Boer, & Liu, 2001):

- How do you usually merge from a ramp onto the freeway?
- Do you usually face any difficulty/challenge when you are about to merge onto a freeway?
- Do you usually maintain the same lane after you merge onto the freeway, or do you change lanes?
- Do you usually face any challenge/difficulty when you change lanes on a highway?
- Do you prefer getting messages by mobile or through a signal at the merge or lane change to have a safer merge/change without any delay?

```
set count 0
#Set timers for vehicles
#Vehicle 1(Land Cruiser Black) created when ahead vehicle is 30mph
TimerProCreate veh1vis{
    set count [expr $count + 1]
    EntityCreate Vehicle1 "Land Cruiser Black" 10952.8 11275.5 90
    EntityJoinRoadway Vehicle1
    EntitySetRoadwayVelocity Vehicle1Fixed 60MPH
    SimSetRoadwayVelocity Vehicle 1
}
TimerProcAdd Veh1vis 3
#Vehicle 2(Land Cruiser Black) created when ahead vehicle is 30mph
TimerProCreate veh1vis{
    set count [expr $count + 1]
    EntityCreate Vehicle2 "Land Cruiser Black" 10952.8 11275.5 90
    EntityJoinRoadway Vehicle2
    EntitySetRoadwayVelocity Vehicle2Fixed 60MPH
    SimSetRoadwayVelocity Vehicle 2
}
TimerProcAdd Veh1vis 7.37
```

Figure 5. TCL scripting for the simulated car.

After the survey, each subject received a set of instructions about how to drive on the simulator. The first session was recorded for all 18 participants, one after the other, followed by the second scenario recording one by one. The total time to record the entire experiment for all five subjects with two sessions was 2 hours and 30 minutes.

Primary Task Driving Session

This scenario lasted 5-6 minutes for each subject. Participants were told to merge onto the highway with a maximum ramp speed of 35 mph and a maximum highway speed of 60 mph. They were instructed to change lanes whenever possible and safe. After merging onto the highway, they were told to take the first exit. After taking this exit, the facilitator signaled them to park the car in the emergency lane, which concluded the session.

Secondary Task Driving Session

The second scenario also lasted 5-6 minutes. In this scenario, all of the instructions were same as for the first scenario, except that the participants were told to take the second exit instead of the first after merging onto the highway. The speed limit and lane changing instructions were the same. In addition, three passengers were introduced in the car along with the driver. The driver and passengers were instructed to converse about random topics that involved discussion and some mild debate. So conversation with passengers was the secondary task in this scenario. Immediately after this session, the participants were instructed to take an online questionnaire about the driving task on the NASA TLX website in order to evaluate their cognitive mental load after driving.

Results

The results showed a comparison of driving behavior between two age groups. Data were taken directly from the simulator and converted into Microsoft Excel for analysis. As the driving speed of each subject was different, they finished the entire task at different times. So the first 280 seconds from each recording was taken for uniform analysis. In this study, the authors considered the velocity (mph) as well as the maximum and minimum speed of every participant in both the sessions. Since variance is a more robust measure of performance, the authors determined the speed variability for each subject, as shown in Figure 6. Additionally, according to some researchers, speed variability is responsible for more accidents on roadways than vehicle velocity.

The results indicate that the second scenario has a much higher speed variance than the first for younger adults; but, for the elderly group, speed variance in these two scenarios was relatively uniform. This suggests that younger drivers were not attentive to their speed during the secondary task of conversation with passengers. Additionally, it was assumed that the drivers may have been distracted from the emotional response of the conversation (anger, frustration, and excitement). The elderly subjects had less variability in speed, probably due to emotional stability during the secondary task, since they avoided excessive talking while driving. This could be a reason for less distraction for this age group. Whereas younger drivers have a tendency to multitask, they were also more actively participating in discussions with passengers while driving. From the driver simulator data, the authors estimated the lane positioning of the driver continuously for 280 seconds in each trial, and calculated the number of times a driver touched the shoulder of the road while driving. Figure 7 shows a comparison of the number of times drivers in both age groups went off the road or touched the shoulder in both scenarios.

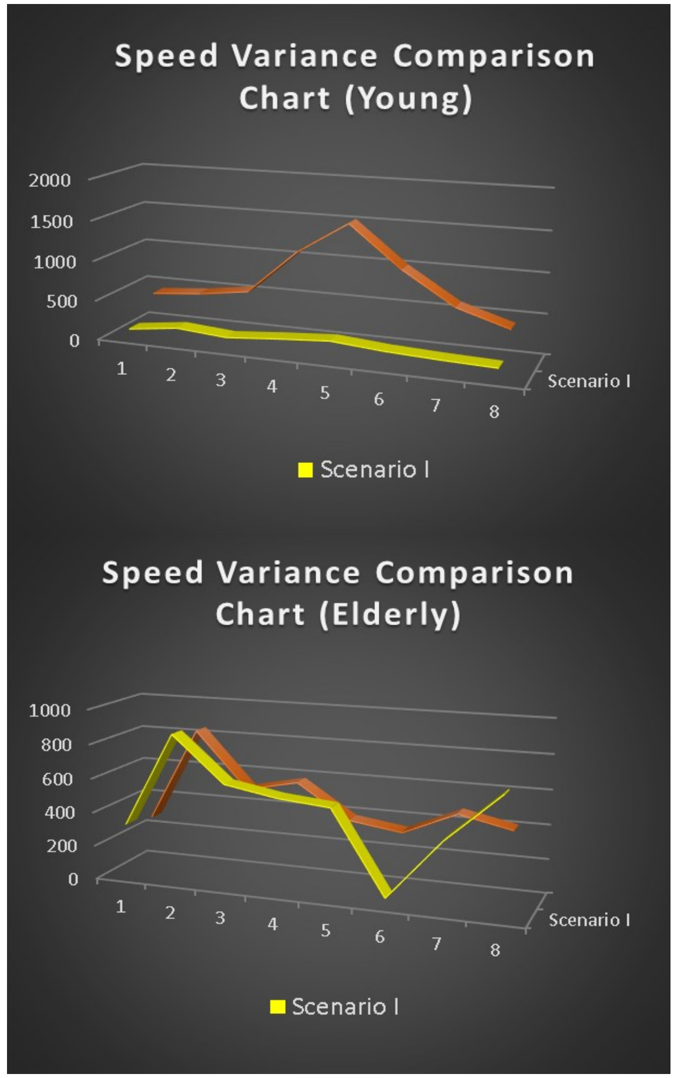

Figure 6. Speed variance comparison chart.

These data show that the younger participants went off the road more times during the second scenario, supporting the argument of distraction while conversing for this age group. Due to high speed variability, younger drivers went towards the shoulder of the road more often. This proves that a secondary task while driving hindered proper lane maintenance. Subject 2 of the young driver profile went off road only once when he drove alone, but he went off five times when he drove with passengers. Similarly, Subject 5 of the young driver group went off three times during the first session and eight times for the second. This shows a big variability of driving during multitasking. For Subject 4 of this group, the data were interesting. There was no off-road driving in the first scenario but two times in the second. There can be several reasons for this result. It was assumed that it might be driver fatigue, as the data were recorded on the same day for both scenarios. But the more logical reason might be multitasking. In the second scenario, the driver was actively talking to passengers for the entire session, which might have caused increased distraction. Hence, lane positioning was not well maintained while performing other tasks along with driving.

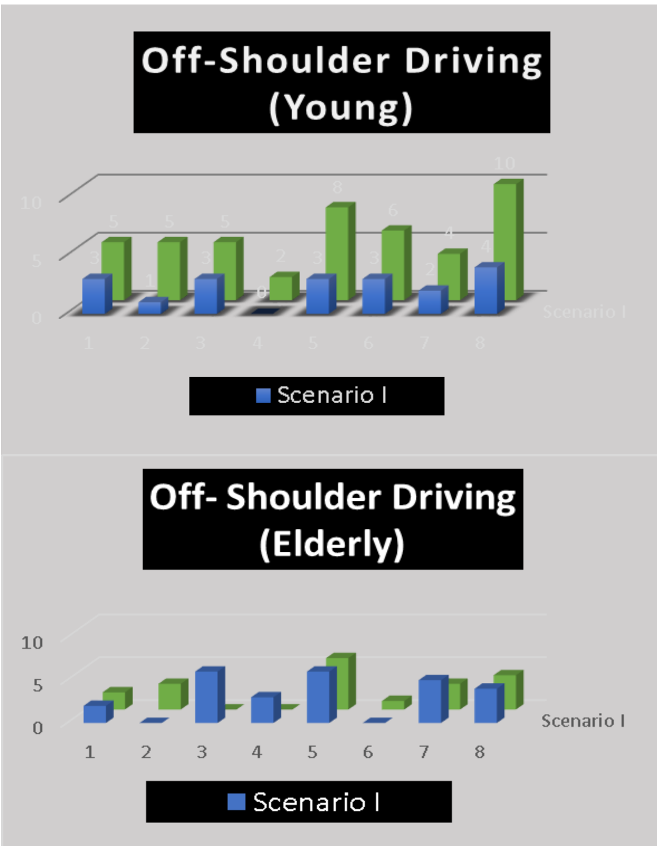

Figure 7. Off-shoulder driving comparison chart.

Looking at the driving results for the elderly drivers, their off-road driving in the second scenario was not very high, compared to the first scenario's speed variability. Elderly drivers were less distracted by multitasking and could maintain lanes more accurately than the younger group. To gain deeper insight about causes that influence a driver's mental and emotional state, the NASA TLX results were compared with the simulation data. TLX is online software developed by NASA that is used for subjective analysis of the workload and mental load of a person. It has an online set of questions related to tasks, and it calculates the mental load, physical load, effort, and frustration levels based on the individual's responses. Mental load in NASA TLX measures how perceptual the activity was and whether the activity was hard or easy. As driving in a simulator is more of a mental task, the authors considered the cognitive mental load and the frustration level of each driver after the first scenario to evaluate total mood disturbance. Each subscale in NASA TLX ranges from 1 to 20, and evaluates cognitive factors by 15 pairwise combinations, depending on the participants' responses on the score sheet. The results were evaluated based on how much a cognitive factor contributed to affect other factors. Table 2 shows NASA TLX results for each of the subjects in the young profile, and Table 3 is the NASA TLX score for the elderly drivers.

Table 2. NASA TLX for young driver profile (20-30 years old).

Subject	Mental Load	Frustration	Total Cognitive Disturbance
1	81	66	147
2	82	16	108
3	91	79	170
4	81	41	122
5	64	38	102
6	18	28	46
7	58	18	76
8	72	50	122
9	27	6	33
Average			102.88

Table 3. NASA TLX for elderly driver profile (55-65 years old).

Subject	Mental Load	Frustration	Total Cognitive Disturbance
1	69	64	133
2	39	54	93
3	44	26	70
4	25	15	40
5	51	60	111
6	59	45	104
7	61	50	111
8	55	13	68
9	62	9	71
Average			68.77

The results of the NASA TLX data aligns well with the speed variance and off-road driving results from this current study. The metal load and the frustration level of each subject was considered in the determination of the total cognitive disturbance for each subject. The average cognitive disturbance for the younger subject was 102.88 (see Table 2), and the average cognitive disturbance for elderly subjects was 68.77. This clearly shows that the elderly subjects had a stable emotional balance and, hence, that they were not distracted with secondary tasks such as conversation. But the cognitive disturbance for young drivers was much higher compared to the elderly drivers in the second scenario. This is extremely dangerous, as it causes distraction while driving.

Conclusions

In this study, the authors performed an experiment that examined the behavior of lateral variation of vehicles using speed variance and off-road frequency and validation by cognitive workload measurements. This method of analysis helps in a basic understanding of driver behavior and emotional disturbances while performing a secondary task. Calculating the variance of speed and off-road driving in both individual and multi-passenger scenarios allows for more research in this field. Future studies can be conducted on the effect of emotional disturbance on drivers while talking to passengers or on a mobile phone. Identifying this aspect might help reduce highway accidents.

Also, this study was conducted on both young and elderly drivers. Although it is known that motor skills and reflex actions of every person degrade with age, with conversation as a type of secondary task the result is reversed, indicating more stable emotional control with age. So for younger drivers, emotional disturbance while driving might result in fatal accidents. This study validates the argument with an objective analysis of mental and cognitive disturbance to formulate an algorithm of the maximum distraction of an individual, beyond which might result in fatal accidents.

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A MULTI-SEMESTER PROJECT LINKING PROGRAMMING, DIGITAL DESIGN, AND MICROCOMPUTER COURSES

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Abstract

Designing, implementing, and executing a cohesive curriculum in all fields of study requires constant care and attention. While the purpose behind sequences of courses may be apparent to faculty, students may not be aware of the interplay as they progress through their time as undergraduate students. The use of multi-semester projects offers a means of explicitly linking course material in the mind of the student, without significantly displacing more traditional course material. The project described here is intended for use in an electrical and computer engineering technology curriculum. A microprocessor was designed over the course of five to six semesters to guide the students in connecting concepts such as digital logic design, hardware description languages, assembly language, high-level language design, and the fundamental structures of microprocessors.

A student/faculty team performed the work presented here as a demonstration of the students' ability to accomplish the task and serve as a model for future development. The students implemented the processor as a simulation using the Python programming language and on an FPGA using the Verilog programming language. A subset of unit test results demonstrated the results of the students' design before the presentation of output from a simple assembly language program written by the students. The output of the simulator and FPGA implementation were compared to demonstrate consistency between the two projects.

