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Hands-On Measurement and Instrumentation Course Accessibility for Visually Impaired Students

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I. Introduction

The Aerospace and Mechanical Engineering (AME) Department at the University of Southern California has been working to adapt their Mechanical Engineering (ME) curriculum to be accessible for the visually impaired since Fall 2021, when a visually impaired student enrolled as a Freshman in the ME program. The AME department was able to successfully deliver classroom-based engineering curriculum during this student's Freshman and Sophomore years. However, USC's dedication to a hands-on engineering pedagogy, which accelerates during student's Junior year, presents unique challenges for accessibility.

The cornerstone of the active learning ME curriculum during Junior year is the two-semester laboratory sequence AME 341a: "Measurement and Instrumentation Laboratory" and AME 341b: "Mechoptronics." These courses teach students essential laboratory skills, critical assessment of engineering measurements, and the fundamentals of electronics, automation and integrated systems. These courses are purposely structured to break students from habits of rote learning and the expectation that all engineering problems have a "right" answer. Successful completion of the AME 341 sequence requires students to develop their own intuition and independence in a laboratory environment. Bridging the classroom and work environment, the laboratory experiments are specially designed to ensure that students stop, think, decide, and discover. It is therefore crucial for all graduating AME students to receive the full laboratory experience.

This paper aims to present the accessible solutions developed for the AME 341 course sequence, and reflects on the experience from the point of view of instructors, teaching assistants, and a visually impaired student. It initially was found that there were no ready accessibility solutions for test and measurement hardware. Thus, USC developed their own hardware and curriculum to ensure that visually impaired students would receive the same educational experience as their sighted peers.

a. Existing Literature

Vision-based teaching methods have become ubiquitous in the modern mechanical engineering curriculum through the universal adoption of computer-based tools in both the classroom and laboratory. However, this heavy reliance on a vision-based teaching and engineering practice does not consider the needs of visually impaired students. This gap in accessibility is even more challenging in engineering laboratory courses.

Globally, over 250 million people live with some form of visual impairment, according to a study done by the CDC in 2017 [1]. In the US, of the over 20 million persons living with visual impairment, only 1 in 100 continue to higher education, in part due to lack of accessible devices and the large expense of current accessibility options [2]. As STEM education has become a primary pillar of today's economy and livelihood, it has highlighted the necessity of making engineering education accessible.

Some of the key challenges in creating an accessible environment for visually impaired students include accessing technical notation, visual resources, and teaching methods and strategies [3]. Producing Braille math requires knowledge of Nemeth Braille or secondary software to convert equations for presentation on a Braille display. LaTeX equation mark-up doesn't translate well to tactile or Braille displays and requires the use of screen reading software where the end-user must translate the LaTeX code and punctuation. Microsoft Word's latest version of Equation Editor is compatible with screen reading software and provides mathematic notation in a tractable format.

STEM courses rely heavily on visually-delivered information in the form of diagrams, graphs, charts, images, etc. Being able to access visual references is assumed in an engineering course, so teaching methods must be revised to deliver similar information in either a tactile, audio, or alternative method. Access plans for education technologies must be developed such as those described in Clippinger et al. [5]

There have been several efforts to automatically create tactile graphics for the visually impaired for personal and professional use [6]. Race et al. have created a discernible tactile schematic using low-cost microcapsule fusers. These schematics act as tactile based circuit diagrams for visually impaired with raised surfaces on paper [7]. Another approach given by Engel et al. is SVGPlott, which is an accessible tool to generate highly adaptable audio-tactile charts for the visually impaired [8]. Hakim et al. proposed a mechatronics approach to process digital images, displaying them in tactile graphic format using a Raspberry Pi 3 and a mini push-pull solenoid with a combination of Python and OpenCV to create an assistive device for the visually impaired [3]. There are multiple development projects approaching engineering education for the visually impaired, but these techniques are still in-progress and there is no complete or commercial option for effective accessibility. Similarly, there is no defined standard for communication of equations, graphics and low-accessibility legacy charts and graphs. Thus, universities currently working with the visually impaired must develop their own teaching techniques.