Introduction

Designing a microcontroller requires broad knowledge of digital electronics, design, and computer programming. Undergraduate courses covering these topics often span many semesters, potentially leaving the students to link the topics necessary to complete the design. The project described here serves as an archetype for students while learning the connections between the topics studied in previous courses. With this goal in mind, a student/faculty team designed, implemented, and tested a microprocessor, simulator, and assembler using a unique instruction set of the students' design. In this paper, the authors present the goals, design requirements, technical challenges, and results of the test cases used as part of the project.

Background and Literature Review

Designing the system described above requires knowledge from the following classes typical in an Electrical and Computer Engineering Technology program:

- Programming Foundations
- Digital Devices and Circuits
- FPGA Programming
- Microprocessor Architecture
- Advanced Microprocessor Architecture

Each course has its own separate objectives, which can lead to compartmentalized knowledge. However, there are instances of shorter course sequences within this list. First, Alaraje and Sergeyev (2010) established the need for FPGA programming and the use of hardware description languages (HDL) in engineering technology curricula. FPGA programming requires knowledge of digital logic circuits. Second, microprocessor courses often cover two semesters, as described by Blanton and Rajai (2001). Last, the programming courses necessary to develop the assembler and simulator often cover two semesters (Reges, 2006).

These works describe the typical short sequence of courses seen in engineering technology curricula. The work of linking concepts is left to capstone courses, where small student teams work on unique projects selected and developed by the students, as discussed in Broderick, Guerrette, and Prucker (2017). Leaving this task to student-led projects does not ensure consistent outcomes for all students. Nisan and Schocken (2005) partially address the problem by presenting a specification for a microprocessor broken down into smaller tasks. That work suggests that students complete the design over a single semester with the possibility of extending the work to two semesters. Much of the knowledge of how to accomplish the task is left to other courses, textbooks, or learning resources. While engineering technology students benefit from project-based learning, the projects are most effective when completed in close proximity to the supporting material from other classes (Hadim & Esche, 2002). The project presented here may serve as a multi-semester project bridging the five courses listed above. It is not meant to supplant other coursework, and faculty can integrate the work into the natural progression of each course.

System Overview

The team divided the work into three distinct parts:

1. Designing and implementing the microcontroller using Verilog and a terasIC DE0-Nano field programmable gate array (FPGA)
2. Programming a simulator in Python to serve as a learning aid for students and a means of verifying the hardware implementation of the same processor
3. Programming an assembler written in the C language to provide machine code files that are compatible with both the FPGA and simulator implementations of the processor

The definition of the assembly language served as the interface making all of the parts compatible with each other. Figure 1 depicts the interaction between the parts listed above.

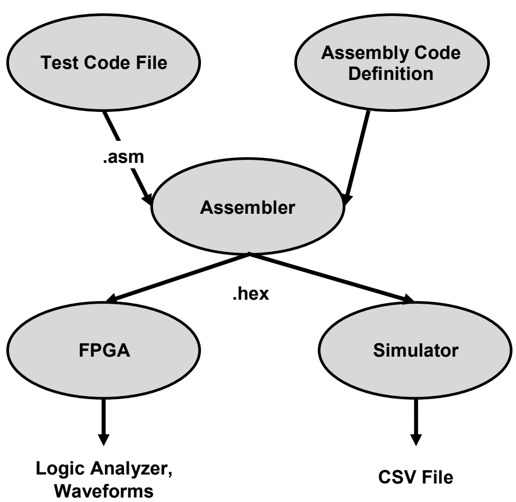

Figure 1. Interaction between project components.

The output of the assembler is a .hex file containing a hexadecimal representation of machine code. The FPGA hardware implementation and the simulator both use the same machine code file. The team used the same test code on both platforms to compare the output of one against the other as well as against expected results. The specification did not include any requirements on implementation language. The students chose the languages used for implementation based on their comfort and previous experience. While this group used Verilog, another group may be more comfortable using VHDL. Similarly, any suitable high-level language may be substituted for the Python and C implementations of the simulator and assembler, respectively. The architecture of a processor defines many aspects of the implementation. Figure 2 depicts the architecture used in the development of the processor for this current study.

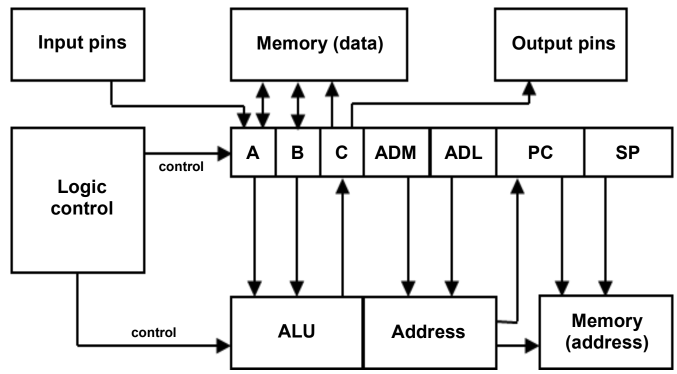

Figure 2. Processor architecture.

The registers shown in Figure 2 can be divided into three categories:

1. External-interface
2. General-purpose
3. Internal-use

The first pair of registers belongs to the external-interface category. The input and output pins are referred to as PINSIN and PINSOUT, respectively, through the implementation. Each is eight bits wide and provides for the input of external digital signals and output of eight digital signals controlled by the eight individual bits of the registers. The second group of registers belongs to the general-purpose category. The registers referred to as A and B throughout the implementation serve as inputs to the arithmetic logic unit. Register C serves to store the result of arithmetic operations. The third and last group of registers belongs to the internal-use category. These are registers used to control execution of machine code and control of the other components of the processor. These registers are not available for external interface or use beyond their designed purpose.

The ADM and ADL registers act as a source of the sixteen bits of the address bus. The eight-bit register width requires that the address be stored in two separate registers. The ADM and ADL register, therefore, hold the most-significant and least-significant bytes, respectively. The 10-bit program counter (PC) facilitates fetching an instruction word between a range of 0 and 1023. Similarly, the 10-bit stack pointer facilitates stack operations.

Summary of Instruction Set

The aforementioned registers along with the instruction set are key elements of the specification the students work to meet. While the register architecture describes what "data in" are present in the processor, the instruction set describes what the user can do to that data. Table 1 shows a summary of the instruction set. The instruction set structures the operations in such a way that operation types are grouped to ease implementation.

Table 1. Summary of opcodes.

Mode	bit 7	bit 6	bit 5	bit 4	bit 3	bit 2	bit 1	bit 0
LOGIC	0	0	0	neg	op	op	op	op
ARITHMETIC	0	0	1	op	op	op	op	op
DATA	0	1	0	0	dir	reg	reg	reg
STACK	0	1	0	1	dir	reg	reg	reg
FLOW	0	1	1	cmpr	cmpr	cmpr	0	x
SPECIAL	0	1	1	spec	spec	spec	1	x
IMMI (least sig. nibble)	1	reg	reg	0	x	x	x	x
IMMI (most sig. nibble)	1	reg	reg	1	x	x	x	x

In both implementations, the processor operation describes the state machine pictured in Figure 3. The first state is referred to as the OPLOAD state. In this state, the processor reads instructions from memory into the appropriate register. The second state is referred to as the OPPERF state. In this state, the processor performs the instruction loaded previously and the result is stored.

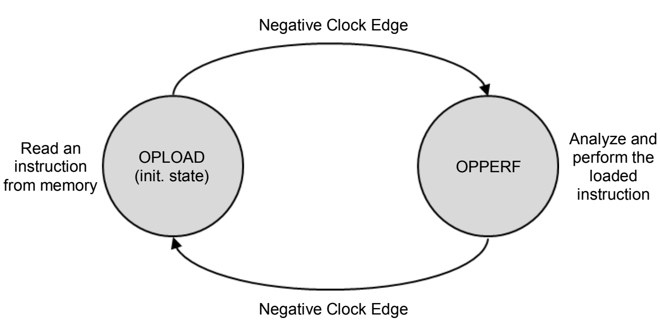

Figure 3. Microprocessor state machine.

The processor performs a single instruction over two clock cycles. The processor executes the actions performed during the OPLOAD and OPPERF states on the positive-going edge of the clock signal. Figure 4 depicts the timing of these events in relation to the clock signal.

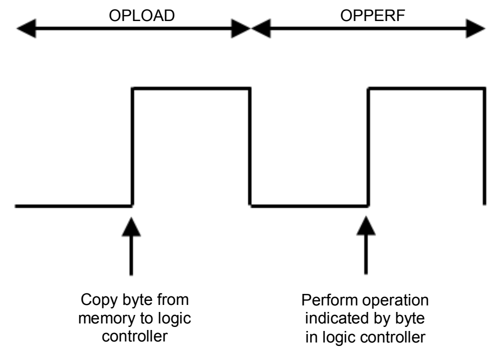

Figure 4. Timing diagram.

The students implemented the processor in two forms. The first was the implementation of the processor using a terasIC DE0-Nano programmed with the Verilog language. This implementation served the student by providing a complex comprehensive application of their digital devices and microprocessor courses. The second was a simulator written in the Python language. The simulator served as a training tool to introduce students to assembly language programming and the fundamental structures of processors. The students were also allowed to use the simulator to improve their ability to program in assembly language without the requirement of possessing hardware and test equipment.

The simulator requires special attention, given the mismatch in data types present. The simulator runs on a 64-bit personal computer with many primitive variable types exceeding the width of the FPGA implementation's 8-bit registers. Input is received from the assembler as a text file containing machine code, processed through Python programming language, and the register values are output to a comma separated values (CSV) file. The simulator code takes each input operation code (opcode) in turn and determines the correct operation to perform. The simulator reads the opcode as a hex value and determines the operation procedurally by stepping through multiple conditional statements. Once the correct condition is met, in a broad range of opcodes, a more specific condition is matched and the operation occurs. The simulator runs a carry flag check at the end of logical and arithmetic operations.

Operations

The simulator implements logical and arithmetic operations using the Python built-in bitwise and arithmetic operations, respectively. The simulator performs a check on the sign of the result in the C register at the end of the logic and arithmetic operations. If the value is negative, the simulator masks the value to extract the lowest eight bits of the value in the C register. During the transition from the OPPERF state to the OPLOAD state, the simulator performs a carry flag check. If the opcode is between 0x00 and 0x29, the carry flag is serviced. The simulator checks the three general-purpose registers to ensure the value is not wider than eight bits. If it is, the simulator masks it to limit the value to the least significant byte and the carry flag is set. The instruction set splits memory operations into hex values of 0x40 to 0x4F, and 0x50 to 0x5F, the former being memory move operations and the latter being stack movement operations. During memory-move operations, the simulator loads the RAM values into the A register, B register, C register, or ADL, or stores the values in the registers into the address of RAM. For the stack movement operations, the simulator adds values to the top of the stack or removes values from the top of the stack.

The simulator implements jump operations as single value checks for opcodes in the range of 0x60 to 0x78. If the opcode indicates an unconditional jump, the simulator alters the program counter to ensure that the next operational code executed is that stored in memory at the specified location. For conditional jump operations, the simulator performs two checks, one for the opcode value and one for the condition of the jump. The conditions of these jumps are limited to the states of the A and B registers. If the condition is met, the address bus value is altered as previously described. The simulator implements immediate-mode operations as individual value checks from 0x80 to 0xFF. The simulator determines which operation to perform by the first number in the hex value of the opcode. As each opcode is 8-bits in length, the instruction set implements immediate-mode instructions by the nibble. Therefore, a single byte must be loaded with two operations: the first for the most-significant nibble and the second for the least-significant nibble.

Output Format

The simulator produces an output formatted as a CSV file. The simulator writes a header at the top of each file in the following order:

1. Program counter
2. Stack pointer
3. Opcode
4. A register
5. B register
6. C register
7. Address bus (most significant)
8. Address bus (least significant)
9. Carry flag

The simulator writes the data values corresponding to these column headers to the CSV file each time the state machine transitions to the OPLOAD state. If the PC is higher than 1023, the while loop is broken, the CSV file is closed, and the simulator ceases execution.

Results

The students performed tests on both the FPGA and simulator. They compared these results against expected values as well as to each other to ensure consistency. The students performed more than 50 unit tests of individual opcodes distributed between five test files containing machine code. The students manually examined each case for correctness of processor operation by observing the behavior of the registers. Table 2 represents the data that was outputted into a table format while testing with the simulator. The test case in question represents the execution of the TAU opcode, which transfers the value of register A to register C.

Table 2. Unit test results for TAU opcode.

Edge	Clk	Op Code	State	PC	A	B	C
POS	1	01	1	005	0xA3	0xB5	0x00
NEG	0	01	0	006	0xA3	0xB5	0xA3
POS	1	01	0	006	0xA3	0xB5	0xA3
NEG	0	01	1	006	0xA3	0xB5	0xA3

The expected result is the transfer of the value 0xA3 from the A register to the C register on the positive edge of the OPPERF processor state. The students observed a similar result from the FPGA with a required additional operation to transfer the output value to the PINSOUT register to be read by a logic analyzer. Table 3 represents the operation of the AND opcode, as performed with the simulator. The operation performs a bitwise AND operation of the values in registers A and B. The result is stored in register C.

Table 3. Unit test results for the AND opcode.

Edge	Clk	Op Code	State	PC	A	B	C
POS	1	02	1	006	0xA3	0xB5	0xA3
NEG	0	02	0	007	0xA3	0xB5	0xA1
POS	1	02	0	007	0xA3	0xB5	0xA1
NEG	0	02	1	007	0xA3	0xB5	0xA1

The expected result is a value of 0xA1 stored in register C on the positive edge of the OPPERF processor state. Again, the students observed similar results with the FPGA and logic analyzer. These tests, along with others not depicted here, serve as a thorough trial of the individual operations and movement of data through the processor. The consistency of results, when compared against the expected values and the values from the other students, demonstrates the successful implementation of both the simulator and FPGA.

Demonstration of a Simple Program

The students performed additional system-level tests to accomplish two goals. First, to demonstrate that the assembler correctly translates the opcodes of short programs into the corresponding machine code. Second, to demonstrate the efficacy of the processor they designed to accomplish tasks that are more complex. The code shown in Table 4 generates the Fibonacci sequence in register C prior to moving the value to the output pins connected to the PINSOUT register. The code exists in separate locations in memory as well as in Table 4. The code beginning at location 0x00 loads initial values into the A and B registers before jumping to location 0x20. The left-hand column of Table 4 shows this code.

Table 4. Summary of assembler output for the Fibonacci test code.

Location	Asm	Op Code	Location	Asm	Op Code
0x00	IMMI.AM _0	0x90	0x20	ADD	0x20
0x01	IMMI.AL _0	0x80	0x21	OUT	0x62
0x02	IMMI.BM _0	0xB0	0x22	PUSH.C	0x5A
0x03	IMMI.BL _1	0xA1	0x23	PUSH.B	0x59
0x04	IMMI.MM _0	0xD0	0x24	POP.A	0x50
0x05	IMMI.ML _0	0xC0	0x25	POP.B	0x51
0x06	IMMI.LM _2	0xF2	0x26	JMP	0x60
0x07	IMMI.LL _0	0xE0			
0x08	JMP	0x60			

The code beginning at location 0x20 runs as a loop generating each value of the sequence in turn and then moving the value to the output pins. The right-hand column of Table 4 shows this code. The results, over fifteen cycles, demonstrate the correct behavior, respecting the limitations of the eight-bit registers. The first twelve operations resulted in the values 0, 1, 3, 5, 8, 13, 21, 34, 55, 89, 144, and 233. Both Table 5, the simulator output, and Figure 5, the output of the FPGA using a logic analyzer, show these values.

Table 5. Simulator output in response to the Fibonacci test code. Output pin column (gray) for comparison against recorded outputs for the FPGA.

A Reg	B Reg	C Reg	Carry Flag
0	0	0	0
0	1	1	0
1	2	3	0
2	3	5	0
3	5	8	0
5	8	13	0
8	13	21	0
13	21	34	0
21	34	55	0
34	55	89	0
55	89	144	0
89	144	233	0
144	233	121	1
233	121	98	1
121	98	219	0

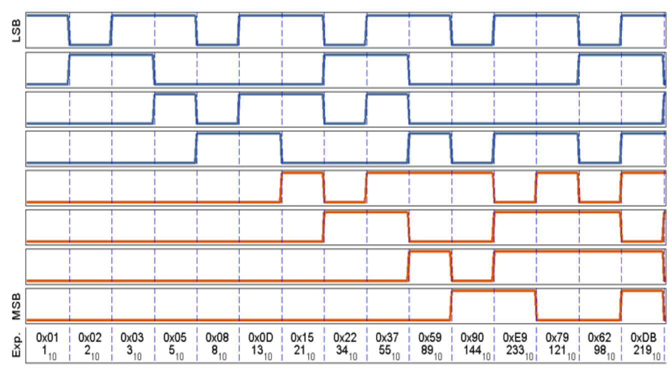

Figure 5. Recorded FPGA output and expected values in both hexadecimal and decimal. Least-significant nibble (blue) and most-significant nibble (orange).

The thirteenth operation should result in 377. This value exceeds the range of an eight-bit number, 0-255, causing an overflow and the carry flag to be set. This is evident in the simulator, as the flags are monitored and available in the output CSV file. The behavior is evident in the logic analyzer data, given that the Fibonacci sequence modulo-256 should result in 121, 98, and 219 for the 13^{th} through 15^{th} operations, respectively.

Discussion

The students' successful completion of the three distinct parts of the project (FPGA, simulator, and assembler) shows that a senior studying electrical and computer engineering technology has learned the material necessary. Curricula frequently leave the linking of topics to senior-level capstone projects. The students will be served better by embedding smaller projects into the course covering the necessary topics, as established previously by Hadim and Esche (2002). Faculty implementing the projects can spread the work across a number of courses that may differ, given other curricular constraints. Table 6 shows one such suggested implementation. Faculty implementing such a curriculum must take care to explicitly link the components of the project when each subproject is introduced. Faculty may accomplish this by providing completed, compiled subprojects in order for students to troubleshoot the individual piece they are developing. For example, faculty may provide a working assembler to students currently developing the simulator, as in Nisan and Schocken (2005).

Conclusions

A student/faculty team designed and implemented a microprocessor, simulator, and assembler. The project was intended to be broken into smaller parts in order to link the topics conceptually as the students progressed through a curriculum in electrical and Computer engineering technology. The three components were designed and implemented using the Python, C, and Verilog programming languages. Results were recorded from the simulator as a CSV file and from the FPGA using a logic analyzer to perform unit and system tests. All results indicated that the students implemented the design of their own creation. Simulator, logic analyzer, and expected results matched in all cases. The assembler output was successfully used to generate machine code for all unit and system tests. Faculty implementing the project throughout their curricula should note that it may be extended in both directions. It is possible to implement lower-level logic gates on the transistor level, thereby incorporating courses on semiconductors and analog circuits. It is also possible to move beyond the assembler and extend the project into higher-level computer science courses through the design of a compiler and/or an operating system.

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Table 6. Suggested breakdown of projects by course.

Course Name	Course Topics	Project Topics
Programming Foundations	Problem solving, data types, input/output, control structures, loop structures, and program modularity	Begin implementation of assembler and simulator
Digital Circuits	Numbers systems and codes, logic gates, Boolean algebra, minimization, flip-flops, and registers	Design control logic and arithmetic components
Micro. Arch.	Reading, writing, and debugging assembly language. Opcodes, operand forms, addressing modes, flow control, and use of the stack	Complete implementation of assembler
Adv. Micro. Arch.	Control logic, addressing registers, memory units, arithmetic units, interrupts, and input output structures.	Implementation of simulator
Digital Devices	CPLDs, FPGAs, VHDL/Verilog, State Machines, Analog to Digital conversion, and digital to analog conversion.	FPGA implementation of processor

Biographies

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LON-CAPA: Finally, a Course Management System Suited for Engineering and Technology

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Abstract

Although learning management systems (LMSs) have been around for many years, most are seriously deficient for use in science, technology, engineering, and mathematics (STEM) disciplines. Today's STEM educators need a tool that can not only manage a course, but also create and integrate online homework and quizzes using appropriate mathematics notation, graphing, and multi-part problems. Such a tool already exists, and it is open source. The Learning Online Network with Computer Assisted Personalized Approach, a.k.a. LON-CAPA, addresses these issues and more. The first version of the system was created over two decades ago and is currently being used at hundreds of institutions around the world, but primarily in the science and mathematics disciplines. The author of this current study, along with some of his departmental colleagues, have found LON-CAPA to be an invaluable aid in teaching electrical engineering technology courses. The purpose of this paper is to begin spreading the word about LON-CAPA to the engineering and engineering technology education communities.

The author begins with a brief history of LON-CAPA's development, its current status, and itemizes some of the many problem types the system can handle. A more-detailed discussion of a few of those problem types is also presented, including two styles of multiple-choice problems, numerical response and multi-part problems, and a description of how to use the Maxima math package to display standard mathematical symbols like integral and summation symbols, while also incorporating randomized variable values. In addition to the technical details of constructing problems, the author also addresses pedagogical and other benefits, as well as the learning curve and costs associated with using LON-CAPA.

Introduction

What is now LON-CAPA (Learning Online Network with Computer Assisted Personalized Approach) began as CAPA, a pilot project for a class of 92 physics students in the fall of 1992 (History, 2013). It served problem sets, quizzes, and exams via the internet. The Lecture Online project started in 1997 and allowed instructors to combine internet material into coherent presentations, create individualized online homework, do grading, and other tasks (History, 2013). In 1999, the two systems merged to become LON-CAPA, which was first beta-tested at Michigan State University in the spring of 2001. Today, it is used by over 150 institutions around the world, from middle school to graduate-level courses and in many different disciplines, including biology, chemistry, computer science, engineering technology, mathematics, and physics (History, 2013; LON-CAPA, 2013). Since 1999, it has been an open source system used by about 150 institutions around the world that has hosted thousands of courses and generated tens of millions of homework, quiz, and exam problems for students to solve (LON-CAPA, 2013).

Although outside the scope of this paper, LON-CAPA does incorporate a number of tools to manage courses, such as discussion boards, printed and/or electronic exam generation, etc. The author believes the most distinctive characteristic of LON-CAPA is its ability to handle technical content in online quiz/homework assignments, which is the focus of this paper. First, a brief, high-level description of many of the problem types that LON-CAPA can host, followed by a detailed description of some common problem types in order to introduce the reader to how problems are constructed using both the "colorful" and line editors. These descriptions include screenshots illustrating how the problems look when "served" to the student, views from the "colorful" and line editors, and a description of the code behind each problem. Finally, the author presents a discussion of the benefits, both pedagogical and administrative, followed by some information about what is needed to learn, use, and administer the system. Future papers will deal with some of the more advanced problem types introduced in the next section.

Problem Types

LON-CAPA has a multitude of problem templates so users do not have to start from scratch. Figure 1 shows how the user, when first authoring a new problem, is able to select any of the available templates. There are several possibilities for what could be categorized as multiple-choice problems, but each displays a list of possible answers to the student. First is the radio-button style for which there is only one correct answer. In this type of problem, the student must select the button corresponding to the one correct answer. Second is the true/false option response, where more than one answer may be correct; here, each option has a checkbox beside it that can be checked or cleared independently of the other options. Third is the matching option response. For this problem style, there is a dropdown menu of available answers next to each item listed. The student must select the corresponding dropdown answer for each item in the list. Fourth is the rank-order response. This is very similar to the matching style, except that the items are rank-ordered using the dropdown menus. Another category that is very important in any STEM (Science, Technology, Engineering, and Mathematics) field is numerical problems. This is an area in which LON-CAPA really begins to distinguish itself. Numbers can be randomized in multiple ways, and the system allows answers to be processed as right or wrong with an author-defined tolerance, so numbers may be required to be accurate to a specified number of decimal places, within a certain percent, or with a precise number of significant digits. Moreover, it recognizes both standard units (e.g., meters, feet, grams) and prefixes (e.g., *m* for milli, *k* for kilo), and will accept 2500g for a problem whose answer is defined as 2.5 kg.

LON-CAPA can also be easily configured to accept multiple answers for questions that have multiple correct answers. For instance, the square root of 49 has two correct answers: -7 and +7. It also handles multi-part problems with aplomb, making it easy to set up problems that require sev-

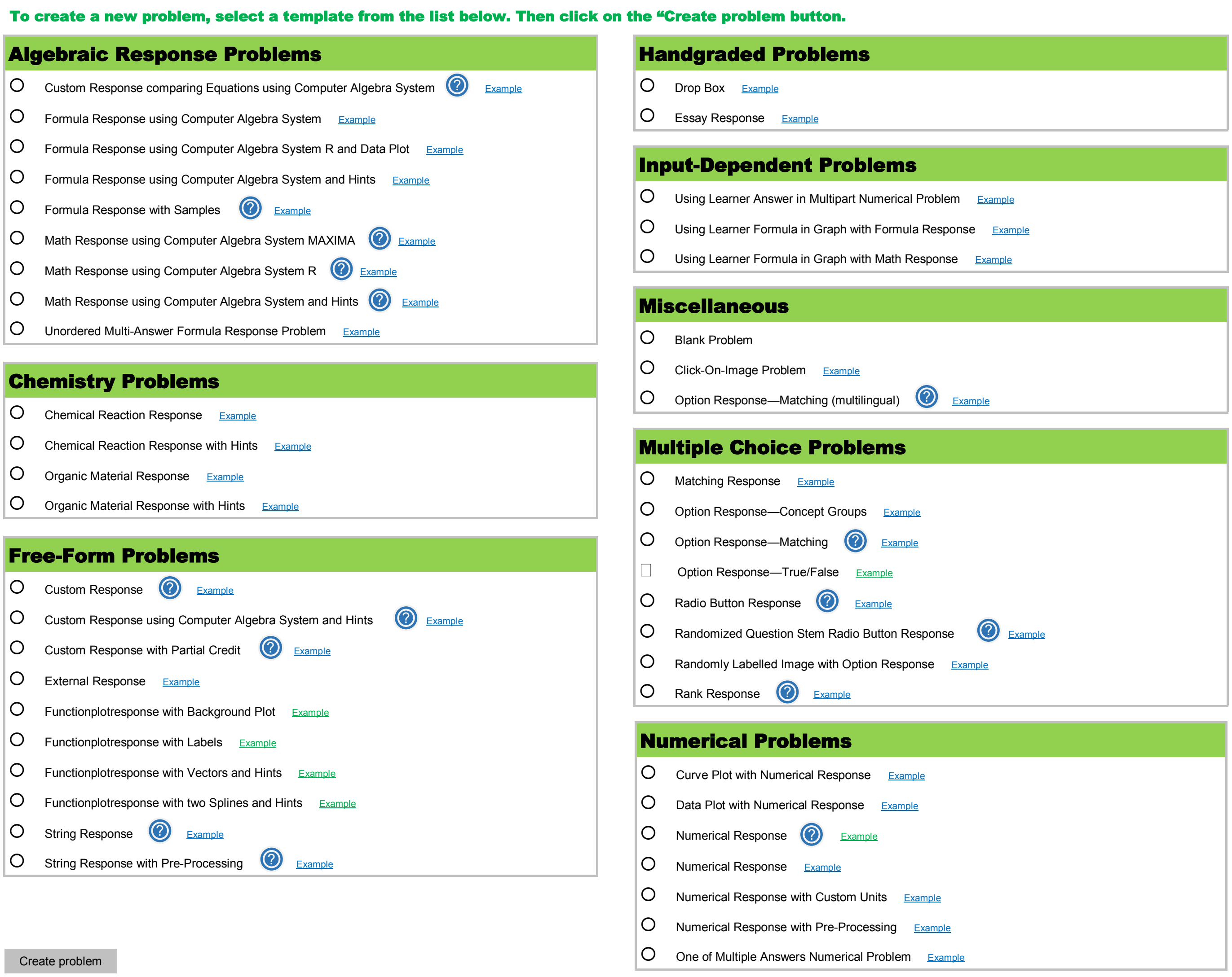

Figure 1. Template selection window for new problems.

eral steps to solve. Additionally, there are options for displaying the correct answer for each step, or not, as is appropriate for a given situation. There are many applications in which generating a plot is appropriate. LON-CAPA uses gnuplot to plot in two modes, either as a function (e.g., f(x) = $2x^2$) or a set (x, y) of data points. Also, the previously mentioned randomization capability still applies, so plots can be based on randomly generated numbers instead of being hard-coded.