USC's AME department began the process of creating accessible content for laboratory instruction well in advance of the semester. The goal of this project was to implement accessible solutions in the laboratory, which would allow visually impaired students to conduct the same labs as their sighted peers and retain the unique and necessary education that comes from hands-on learning.

b. Implementation Timeline and Resources

The development of accessibility resources for AME 341a & AME 341b began in early March of 2023, six months ahead of the 2023/2024 school year. The first point of contact was USC's Office of Student Accessibility Services (OSAS). OSAS provides accessibility recommendations to instructors and coordinates standard accommodations for lecture-based courses, such as ordering braille textbooks and providing accessible testing centers for exams. However, the creation of specific laboratory-course accommodations was ultimately delegated by OSAS to the Aerospace and Mechanical Engineering (AME) department.

The AME department provided significant and necessary support for its instructors to develop accessible course materials. A Ph.D. student was hired as a full-time teaching assistant (TA) throughout the summer to develop lab accessibility hardware under instructor supervision. This Ph.D. student was returned to research assistant status in the Fall by their advisor, so the AME department again requested, and was granted, permission to hire an MS student as a full-time TA for the 2023/24 academic year. This MS student's sole duties were to support the visually impaired student in AME 341. By offering full TA support to a continuing M.S. student, the department was able to attract and hire a student who had previously received an A in the AME 341 sequence and approached the semester with knowledge of the course structure and material. Additionally, hiring an MS student ensured continuity throughout the full academic year. It should be stressed that providing a significant employment offer, beyond the typical note-taker positions offered by OSAS, was needed to attract the necessary talent to this position.

In addition to full-time TA support for AME 341, it was also essential for the AME department to provide a "course producer" to support accessibility for all other AME and engineering courses. This staff member was paired with the visually impaired student starting from freshman year in AME 101. By forming this working relationship early, a vernacular was developed, allowing for efficient communication of course materials. By starting this process in AME 101, which is a precis of the larger engineering curriculum, effective communication methods for engineering education were established early. It would not have been possible to smoothly transition into the accessible version of AME 341 without the previous two years of work.

Full-time staff dedicated to accessibility development and implementation was essential to adding accessibility to our laboratory courses. AME 341 typically has an enrollment exceeding 160 students and over 20 hours of student contact hours per week for each instructor. A separate full-time staff member dedicated to accessibility was required to have sufficient bandwidth to effectively prepare accessible labs, course materials and assignments throughout each week.

It is strongly recommended that a similar approach be taken at other universities who are working towards accessibility for the visually impaired in Mechanical Engineering. Assessment of available University resources needs to occur well in advance and staff needs to be appointed so that sufficient time is available to develop meaningful accommodations. By not solely relying on already time-limited instructors to develop additional course content, USC's approach ensured all students were able to have a meaningful course experience.

c. Resources Overview

Accessibility in AME 341a & AME 341b was approached using both standard accessibility methods as well as course-specific tools developed at USC. Standard accommodations used in preparation of AME 341 included braille textbooks, course documents in MS Word with screen reader accessible headings and equations, and the preparation of alternative lecture slides prior to lecture which were sequenced using the previous year's lecture notes. These non-laboratory, course-specific accessibility tools should and can be applied to all courses.

Each course in the laboratory sequence will be discussed separately due to their unique educational requirements and separate focus. In addition to the tools developed at USC, this paper also hopes to highlight implementation roadblocks uncovered during our development process and present accessibility requirements that are non-obvious to those without experience working with the visually impaired. What can appear as a small oversight can have a significant impact on access to the course content as a whole.

Furthermore, this paper can serve as a guide not just for university departments, but also for industry. Developing accessible test and measurement tools is essential for professional inclusion and appears to be an underdeveloped aspect in multiple fields of engineering.