There are several other response types that will be covered in future papers. One is fairly common: string response. This form requires a string typed in by the student, and the string can be case sensitive, or not, as appropriate. Another style is the formula response, where the student must enter a formula instead of a number. For example, the derivative of $y = 3x^2$ would require an answer of 6x. A related problem type pertinent to the chemistry domain is the chemical reaction response, which requires a balanced chemical reaction expression, such as 2H2 + O2 -> 2H2O. Also in the chemistry area is the organic material response, which takes a specialized input using a graphical processing script to generate maps of molecular bond structures. Another valuable technique is the interactive plot. LON-CAPA can interact with Geogebra to create problems in which the student must draw a plot using points, lines, curves, polygons, etc. Examples of this include free-body diagrams and frequency spectrum plots. LON-CAPA has an embedded capability called the function plot response, but also allows embedded Geogebra applets and custom responses for greatly extended flexibility at the expense of more coding.

Detailed Problem Descriptions

The radio-button problem is very straightforward. It is a multiple-choice problem with only one correct answer. Note that multiple correct choices can be coded into the problem. In this case, LON-CAPA randomly selects one of them and displays it along with the incorrect answers. This type of problem is coded entirely in extensible markup language (XML), which is similar to hypertext markup language (HTML). All LON-CAPA problems use XML, but some forms also use other types of code. Figure 2 shows the standard radio-button template. This is the view of the problem as seen by an author when editing. It is similar to the student view, but has some extra buttons not available to the student. Figure 3 shows the line-editor view. The “maxtries” parameter statement near the top sets the default number of tries the student allowed in order to solve the problem. This parameter can be overridden when setting up an online quiz. The line can also be deleted altogether, if the author does not wish to set a default value.

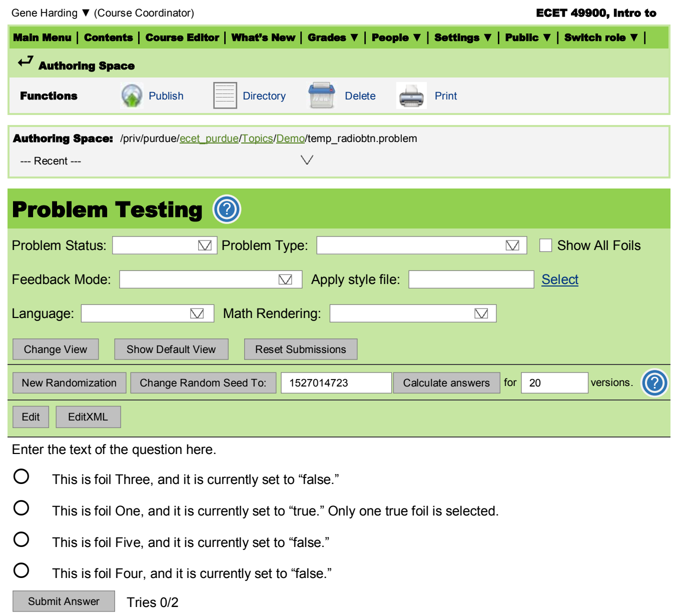

Figure 2. Author view of the radio-button template.

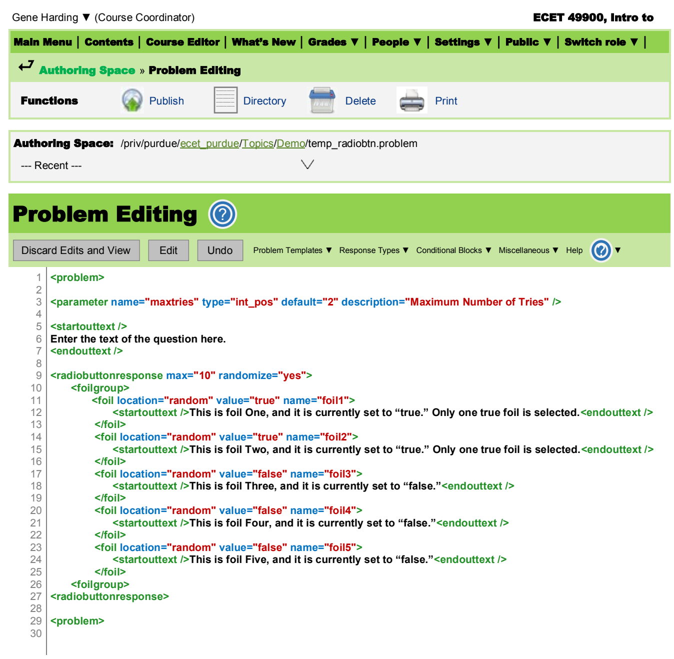

Figure 3. Radio button template; line-editor view.

The next section, bracketed by XML statements <startouttext /> and <endouttext />, is the question text. The author simply replaces this text with his/her question. The third and final section is the “radio-button-response” section. The first statement sets the maximum number of answers to be displayed and whether their order is randomized. In this case, if more than ten answers are defined, LON-CAPA will only display ten, and their order will be randomized each time the problem is reset. The foil-group section lists the set of possible answers, whether each one is correct or not (indicated by true or false), and whether its order is random or not.

There is, however, another editor available. Called the "colorful" editor, it is much bulkier but can be very helpful when editing a problem type that is unfamiliar. This editor has dropdown menus for many of the parameters and options, so the author does not have to know the syntax in advance. Moreover, there are dropdown menus for entire sections of code, which can be inserted simply by selecting the corresponding dropdown option. Figure 4 illustrates the colorful editor. After the editing is complete, the problem must be published before it can be viewed by students. It also must be imported into a quiz. Figure 5 shows the student view of a radio-button problem. This particular problem also uses a figure of a high-pass filter response. Figures are easy to add to problems, but must first be uploaded to LON-CAPA and published before they are viewable to students.

At this point, it is worth revisiting the previous statement that a problem must be imported before being used in a quiz. Unlike many, if not most, learning management systems (LMSs), LON-CAPA segregates course management from content development. Problems are created and stored in the "author space," which is essentially a library of content that can be accessed by multiple courses. Indeed, since LON-CAPA is an open system, problems can be imported and used even if they are created and stored on a server at a completely different institution (if set up as "open" by the author). The next problem type is the multiple-choice checkbox. LON-CAPA refers to this problem type as a true/false option response. The difference between this response type and a radio-button response question is that more than one answer may be correct. In a radio-button problem, selecting any option automatically clears the buttons for all of the other options. For a true/false option response problem, there is a checkbox beside each option, and each one can be checked or cleared independently from any of the other options in the list. Figure 6 shows the standard LON-CAPA template for a true/false option response problem.

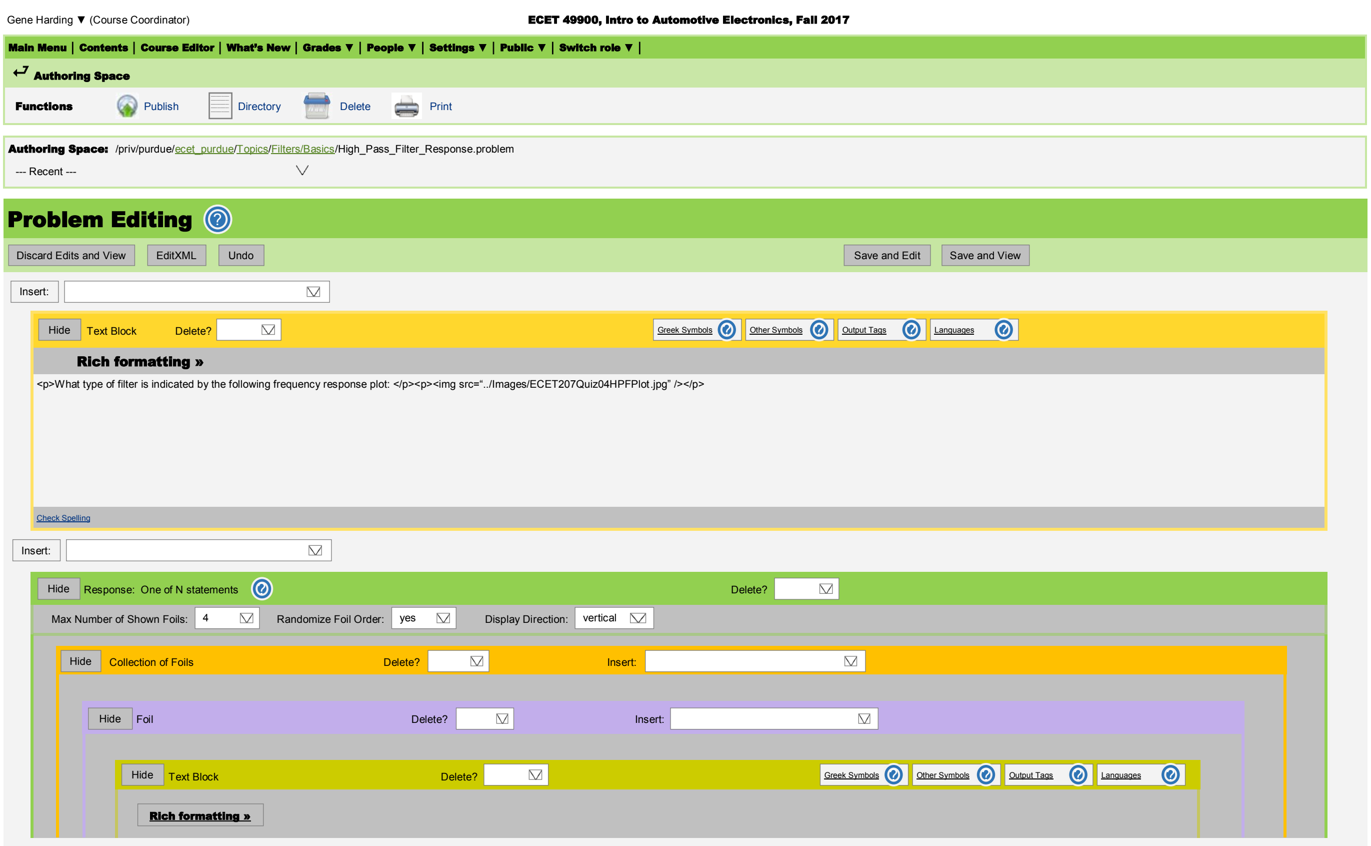

Figure 4. Colorful editor.

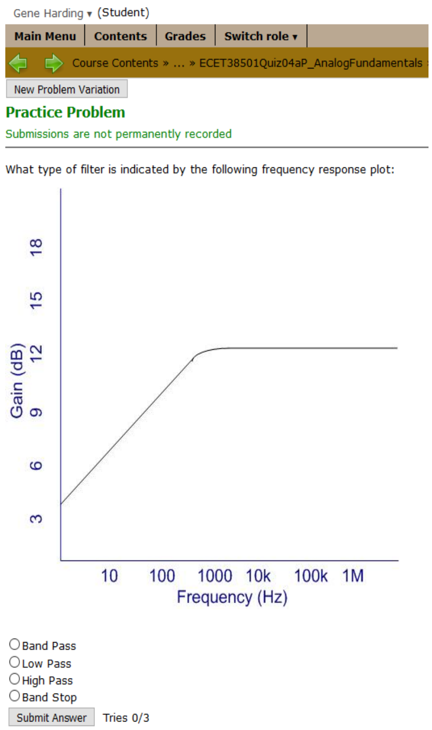

Figure 5. Student view.

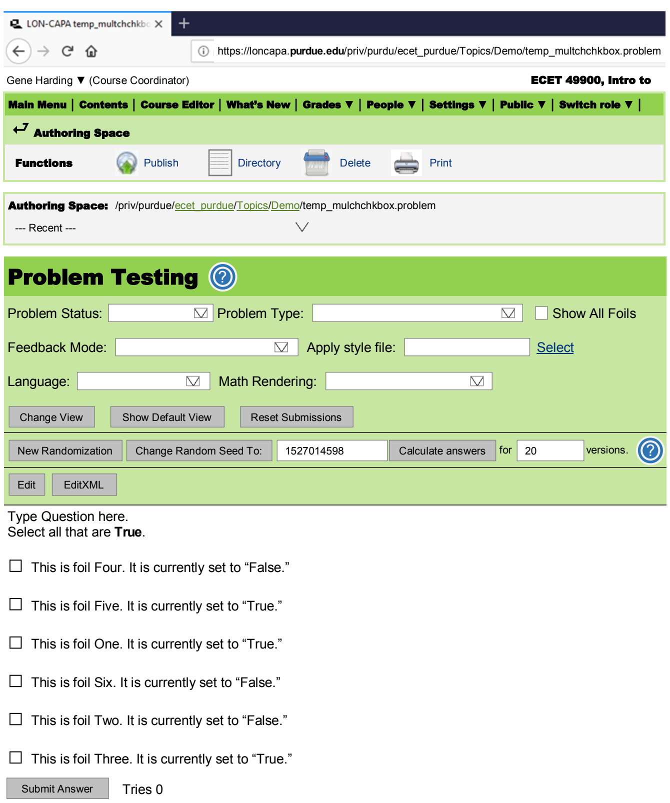

Figure 6. Author view of the true/false option response template.

Like the radio-button problem, option response problems can be coded exclusively in XML. Figure 7 shows the code for this template. As for the radio-button problem, the first section is the question text, delimited by <startouttext /> and <endouttext />. Unlike the radio button, however, the next section is an "option-response" block instead of a "radio-button-response" block. The foils, however, are essentially the same as before, so all that is needed to create a new problem is to type over the template's question and foil texts. Figure 8 shows an example problem used in one of the author's courses.

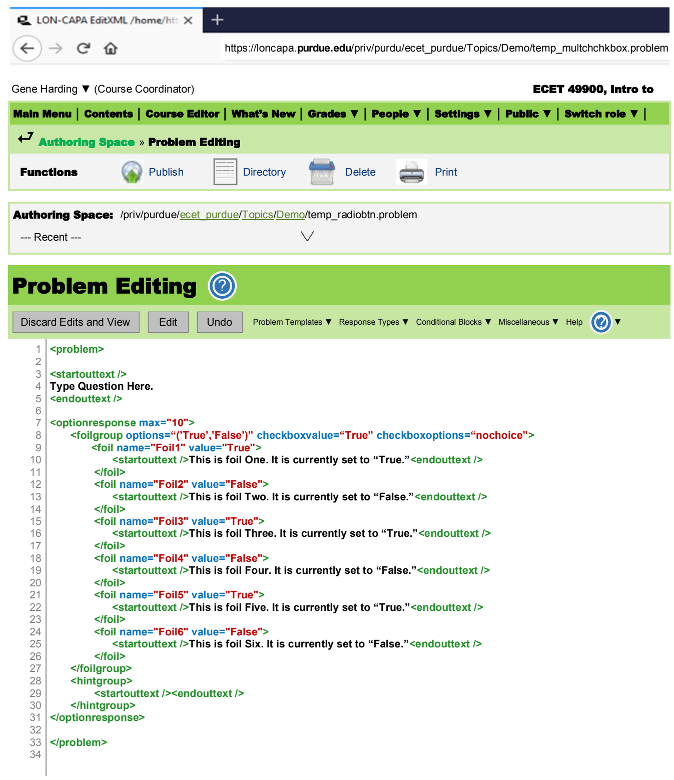

Figure 7. True/false option response XML code.

The power of LON-CAPA becomes apparent when creating "numerical response" problems. Calculations are done in Perl script, while problem display is done using XML, similar to other types of problems. Variables computed in the Perl script are passed seamlessly to the XML for display and to determine whether or not submitted answers are correct. Figure 9 shows the standard LON-CAPA template for a numerical response problem, while Figure 10 shows how the corresponding code is displayed. The Perl script shows one use of the "random" function and a simple equation, but a plethora of Perl functions are available for use, including trigonometric, logarithmic, exponential, floor and ceiling, and many others (LON-CAPA Group, 2017). Typically, numerical response problems have a Perl script at the beginning, followed by XML. The text for this type of problem is displayed the same way as for the previously discussed problems. Note the "numerical-response" block. In the template, the tolerance is expressed as a percentage of the answer, but it can also be expressed as an absolute number, such as 0.05. Moreover, it can also require a specified number of significant figures, although, in this case, the Perl script must calculate the tolerance based on the randomized answer.

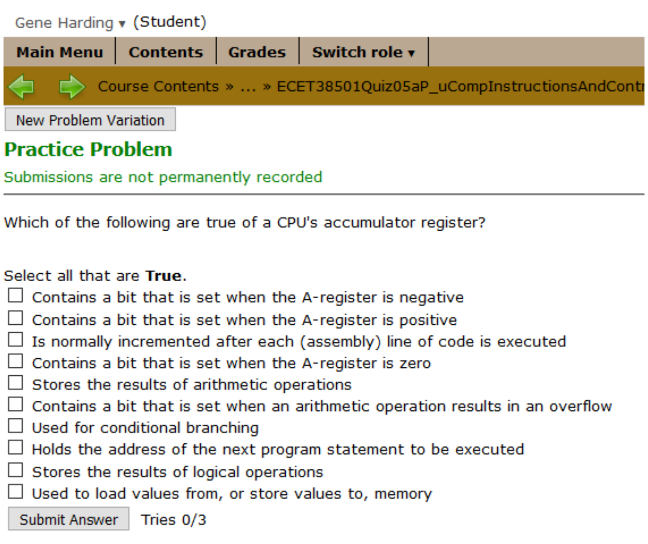

Figure 8. Student view of the true/false option response problem.

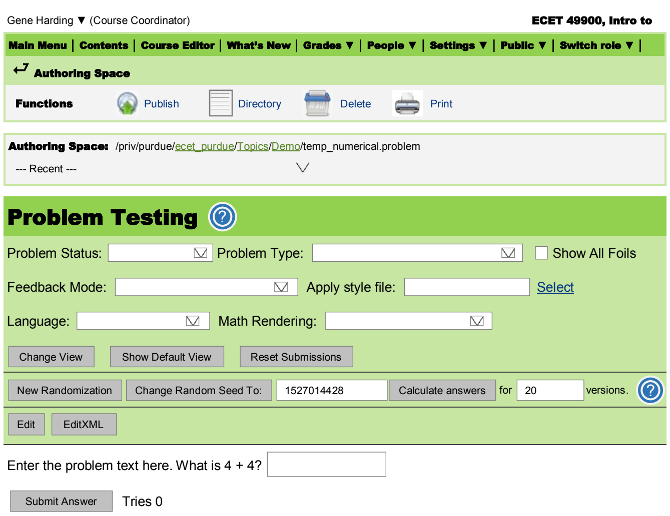

Figure 9. Numerical response problem template.

Other great features of LON-CAPA include the ability to do multi-part problems, where calculations carry across the different parts, display complicated mathematical formulas with embedded randomized numbers linked to variables in the Perl script, and display dynamic plots based on randomized numbers in the Perl script. The computer algebra system Maxima (n.d.) and statistics package R (n.d.) are both available within LON-CAPA (LON-CAPA Group, 2017). The example problem shown in Figure 11 is an example of a multi-part problem that uses Maxima to render a fairly complex equation in an appealing form (with randomized values).

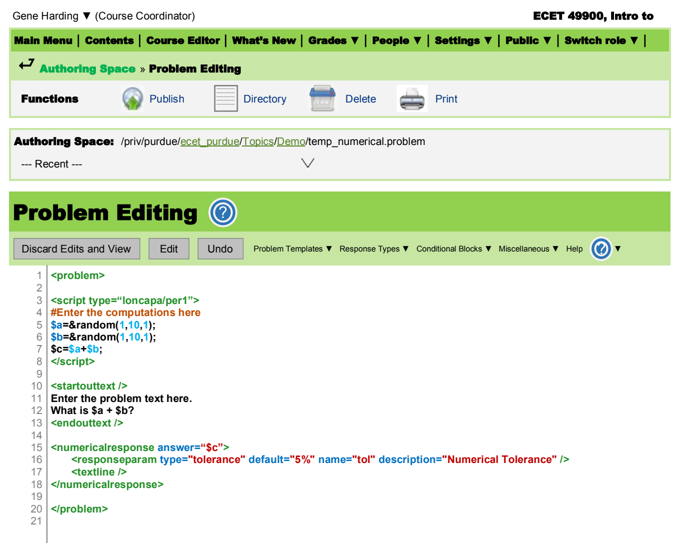

Figure 10. Numerical response template code.

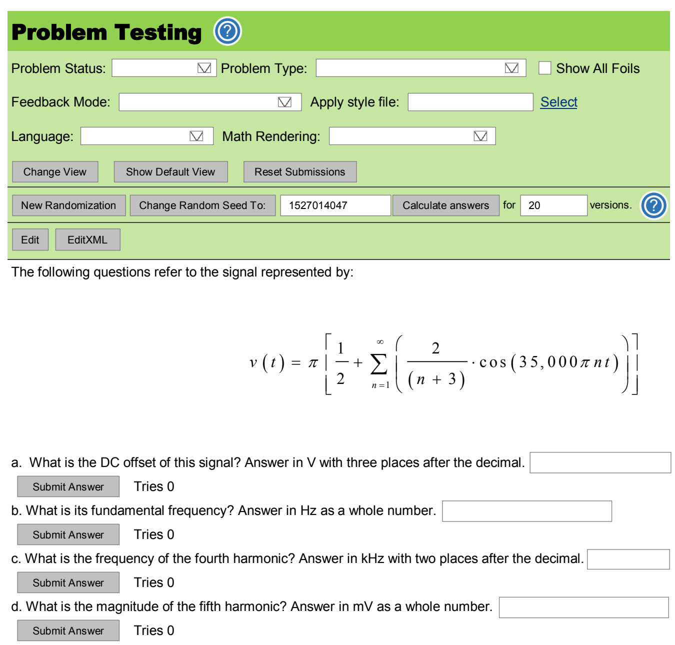

Figure 11. Multi-part numerical response problem using Maxima to render an equation.

Another useful system available in LON-CAPA is gnuplot (2018; LON-CAPA Group, 2017). This plotting engine can be used to display dynamic plots based on variables in the Perl script, either based on a function (e.g., $f(x) = 2x^2$) or a set (x, y) of data points. Figure 12 shows an example of a multi-part numerical response problem that uses a dynamically generated gnuplot. Also, note the displayed answers in the lower left part of the figure. These have been cropped out of the other figures, but are only present in the Author View. They are not present in the Student View.

Benefits

There are at least three pedagogical benefits to using an online system like LON-CAPA. First is the ability to fail without penalty while learning, assuming the student is allowed multiple tries to solve each quiz/homework problem. Second is immediate feedback. Traditional grading methods for paper homework can be very frustrating, because of the time delay between turning in an assignment and finding out whether it was correct or not. On the one hand, multiple tries and immediate feedback provide a useful tool for enhancing student learning (Clariana & Koul, 2006). On the other hand, some students, especially if allowed a large number of tries, will resort to guessing instead of analyzing a problem. One study specifically investigated this behavior and determined that limiting the number of tries to approximately five is the most productive (Kortemeyer, 2015). Nevertheless, this current study and others, along with simple intuition, suggest that such technology can profoundly impact student learning, if used properly (Kashy, Albertelli, Kashy, & Thoennessen, 2001). A third benefit is self-pacing. The previous two benefits permit students to progress at their own pace. Students needing extra time can take extra time to figure out new material. The effect of these three benefits is that it puts more control of student learning into the students' hands, which is probably a large part of why student feedback is so positive (Kashy, Albertelli, Kashy, & Thoennessen, 2001).