II. AME 341a: Measurement and Instrumentation Laboratory

a. Course Overview

The first class in USC's test & measurement laboratory sequence is "AME 341a: Measurement and Instrumentation Laboratory." The goal of this course is to teach students how to independently take and interpret measurements in a laboratory setting. The course begins with asking the question, "what is a measurement?" and focuses on uncertainty quantification and effective laboratory techniques with common tools such as digital oscilloscopes, digital multimeters, and waveform generators. After students are proficient in the use of laboratory equipment, the course focuses on building basic circuits including voltage dividers, low-pass and high-pass filters and common operational-amplifier circuits. The purpose of instruction on basic electronics is for students to become literate in the foundational theory which forms the building blocks for the majority of laboratory equipment. In this manner, future use of test equipment isn't simply working with a "black box." Finally, students use their measurement skills to characterize these basic electronic circuits and compare their real-world behavior to simplified first-order models and assess if their approximated models are sufficient to describe essential system behavior.

AME 341a encourages students to approach engineering quantities and measurements with a critical approach so that they don't take reported numbers at face-value. Assessing measurement limitations and the assumptions which underly common models and equations allows students to leave AME 341a with an understanding of what reported numbers physically represent and the real-world limitations to their experimental knowledge. These goals can only be achieved through hands-on instruction and moments of discovery in the laboratory. It is required that students build their own circuits and capture their own measurements, forcing them to independently evaluate the efficacy of their measured quantities. Instructors and teaching assistants oversee the laboratory with a "hands in pockets" approach, requiring that students reason through their choices and evaluate their results, rather than just wait for the correct answer. This process builds intuition for students, ultimately leading to fundamental understanding and the development of lifelong skills.

Accessibility for AME 341a requires that all students be able to conduct hands-on learning and utilize laboratory equipment. Without the ability to independently make measurements choices, the course loses the element of discovery and is fundamentally altered. As discussed in the Introduction, there are limited accessibility options for the visually impaired for common laboratory tools. Thus, novel measurement tools had to be created from scratch to preserve the laboratory experience.

It was determined that the oscilloscope was the most impactful piece of laboratory equipment for measurement and characterization of experiments in AME 341a. Laboratory experiments require the characterization sine wave circuit input/output, and graphic representation of attenuation and phase delay are core elements of the laboratory experience. Furthermore, the built-in functionality of the oscilloscope to measure quantities such as the mean, RMS, V_{p-p}, etc. can replicate most measurements captured on other laboratory hardware. In addition to measurements, students learnto manipulate the oscilloscope's controls for resolution in both voltage and time, observing the effect of these choices independently.

USC developed a novel "tactile oscilloscope" in-house to meet the accessibility needs of the AME 341a. This piece of equipment became the foundation of the AME 341a laboratory experience and enabled active participation in the existing laboratory structure. Additional laboratory tasks were effectively accomplished in tactile manner through the regular use of electronic equipment with braille labeling and labeled circuit elements. Tasks without a readysolution for the visually impaired were explained and accomplished by a sighted aid (i.e. adjusting waveform generator settings).

b. Development of the Tactile Oscilloscope

1. Goal for the Device

Oscilloscopes take electrical signals and output numeric measurements of several key signal parameters and clearly visualize the signal on a built-in display. Additionally, the display of an oscilloscope presents a clear, graphical visualization of the shape of a measured signal. This visualization provides intuitive and immediate insight into the underlying phenomena. A similar intuition is difficult to achieve purely from measured numeric parameters. The ability of an oscilloscope to provide a graphic representation of a signal is especially valuable in an educational environment, being able to visualize the signal helps the student ensure that any measurements taken by the oscilloscope are reasonable, and that the oscilloscope settings are adjusted appropriately for the signal under investigation.

Oscilloscopes present all their data via a built-in screen making these devices inherently inaccessible to visually impaired users. The goal of the tactile oscilloscope was to provide the utility of a typical screen-based oscilloscope in an accessible format. Moreover, since this device will be used in an educational setting, it was desirable that the user experience be as similar as possible to that of using a traditional oscilloscope. Lastly, all system components were developed inclusively so a visually-impaired user could understand all the programming and hardware implementation and make changes as they felt necessary.