There are a number of other benefits to using LON-CAPA, over and above the pedagogical benefits. One is that most students today expect to see some modern teaching methods, and LON-CAPA meets that expectation. They adapt to it quickly. There are also several benefits related to content creation. First, instructors have the ability to create

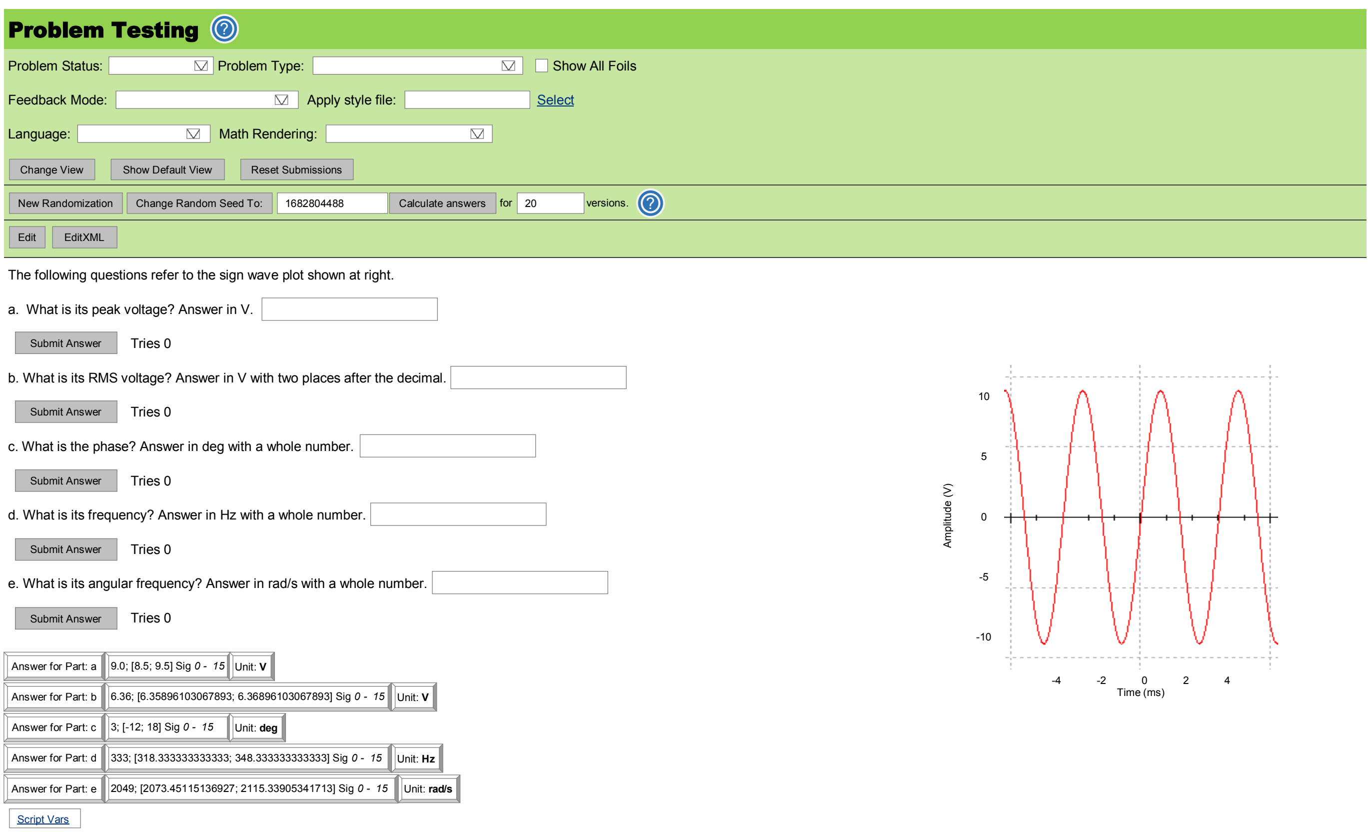

Figure 12. Multi-part numeric response problem with dynamically-generated gnuplot.

their own content, from simple to highly sophisticated problems that suit their needs. Second, LON-CAPA is an open system, so many vetted problems already exist, especially in the physics, chemistry, and mathematics domains. Third, experience at Purdue's main campus indicates that it is fairly easy to find both undergraduate and graduate student coders. And fourth, although there is no help desk, as it is an open system, there is a listserv that this author has found to be a great resource on a number of occasions.

LON-CAPA can also be a big cost saver. Some departments at Purdue have eliminated textbooks altogether from a few of their courses, a benefit that is highly appreciated by most students. From the faculty perspective, the automatic grading is a great time saver, allowing instructors to invest their time into other areas to benefit student learning. Finally, an online system like LON-CAPA enables distance learning. The author converted the lecture portion of one of his courses to all-electronic format using LON-CAPA, and has offered it by distance education to students at several other campuses around the state. This particular course would otherwise not be available to those students.

Cost

There are, of course, some costs associated with LON-CAPA. Since it is an open system there is no fee for using it, but there is a learning curve for users as well as administrative costs to host it. The learning curve for using LON-CAPA is probably about the same as for using most any LMS. Moreover, the learning curve to create simple problems like radio-button, true/false option response, and string-response problems is relatively easy to overcome. Such problems only use XML and have pre-made templates to simplify making new problems.

The learning curve for creating numeric problems is a little steeper. These problems use both XML and Perl script, but are still fairly straightforward for anyone with some coding acumen. Building multi-part problems, with either all numeric response parts or with a mix of part types, is also not complicated. On the other hand, the learning curve can quickly become steep, when creating problems that use other systems such as Maxima, R, gnuplot, and Geogebra. Nevertheless, the ability of LON-CAPA to interface with such systems is one of the things that makes it so flexible and powerful.

Naturally, any hosted LMS must be supported by the institution's information technology personnel. For LON-CAPA, that requires a Linux server and comes with all of the pros/cons of open source systems. There is, however, a consortium available to provide advice.

Conclusions

LON-CAPA is arguably the best LMS for managing courses in a variety of STEM fields. In addition to tools for course administration, it provides a powerful set of tools for creating online quiz/homework questions, which provide numerous pedagogical and administrative benefits. Forms of online questions that can be created include radio button, true/false option response, matching option response, numeric response with randomized numbers and a variety of allowable tolerance specifications, equation rendering using randomized numbers, algebraic formula response, chemical formula response, dynamic plot generation using randomized numbers, interactive plot response, and multi-part problems using a mix of any or all of the above.

LON-CAPA is an open system used by over 150 institutions around the world. The learning curve to use its basic capability is reasonably low, but to use its full capability requires learning other systems, such as the Maxima algebra system, R statistics package, gnuplot plotting software, and Geogebra interactive mathematics and plotting system. Since LON-CAPA is an open system, there are many online quiz problems openly available to new users, especially in the physics, chemistry, and mathematics spaces. Unfortunately, penetration into the engineering and engineering technology spaces is low. One of the primary purposes of this paper, and others to follow, is to inform instructors in those spaces of a not-so-new but relatively unknown and very powerful tool available to them for improving teaching and learning in their classes.

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Biography

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Assessment of an Integrated Engineering General Education/Senior Projects Course

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Abstract

San José State University (SJSU), as part of the California State University (CSU) system, required that all undergraduate degrees, including engineering, be reduced to no more than 120 units. The mandate necessitated change to the overall structure of the College of Engineering's upper division general education (GE) requirements. The result of the restructuring has yielded a new two-course sequence intended to establish a relationship between the student's classroom experiences and engineering in the community, both in the U.S. and globally. Faculty in the engineering senior project classes then created GE activities linked to specific majors.

In addition to the university GE learning objectives, these courses meet ABET requirements. This integrated GE course sequence has been used for five years at SJSU. In this paper, the authors describe the structure of the senior-level GE course sequence and the evolution of this course over the past five years. Presently, most seniors take ENGR 195A/B concurrently with their two-semester senior project classes. Results indicate that approximately 95% of the students either met or exceeded the criterion for each GE student learning objective in the course. The overall assessment results indicate that this innovative structure has worked.

Introduction

Five years ago, the CSU Board of Trustees, in order to increase the four-year graduation rate and address budget issues, set a new policy: all undergraduate degrees, with a few exceptions, had to be reduced to 120 semester units (credit hours). Since the late 1990s, CSU has encouraged campuses to reduce the number of units required for bachelor's degrees to 120 units. By 2008, over 80% of the CSU degrees had been reduced. The CSU Board of Trustees decided to take a more proactive approach to this issue and mandated that all degree programs must be reduced to 120 units. CSU allowed campuses to petition to retain majors with over 120 units; however, SJSU administration elected to require all degree programs be limited to 120 units and did not submit any petitions for excess units.

The timeline was brief and required that the CoE move quickly so that proposals for how to proceed could run through the appropriate channels for review and approval via campus curriculum committees by the deadline of April 2013. Many programs looked towards double counting curriculum courses, which meant revising major courses to meet the GE requirements as well as the major requirements existing in the course.

In this paper, the authors report on one restructuring effort. SJSU students are required to take core GE courses in their first two years (English, speech, math, etc.). In their last two years, the university requires that students take upper-division GE (UDGE) courses (called SJSU Studies at SJSU). For over 10 years, the CoE has used a double-counted course, ENGR 100W: Engineering Reports, to meet both the upper division writing requirements for GE (alternatively known as Area Z) as well as one of the areas in SJSU Studies (Area R: Earth & Environment). Five years ago, the CoE decided to integrate the remaining two SJSU Studies areas (Area S: Self, Society and Equality in the U.S. and Area V: Culture, Civilization and Global Understanding) into the senior project classes. The revisions to the GE requirements were previously presented at ASEE (Backer & Sullivan-Green, 2016). Before the reduction to 120 units, SJSU engineering degrees consisted of 130 to 134 units. The reduction plan to 120 units included both double counting between GE and major courses and reducing required technical units for all degrees to 96 units.

The SJSU guidelines state that "the SJSU General Education Program incorporates the development of skills, the acquisition of knowledge, and the integration of knowledge through the study of facts, issues, and ideas. Regardless of major, all who earn undergraduate degrees should share common educational experiences, as they become university scholars. In combination with major, minor, and elective courses, the General Education curriculum should help students attain those attributes found in an educated person" (SJSU, 2014). It was the goal of this project to meet some of these UDGE requirements in an engineering context. To do this, the UDGE program for engineering majors was designed to include part of the math and science core, stand-alone UDGE courses, and integrated engineering/UDGE courses.

Review of the Literature: Incorporating GE into STEM

The first two years of college for most STEM undergraduate students focuses on gateway courses in calculus, physics, and chemistry. This process of completing pre-requisite courses while sitting in large lecture halls "weeds out" many students, with most dropouts from STEM majors occurring in the first two years (Griffith, 2010) and women and underrepresented minority (URM) students leaving STEM majors at disproportionately higher rates (McDade, 1988; Chen & Thomas, 2009; Tyson, Lee, Borman, & Hanson, 2007). Hynes and Swenson (2013) believe that not only does it weed out students with weaker math and science skills, it also weeds out people who may have been excited about working with people to solve problems that contribute to society. Previous research in STEM suggests female students prefer curricula that reflect real-world issues and focus on socially relevant material (Farrell, 2002; Litchfield & Javernick-Will, 2015; Schaffhauser, 2017).

In 1985, the National Research Council (NRC) recommended that social context should be included in engineering and that engineers should be prepared "not just from a technical standpoint, but on a social basis as well." Recent reports from the NRC (2003; 2005) and the American Association of Colleges and Universities (Global, 2007; Integrated, 2007) on STEM education have promoted integration for undergraduates, because this is better preparation to address the interdisciplinary nature of current STEM problems. Several institutions (Amber, 1998; Whittier, 2017) have integrated liberal arts content into STEM, including the D80 Center at Michigan Technological University (Paterson & Fuchs, 2007), the Mortenson Center Engineering for Developing Communities at the University of Colorado (Amadei, 2003), and the National Academy of Engineering's Grand Challenges initiative at several institutions (NAE, 2008; 2017).

Research into motivation has demonstrated that student motivation can be changed by changing instruction. A key predictor of motivation is the relevance of STEM course material. According to Cromley, Perez, and Kaplan (2015), this is "the students' perception that the content is valuable to them, either now or for future goals, such as their degree or career. Unfortunately, research shows that many undergraduates do not see the relevance of much gateway course content, such as calculus, and struggle in these required courses." Research has shown that motivation is related to grades (Ironsmith, Marva, Harju, & Eppler, 2003; Obrentz, 2012; Zusho, Pintrich, & Coppola, 2003) and retention in a STEM major (Hurtado, Newman, Tran, & Chang, 2010; Jones, Paretti, Hein, & Knott, 2010).

For future engineers, industry has been calling for a more holistic approach to engineering education to provide graduates with better communication skills, a more thorough knowledge of the impact of engineering on society (Spinks, Silburn, & Birchall, 2006; Black, 1994) and an ability to understand the social impact of new technologies globally (Layton, 1986; Shuman, Besterfield-Sacre, & McGourt, 2005; Jonassen, Shen, Marra, Cho, Lo, & Lohani, 2009). Crane and Chiles (2001) note that one way to develop this critical understanding is through the partnership of STEM and Liberal Arts faculty. The integration of GE and engineering content also addresses a retention issue with women engineering students: research into retention shows that women are retained in higher numbers if the engineering content emphasizes the social aspect of engineering (Berenson, Slaten, Williams, Ho, 2004; Duncan & Zeng, 2005; Thom, Pickering, & Thompson, 2002; Zastavker, Ong, & Page, 2006; Swan, Paterson, & Bielefeldt, 2014).

One of the first initiatives to integrate liberal arts into engineering was the Sloan Foundation's New Liberal Arts Initiative of the 1980s-1990s (Tobias, 2016). Despite this investment, there was little dissemination of the curriculum and STEM knowledge was not well integrated in the liberal arts education in most universities. More recently, the Teague Foundation and the American Society for Engineering Education (ASEE) partnered on a new project that integrates liberal arts and engineering (2018). This project has resulted in over a dozen courses and programs across the U.S.

Faculty Learning Community

A key piece of this project has been the use of the faculty learning communities (FLCs) to create a cadre of engineering faculty committed to integrated liberal arts content in engineering coursework. The change model underlying the work from this current study for facilitating organizational change is the social-cognition model. Change is non-linear; further, it "is a multifaceted, interconnected, overlapping series of processes, obstacles and individuals" (Kezar & Reich, 2012). The metaphor for change is based on the brain and includes complex and interrelated systems, mental models, and interpretation of new situations. A key to this model is sensemaking, a process of making sense out of change and ambiguity in the educational environment (Weick, 1995; Weick, Sutcliffe, & Obstfeld, 2005). The faculty work together in a multidisciplinary team through an FLC. Using the theory-of-change model (Eckel & Kezar, 2003), interdisciplinary teams facilitate discussions about beliefs and assumptions, because faculty typically work in silos and are not asked why they hold particular beliefs or embrace particular techniques of teaching (Gioia, Thomas, Clark, &

Chittipeddi, 1996). "This part of professional identity development is a process of negotiation between the roles and expectations placed on a profession by society and the individual who enters the negotiation with their own abilities and desires" (Paguyo, Atadero, Rambo-Hernadez, & Francis, 2015). Based on the social cognition model, the Community of Inquiry (CoI) framework was used as the basis for the curricular development and FLCs in this current study. The CoI has three components: cognitive presence, social presence, and teaching presence. Social presence is defined as the "ability to project one's self and establish personal and purposeful relationships" (Garrison, 2007). Cognitive presence is a cyclic process, whereby participants move from understanding the problem to exploration, integration, and application. Teaching presence includes two factors: design of the instructional environment and "directed facilitation" (Shea, 2006). Originally developed by Garrison and Vaughn (2007) for blended learning with online and in-class components, this model was applied to the revised classes.

FLCs were also aligned with the current project's theory of change; FLCs foster constructive interactions and allow faculty to explore their mental models about teaching. The FLCs were purposefully designed to foster faculty leadership and empower faculty to be change agents in their departments and at SJSU (Kezar & Reich, 2012). Research shows that successful FLCs are aligned with organizational goals (Shulman, Cox, & Richlin, 2004), cognitively independent and socially interdependent (Vaughan, 2004), and include people capable of leading and influencing change within their department or the university (Vaughan, 2004). Facilitation is important for fostering an inclusive and action-oriented FLC (Sandell, Wigley, & Kovalchick, 2004). Also, women and other URM STEM faculty are generally "socialized in collectivistic cultures where collaboration rather than competition serves as the energizing force and underlying value" (Petrone & Ortquist-Ahrens, 2004). The FLC model can become a place where "teachers develop powerful pedagogical strategies that support the learning of all students" (Decker Lardner, 2003).

The senior project faculty, along with the General Education faculty, who teach ENGR 195A and ENGR 195B, have formed an FLC aligned with the GE content of the senior project class. Each semester, engineering senior project faculty and course coordinators meet with the ENGR 195A/B coordinator and instructors of the GE senior project courses to discuss issues and potential improvements to the course. Each semester, the goal is to improve the GE content and delivery in ENGR 195A and B, as well as enhance the interrelation between those courses and the senior project classes.

Structure of the Engineering SJSU Studies Course Sequence

In order to receive credit for SJSU Studies, students must complete a two-semester course sequence, consisting of four complementary courses, and achieve grades of C or better in all courses in the sequence. The two general courses, ENGR 195A and ENGR 195B, coincide with Semester 1 and Semester 2 of students' senior project courses, which are specific to each major. ENGR 195A and ENGR 195B meet two hours per week for mini-lectures and presentations, followed by small group discussions. Three modules are done each semester. ENGR 195A and ENGR 195B is a two-course sequence that supports the integration of SJSU Studies Area S (Self, Society, and Equality in the U.S.) and Area V (Culture, Civilization, and Global Understanding) into the engineering major.

The goal of UDGE at SJSU is to assist students in becoming critical thinkers, who can connect ideas and concepts across various spheres. The College of Engineering at SJSU holds that it is crucial to the success of engineering students to have integrated UDGE student learning outcomes within the engineering curriculum. These two courses (ENGR 195A and ENGR 195B) challenge students to understand the role and importance of engineering, and thus their work, and their responsibilities as future engineers, both domestically and to the greater global community. This class sequence uses a case study approach, where students can reflect on the social, ethical, and cultural aspects of engineering. Each case study addresses one or more of the student learning objectives (LOs) in Areas S and V. Assignments in the ENGR course sequence are tied to activities and assignments in the senior project courses, which are discipline-specific.

Implementation of the Course Sequence

The 2013-2014 academic year piloted a modules-based system developed by the GE faculty. This system was developed with flexibility in mind. The new system allowed for changes to be made by additional faculty members, and encouraged more discipline-focused case studies. Every case study module has specific materials for students' learning experiences, including written material and resource links, a set of discussion questions, and a series of written assignments. The various themes addressed in each module provide the foundation for end-of-semester "application papers," where students address social, environmental, and cultural issues inherent in their own senior design project. The ENGR 195A/B courses are already included into syllabi of the senior project courses.

All LOs in UDGE Areas S and V are adequately addressed in ENGR 195A/B when integrated with the complementary student senior project work. The eight CoE programs offer many case studies and discussion questions relevant to each discipline. In addition to the case studies covered in ENGR 195 A/B, this system has students apply these concepts to their own senior project. Case study and discussion themes are listed in all senior project syllabi to emphasize the relationship between the content in the co-requisite courses.

A professor in the College of Engineering acts as the course coordinator for ENGR 195 A/B. All assignments in ENGR 195A/B require grading rubrics, which are reviewed by the coordinator to ensure that they meet the global rubrics for Areas S and V. The coordinator also schedules the instructors for the ENGR195A/B courses, provides an orientation for the students in ENGR 195A and ENGR 195B in the first weeks of class each semester, works with all faculty in ENGR 195A, ENGR 195B, and the senior project classes on creating and revising rubrics for GE assignments, completes and submits the GE Coordinator Summary Report to Undergraduate Studies, manages semester schedules for ENGR 195A/B, and collaborates with the instructors in the senior project classes to ensure the schedules are complementary to their classes, and revises the composite syllabi for ENGR 195A and ENGR 195B, making sure that the assignments for each senior project class and ENGR 195A/B have been updated.

The engineering senior project classes involve either a one-year team or individual project. In the first course in the sequence, students work on project definition, analysis, and design. In the second course, generally they work on construction and testing. Regular class sessions of the senior project courses involve a few lectures, but most course time involves team meetings, project work sessions, and/or presentations. In addition to an engineering project, senior engineering students also participate in discussions of GE topics in relation to their chosen profession in engineering. The first two pilot years of ENGR 195A and ENGR 195B were taught by three different instructors in each class, one per module. This led to inconsistencies in grading of the assignments. There was no relationship between the grades from the instructor of Module 1 to the grades from instructors for Modules 2 and 3. Students surveyed in the class believed that they did not know how to improve their submissions over the semester, since each instructor graded the work totally differently. This led to a change in the staffing of the courses for the 2016-2017 academic year. Instead of three different module instructors in each course, there is one instructor for each course who teaches all three modules.

Faculty teaching the engineering senior project classes requested graders from the College of Engineering to assist in grading GE assignments. As a pilot, the College of Engineering hired a team of graders in 2016-2017 to work with all the engineering senior project instructors in grading the UDGE assignments for the engineering senior project classes. The course coordinator of ENGR 195A/B trains and supervises the graders. Training and coordination of the graders has led to more consistency across the senior project classes in the grading of the UDGE assignments. In response to problems in the coordination between the ENGR 195A/B classes and the senior project classes, additional efforts were put in place in AY 2016-2017 to improve the synchronization between the paired courses. These efforts included additional training for the engineering faculty, regular meetings between the coordinator and engineering faculty, and a collaborative meeting each semester between the coordinator, senior project faculty, and the ENGR 195A/B instructors.

Each department can decide whether to allow students to begin their senior project in any semester or only the fall semester. Based on that decision, enrollment for ENGR 195A/B fluctuates. Enrollment for ENGR 195A is larger in the fall semesters and enrollment for ENGR 195B is larger in the spring semesters. Table 1 displays the enrollment in ENGR 195A and ENGR 195 B for the last academic year.

Table 1. Distribution of students by major, AY2017-2018 ENGR 195A & ENGR 195B.

	Fall 2017		Spring 2018	
Major	ENGR 195A	ENGR 195B	ENGR 195A	ENGR 195B
Aerospace	61	1		57
Biomedical	61			58
Chemical	35			37
Computer	22	27	21	22
Electrical	57	49	68	56
Materials	6			6
Mechanical	164	4	1	165
Software	48	33	46	47
Other	2	1	1	
Total	456	115	137	448

Assessment of the SJSU Studies Sequence

The composite ENGR 195A and ENGR 195B syllabi and the individual department senior project syllabi both include GE assignments. Students write their papers individually, based on Area S LOs (in ENGR 195A and in the first senior project course) and based on Area V LOs (in ENGR 195B and in the second senior project course). Figure 1 shows the ENGR 195.

V-LO3: Explain how a culture outside the U.S. has changed in response to internal and external pressures.

- ENGR 195B Reflection Paper 3 (500 – 750 words): Locate some technology, such as an application, mobile technology, or non-software based technology. Do research on how that technology has had a social impact on a culture or group of people outside of the US, regardless of where it was first designed and developed. Write an essay that addresses the topic above. (Word count: 500-750 words; up to 1500 words maximum).
- AE171B – Essay 3 (minimum 500 words): Assume your airplane will go into production in the US. Describe how your product will put pressure on a culture outside the US. (Choose a specific country.)
- AE172B – Essay 3 (minimum 500 words): Assume your spacecraft will go into production in the US. Describe how your product will put pressure on a culture outside the U.S. (choose a specific country.)
- BME 198B Case Study 1: Explain how an African community has been affected by the availability of medical care or lack thereof (minimum 500 words).
- CMPE/SE 195B, BME 198B, MatE Essay 3: Assume your project has become very successful in the U.S. Describe how your product will put pressure on a culture outside the U.S. (You have to choose a specific country). (Minimum 500 words)
- ENGR 195D Case Study 1: Pick a societal problem (homelessness, mass incarceration, cyber security, etc.). Select a country whose culture has changed to address this problem based on internal and external pressures. (Minimum 500 words)
- ENGR 195D Case Study 2: Select how a product related to your major has put pressure on a specific culture outside the USA. How has the culture been changed by this specific product? (500-750 words)
- ME 195b Individual Writing Assignment 2: Research one of the following renewable energy projects. Describe the cultural and social factors that led to these projects. Describe how these projects (Narmada Valley Dam Project (India), 3 Gorges Dam Project (China), Nam Theun-Hinboun Hydropower Project (Laos)) have evolved and influenced the culture of the country where they are located. If you were working on one of these projects and were a member of the National Society of Professional Engineers, what aspects of their codes of ethics would affect your work? In what way? Minimum word count: 400

Figure 1. Sample assignments for ENGR 195A and ENGR 195B for Area V.

Like all SJSU General Education courses, there is a minimum word count requirement in these courses. All students, independent of their discipline, complete the same writing assignments for ENGR 195A and ENGR 195B, three essays in each class. In addition, there are minimum length complementary essays in each senior project course. Detailed rubrics were developed in Canvas, SJSU's learning management system, to assess student achievement of the LOs (does not meet, meets, exceeds). Students receive written feedback both on grammar, sentence structure, and organization as well as on content using the SpeedGrader function in Canvas. Fall 2017 enrollment was significantly higher than previous years. Overall, there were 460 students enrolled in ENGR 195A in the fall of 2017 and 115 students enrolled in ENGR 195B. This increased number reflects the reduction to 120 units (discussed previously) as well as an SJSU effort to enroll more engineering majors as freshmen and transfer students.

In the fall of 2017, the SJSU College of Engineering undertook its ABET reaccreditation. As part of the process, the College presented the senior project sequence as meeting ABET criteria (j) "a knowledge of contemporary issues" and (h) "the broad education necessary to understand the impact of engineering solutions in a global, economic, environmental, and societal context." As well, SJSU uses the senior project sequence to partially fulfill ABET criteria (f) "an understanding of professional and ethical responsibility" (ABET, 2013). Each year, all GE courses at SJSU must submit an assessment report that records the effectiveness of the course in meeting the GE learning objectives. The college submits two assessment reports each year to the university, one for ENGR 195A and one for ENGR 195B. In addition, each of the engineering departments submits an assessment report for the partnered senior project course sequences.

ENGR 195A Assessment Results

For ENGR 195A, there are four required GE student learning objectives. S-LO 1 is "Describe how identities (i.e. religious, gender, ethnic, racial, class, sexual orientation, disability, and/or age) are shaped by cultural and societal influences within contexts of equality and inequality" (SJSU, 2014). Table 2 shows the results for S-LO1 for AY 2017-2018. Because students traditionally had difficulty with this LO, it was moved to the last essay in the class. Comparing fall 2017 and spring 2018 to fall 2016, more students met or exceeded the criterion after this change was implemented. S-LO 2 is "Describe historical, social, political, and economic processes producing diversity, equality, and structured inequalities in the U.S." (SJSU, 2014). Overall, the results from the AY 2017-2018 assessment are consistent with the 2016-2017 results. The instructor worked on the rubric and grading in the class; therefore, fewer students in 2017-2018 received "exceeded the criterion." However, as the results in Table 3 show, the combined numbers of met or exceeded the criterion are similar to 2016-2017.

Table 2. Results of student achievement on S-LO1, AY 2017-2018.

Number of students	Fall 2016	Fall 2017	Spring 2018	Total (2017-18)
Students who did not meet the criterion	35	4	21	25 (4%)
Students who met the criterion	89	65	25	90 (15%)
Students who exceeded the criterion	261	385	87	472 (80%)
Students who did not submit assignment	0	2	4	6
Total Students	384	456	137	593

Table 3. Results of student achievement on S-LO2, AY 2017-2018.