2. Implementation

A traditional oscilloscope (Tektronix TDS2014c) was used to gather signal data and measure key signal parameters. Data and measurements were then imported from the oscilloscope to a PC via an RS-232 Serial connection and post-processed via MATLAB. The waveform was plotted to exactly resemble the signal plot in the display of the Tektronix oscilloscope, including accurate scaling of the waveform and of the gridlines marking volts/division and seconds/division. An Orbit Graphiti – a commercially available tactile display – was connected via HDMI to the PC and then used to display the MATLAB graph formatted for optimal tactile reproduction. Through the Graphiti, the waveform can be displayed in an accessible format simultaneously with the output on the Tektronix oscilloscope screen.

Additionally, the MATLAB script outputs numeric measurements of various signal and measurement parameters via computer-speech, providing audio feedback. The user requests these, as well as alternative channel configurations, via keyboard commands. This is especially important when measuring multiple signals at once: it was found that two overlapping signals were far easier to perceive on the Graphiti display if each signal could be individually toggled on and off. A schematic of the system is provided below, in Figure 1.

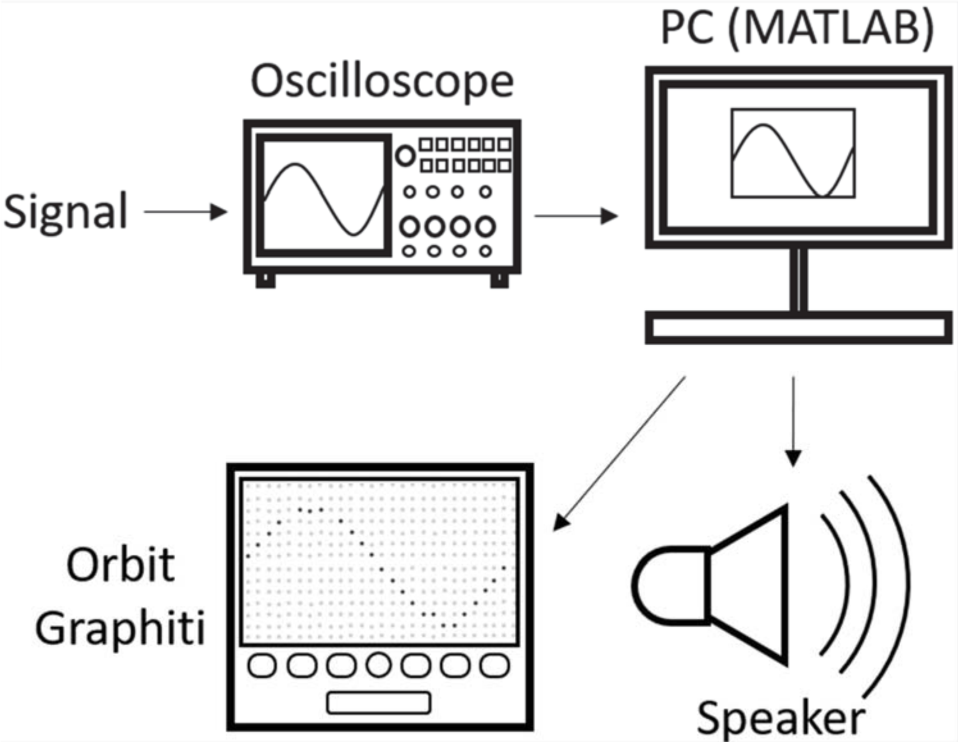

Figure 1: Schematic of the Tactile Oscilloscope. Electronic signals are measured by a conventional Tektronix oscilloscope and data is subsequently passed to a PC that renders the waveform plot via MATLAB script. The plot is then projected to an Orbit Graphiti tactile graphics display, while key signal measurements are available by audio output (accessed via keyboard commands).

3. Comparison to a software-based approach

An alternative approach considered for this project was to gather signals using an NI-DAQ device (or similar) and process the data using existing software, such as NI-SCOPE, which would directly display waveform plots on the PC monitor without the need to develop a secondary software script with custom plots. In principle, plots from existing software would be used and then be projected to the Graphiti for tactile display. However, it was found that the Graphiti's interpreter was incapable of displaying unmodified plots due to the low 60x40 pin resolution.

Each pin on the Graphiti represents a region of pixels on screen, and the height of each pin is determined by averaging the color of its representative region. The plots drawn by existing software-based oscilloscopes typically feature thin lines, which are insufficient to noticeably change the height of the Graphiti pins. An intermediate software-level solution was therefore necessary to format plots that could be consistently captured and replicated by the Graphiti. The choice of MATLAB scripting for the tactile oscilloscope allowed for further functionality to be easily implemented, including audio output of signal measurements and keyboard-commanded control of plot appearance. Additionally, MATLAB is a reasonably accessible software and a cornerstone of the AME 341 education, so developing the tactile oscilloscope program in this environment satisfied the goal that this system be inclusive in its overall architecture.

With regards to the choice of measuring device, the Tektronix oscilloscope was chosen over a digital DAQ with a software emulated oscilloscope because this approach invites its user to interact with the controls of the discrete oscilloscope, providing an educational experience more akin to that of a sighted student.

4. Hardware Used and Hardware Requirements

Table 1 lists the primary system components involved in the tactile oscilloscope, not including necessary cables for connecting the devices. It must be stressed that this was not a "low-cost" accessibility solution. The Orbit Graphiti costs \$15k from the manufacturer with a multi-month lead time. In-stock suppliers of the Orbit Graphiti charge \$25k for the same device.

Table 1: A list of components involved in the tactile oscilloscope

Hardware	Purpose	Set-Up Requirements
Tektronix TDS2014C Oscilloscope	Gathers signal data	• Braille labelling affixed to critical knobs and buttons
Desktop Computer	Imports data from oscilloscope, processes via MATLAB, sends waveform data to Graphiti and announces measurements of signal parameters via speakers.	• Windows 10 installed • MATLAB R2023a installed • Instrument Control Toolbox Addon installed • USB port for connecting to the oscilloscope • HDMI port for connecting to the Graphiti Tablet • Speakers for audio output
Orbit Graphiti	Provides tactile representation of measured signal, 60x40 pixel grid	• Knowledge of Graphiti controls which provide only Braille feedback

Care must also be taken when installing the drivers required for MATLAB to interface with the Tektronix oscilloscope. The oscilloscope communicates with the lab PC via the TEKVISA connectivity software. However, it was found that having National Instruments LabView installed on a given PC alters the driver associations in Windows for VISA prohibiting the TEXVISA software from accessing the oscilloscope. It was not possible to correct this error by manually reassigning the drivers, uninstalling NI LabView or re-installing TEKVISA. Thus, the tactile oscilloscope arrangement only worked on PCs with Windows installations which has never had NI LabView installed.

c. Practical Experience in the Laboratory

The tactile oscilloscope was the primary piece of interactive equipment in the laboratory and Figure 2 shows the implementation of the tactile oscilloscope for one and two channels. Waveforms were displayed on the Graphiti tablet and measurements - including frequency, peak-to-peak voltage, cycle RMS, and mean voltage - were retrieved from the Tektronix oscilloscope via MATLAB and read aloud from an audio output. The Graphiti display updates in quasi real-time to reflect the signal captured by the oscilloscope, allowing the student to interact with the signal and visualize the effects of modifying volts/division and seconds/division, as well as understand the importance of properly displaying a signal when capturing measurements.

Braille labeling was used for discrete controls, allowing the student to adjust volts/division and seconds/division and have those settings read back via an MATLAB audio output. However, controls on the Tektronix scope without discrete buttons remain inaccessible as they require the use of on-screen menus and are not transmitted from the scope via the serial connection. These settings, such as AC/DC coupling, probe attenuation and measurement settings had to be accomplished by the TA. While this process was not independently interactive, the Graphiti successfully demonstrated their effects, thereby accomplishing the primary objective of teaching such settings.