Number of students	Fall 2017	Spring 2018	Total 2017-18	Total 2016-17
Students who did not meet the criterion	13	9	22 (4%)	0
Students who met the criterion	76	56	132 (22%)	52 (10.4%)
Students who exceeded the criterion	359	70	429 (72%)	442 (85.6%)
Students who did not submit assignment	8	2	10 (2 %)	5 (1 %)
Total Students	456	137	593	499

One assignment in the class was used to assess both S-LO3—"Describe social actions which have led to greater equality and social justice in the U.S." (SJSU, 2014)—and S-LO4—"Recognize and appreciate constructive interactions between people from different cultural, racial, and ethnic groups within the U.S." (SJSU, 2014). Table 4 shows that, overall, the results from the AY 2017-2018 assessment are consistent with the 2016-2017 results. The combined numbers of met or exceeded the criterion are similar to 2016-2017.

For all of the S-LOs, the achievement numbers were lower in the spring semesters, when compared to the fall semesters. Table 1 shows that there were different majors in the class in spring, predominately computer engineering, electrical engineering, and software engineering. The course coordinator was going to work with the department coordinators of these majors on strategies to improve achievement numbers. Also, in the fall of 2018, the lead instructor for ENGR 195A was going to work with the engineering faculty on the content and course assignments for both ENGR 195A and the accompanying major assignments.

Table 4. Results of student achievement on S-LO3 and S-LO4, AY 2017-2018.

Number of students	Fall 2017	Spring 2018	Total 2017-18	Total 2016-17
Students who did not meet the criterion	4	21	25 (4%)	4 (<1%)
Students who met the criterion	65	25	90 (15%)	43 (8.6%)
Students who exceeded the criterion	385	87	472 (80%)	446 (89.4%)
Students who did not submit assignment	2	4	6	6
Total Students	456	137	593	499

ENGR 195B Assessment Results

There were three GE student learning objectives for ENGR 195B: V-LO1 is "Compare systematically the ideas, values, images, cultural artifacts, economic structures, technological developments, and/or attitudes of people from more than one culture outside the U.S." (SJSU, 2014). For the results from the assessment of LO V-LO1, Table 5 shows that 5.94% of the students in AY 2017-2018 either met or exceeded the criteria for this LO. This was an improvement over the results from 2016-2017. The instructor of this class worked on improving the class content related to this LO so that students would understand the material in greater depth.

Table 5. Results of student achievement on V-LO1, AY 2017-2018.

Number of students	Fall 2017	Spring 2018	Total 2017-18	Total 2016-17
Students who did not meet the criterion	8	18	26 (5%)	10 (2.3%)
Students who met the criterion	74	115	189 (34%)	139 (32%)
Students who exceeded the criterion	32	308	340 (60%)	282 (64.8%)
Students who did not submit assignment	1	7	8 (1%)	4 (<1%)
Total Students	115	448	563	435

V-LO2 is "Identify the historical context of ideas and cultural traditions outside the U.S. and how they have influenced American culture" (SJSU, 2014). Table 6 shows that 94% of the students in AY 2017-2018 either met or exceeded the criteria for this LO. This is an improvement over the results from 2016-2017. The instructor of this class worked on improving the class content related to this LO so that students would understand the material in greater depth.

Table 8. Assessment results of engineering senior project classes, fall 2017.

AE 171A	Essay 1--Identity	Essay 2--Diversity and Equality	Essay 3--Social Justice	Essay 4--Environmental Responsibility
maximum points	50	55	55	50
Mean	43.5 (87%)	47.15 (85.7%)	47.26 (85.9%)	39.9 (79.8%)
Median	46.50	47.00	48.50	42.00
SD	8.45	4.61	6.05	10.79

AE 172A	Reflection 1--Consider a negative side effect of space technology	Reflection 2--Diversity and Equality	Reflection 3--Social Justice	Reflection 4--Identity
maximum points	50	60	60	50
Mean	41.75 (83.5%)	48.16 (80.3%)	53.08 (88.5%)	48.5 (97%)
Median	42.00	49.00	54.50	49.00
SD	7.15	9.48	6.63	1.70

BME 198A (combined)	Reflection 1--Identity	Reflection 2--inequalities in healthcare	Reflection 3--access and beneficence	Reflection 4--Interactions between classes
maximum points	60	65	45	65
Mean	52.39 (87.3%)	58.37 (89.8%)	35.37 (78.6%)	50.8 (78.2%)
Median	55.00	61.00	36.00	53.50
SD	9.29	9.09	7.83	12.08

CMPE 195A	Essay 1--Identity	Essay 2--Diversity and Equality	Essay 3--Social Justice	Essay 4--Interactions
maximum points	50	75	50	75
Mean	42.17 (84.3%)	56.67 (75.6%)	42.05 (84.1%)	63.3 (84.3%)
Median	49.00	58.00	44.00	69.00
SD	12.07	11.84	8.54	13.15

CMPE 195B	Essay 1--Culture outside U.S.	Essay 2--Influences on U.S. culture	Essay 3 Case Study--Cultural change outside U.S.
maximum points	35	35	30
Mean	27.02 (77.1%)	26.47 (75.6%)	24.2 (80.7%)
Median	28.50	28.50	25.00
SD	7.46	9.58	7.14

EE 198A	*5 year plan (includes identities)	*Area S: SV Symposium	Reflection Paper 1--Social Justice	*Area S Meeting 1 (includes GELO2)
maximum points	50	5	50	40
Mean	46.3 (92.7%)	4.3 (86.7%)	38.87 (77.7%)	37.16 (92.9%)
Median	47.00	5.00	40.00	38.00
SD	3.39	1.71	10.21	2.95

EE 198B	GELO 2, Essay 1: "Tech invented outside of the U.S."	GELO 1, Reflection paper 1: "Successful Company"	Area V Meeting 1 (includes GELO 2)	Area V Meeting 2 (includes GELO 2)
maximum points	100	100	40	30
Mean	82.65	87.56	39.22	27.31
Median	88.00	94.00	40.00	30.00
SD	14.69	11.66	1.42	4.30

ENGR 195C	Essay 1--GELO 4	Essay 2--Diversity and Equality	Essay 3--Social Justice	Essay 4--GELO 1
maximum points	65	55	55	50
Mean	57.8 (88.9%)	36.4 (66.2%)	45.03 (81.2%)	43.25 (86.5%)
Median	59.00	38.00	45.50	42.00
SD	4.94	14.32	7.77	5.11

MatE 198A	Reflection 1--Identity	Reflection 2--Diversity and Equality	Reflection 3--Social Justice	Reflection 4--Interactions between cultures and classes
maximum points	50	50	55	60
Mean	42 (84%)	41.5 (83%)	41.7 (75.8%)	only 4 out of 7 students submitted assignment
Median	42.50	42.00	45.50	
SD	6.58	5.19	12.35	

ME 195A	Diversity & Equality	Ind Writing Assignment 2: Identities and Interactions	Ind Writing Assignment 3: Social Actions
maximum points	100	100	100
Mean	83.42	83.22	80.33
Median	84.00	85.00	78.00
SD	11.33	14.36	11.40

Table 6. Results of student achievement on V-LO2, AY 2017-2018.

Number of students	Fall 2017	Spring 2018	Total 2017-18	Total 2016-17
Students who did not meet the criterion	5	14	19 (3%)	10 (2.3%)
Students who met the criterion	55	75	130 (23%)	139 (32%)
Students who exceeded the criterion	52	345	397 (71%)	282 (64.8%)
Students who did not submit assignment	3	14	17 (3%)	4 (<1%)
Total Students	115	448	563	435

V-LO3 is "Explain how a culture outside the U.S. has changed in response to internal and external pressures" (SJSU, 2014). Table 7 shows that the achievement level of students on this LO was lower in 2017-2018, when compared to 2016-2017. The instructor gave the students more time (until 5/23 in the spring of 2018). Inadvertently, this might have caused the reduction in student achievement. Since the students in ENGR 195B were finishing their senior projects at that time, they probably did not spend enough time on this assignment. The course coordinator and instructor for this class met to discuss this LO and work on improvement strategies.

Table 7. Results of student achievement on V-LO3, AY 2016-2017.

Number of students	Fall 2017	Spring 2018	Total 2017-18	Total 2016-17
Students who did not meet the criterion	12	84	96 (17%)	17 (3.9%)
Students who met the criterion	48	138	186 (33%)	197 (45.3%)
Students who exceeded the criterion	51	216	267 (47%)	214 (49.2%)
Students who did not submit assignment	4	10	14 (2%)	8 (1.8%)
Total Students	115	448	563	435

Assessment of the Complementary Senior Project Courses

As part of the continuous improvement of the GE portion of the senior project classes, the college undertook an analysis of the student outcomes from the engineering senior project courses. Means, medians, and standard deviations of all GE essays in the engineering senior project classes in the fall of 2017 (see Table 8) and the spring of 2018 (see Table 9) were investigated. In particular, focus was directed on essays that had low mean grades (indicated in yellow) and those with high standard deviations (indicated in green). The course coordinator and the engineering senior project instructors were going to work on these assignments.

Summary

As a result of the mandated unit reduction at SJSU, the upper division General Education requirements, known as SJSU Studies, for the College of Engineering were incorporated into the engineering curriculum. Each semester of the two-semester disciplinary senior project course sequence was linked to a one-unit course to cover the upper division GE requirements for Areas S and V and incorporate the GE content into students' senior projects. A series of interconnected modules and projects was developed to assist students in reflecting on the GE outcomes in an engineering context. Since 2015-2016, most senior students have taken ENGR 195A/B concurrently with their two-semester senior project classes. The overall assessment results indicate that this innovative structure has worked, as most students have met the GE learning objectives and improved their social, environmental, and cultural awareness within their engineering discipline.

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Table 9. Assessment results of engineering senior project classes, spring 2018.

AE 171B	Reflection 1--SLO 1	Reflection 2--SLO 2	Reflection 3--SLO 3	Reflection 4-SLO 3
maximum points	50	50	50	50
Mean	38.97 (77.9%)	37.14 (74.2%)	40.55 (81.1%)	38.56 (77.1%)
Median	42.00	39.50	42.00	39.50
SD	7.69	11.79	6.66	5.93
AE 172B	Reflection 1--SLO 1	Reflection 2--SLO 2	Reflection 3--SLO 3	Reflection 4-SLO 3
maximum points	50	50	50	50
Mean	40.68 (81.4%)	43.86 (87.7%)	38.84 (77.7%)	44.6 (89.2%)
Median	41.00	47.00	39.00	46.00
SD	7.85	6.69	6.19	5.49
BME 198B	Reflection 1--SLO 1	Paper 2--SLO 2	Paper 3--SLO 3	Case Study 1--SLO 3
maximum points	60	60	60	40
Mean	56.58 (94.3%)	55.25 90%)	57.39 (95.7%)	35.47 (88.7%)
Median	57.00	56.00	57.50	35.00
SD	2.54	3.74	2.53	2.28
CMPE 195A	Essay 1--SLO 1 Identity	Essay 2--SLO 2 Diversity and Equality	Essay 3--SLO 3Social Justice	Essay 4--SLO 4 Interactions
maximum points	50	75	50	75
Mean	40.8 (81.6%)	57.14 (78.7%)	41.6 (83.2%)	56.1 (74.7%)
Median	41.00	59.00	41.00	55.00
SD	7.18	14.20	6.13	16.17
CMPE 195B	Essay 1--SLO 1 Culture outside U.S.	Essay 2--SLO 2 Influences on U.S. culture	Essay 3 Case Study--SLO 3 Cultural change outside U.S.	# 7 students received grades of zero --w/o zeros, mean would have been 26.4 (75%); ##6 students received grades of zero--without zeros, mean would have been 22.7 (65%)
maximum points	35	35	30	
Mean	26.36 (75.3%)	#22.85 (65%)	##20.3 (58%)	
Median	29.00	24.00	21.00	
SD	9.38	9.93	8.00	
EE 198A	*5 year plan (includes SLO 1 identities)	Essay 2: SLO 2 Your project's implication in Area S	Lead Free Essay: SLO 3 Social Actions	
maximum points	50	50	50	
Mean	40.5 (81%)	40.47 (81%)	40.8 (81.6%)	
Median	41.00	41.00	42.00	
SD	4.74	7.11	5.06	
EE 198B	GELO 2, Essay 1: "Technology invented outside of the U.S."	GELO 1, Reflection paper 1: "Successful Company"	*Area V Meeting 1 (includes GELO 2)	*Area V Meeting 2 (includes GELO 1)
maximum points	100	100	40	40
Mean	76.04	77.82	37.7 (94%)	27.7 (69%)
Median	75.00	79.00	40.00	30.00
SD	10.41	13.63	3.16	5.74
*graded by EE coordinator and/or EE faculty				
ENGR 195D (ENGR Projects in Comm. Service)	***Area VLO 1 Essay	***Area VLO 2 Essay	Area VLO 3 Essay 1	Area VLO 3 Essay 2
maximum points	100	100	50	50
Mean	83.38	58.16	39.47 (79%)	33.9 (67%)
Median	95.00	64.00	39.00	36.00
SD	28.17	22.52	8.53	11.48
MatE 198B	Essay 1--SLO 1	Essay 2--SLO 2	Essay 3--SLO 3	
word count min.	500	500	500	
maximum points	100	100	55	
Mean	83.00	74.00	83.00	
Median	75.50	80.00	83.00	
SD	7.76	12.22	8.84	
ME 195B	Online Module and Individual Writing Assignment #1--SLO 2	Individual Writing Assignment #2--SLO 1	Individual Writing Assignment #3--SLO 3	
maximum points	100	100	100	
Mean	72.6	79.4	82.2	
Median	76	84	88	
SD	21	18.6	20.3	

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