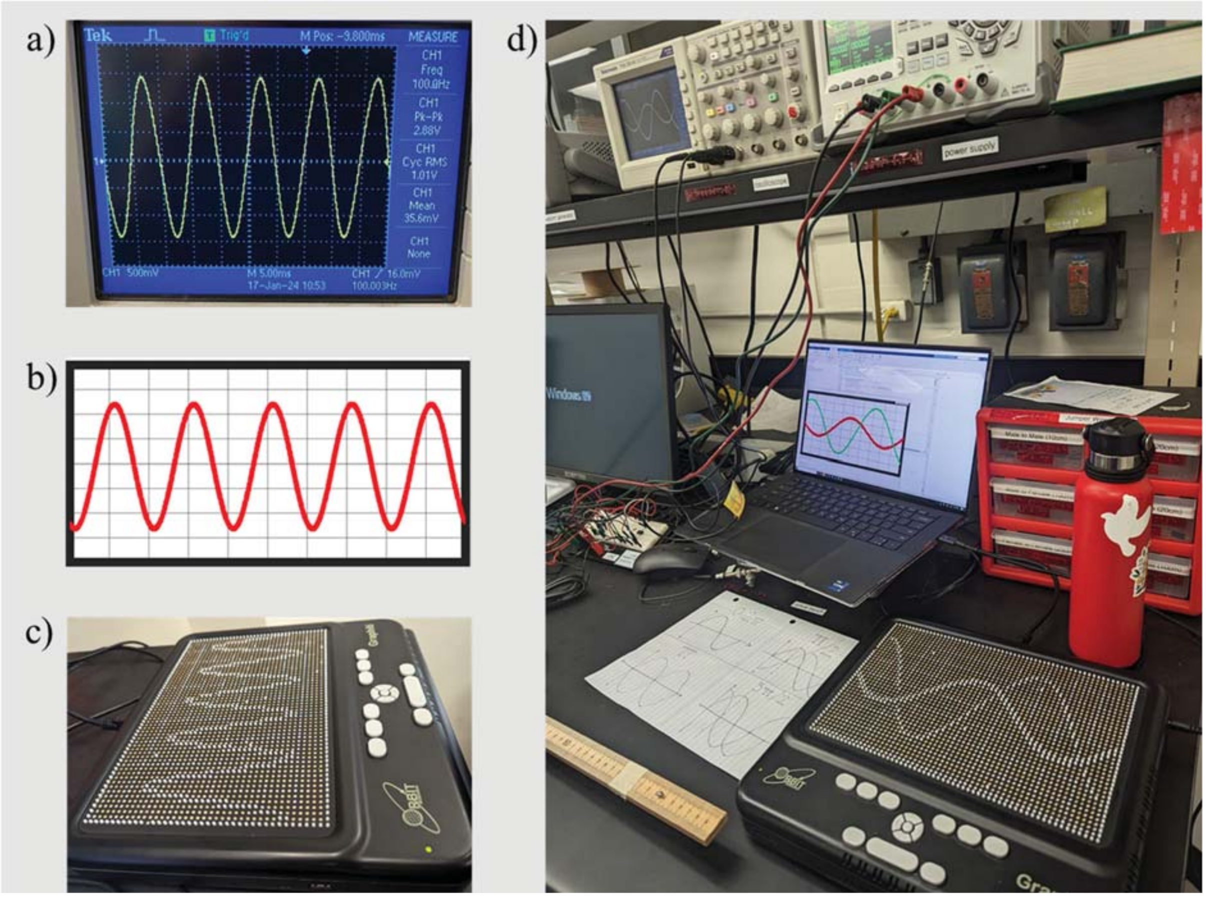

Figure 2: Photographs of the Tactile Oscilloscope in operation. a) A 100 Hz waveform displayed on the Tektronics oscilloscope display. b) The same waveform output to the lab-PC via a serial connection and rendered in MATLAB for optimal display on the Graphiti c) The same waveform displayed on the Graphiti tablet with an identical 8x8 measurement grid. d) A dual-waveform implementation of the tactile oscilloscope demonstrating phase delay and attenuation.

The low-pass filter lab from AME 341a can be used as an example of a typical bench-top experiment to demonstrate the practical experience of using the tactile oscilloscope. In this lab, students measure the input and output to a low pass filter and record the attenuation across multiple frequencies. The lab begins with the student constructing the circuit on a breadboard while the TA checks the coupling, probe attenuation, and measurement settings on the Tektronix oscilloscope. The student then sets the Graphiti to an 8-bit greyscale display to easily differentiate gridlines from the waveform and navigates the display to the projected plot area in MATLAB. Once the signal is displayed, the student uses the MATLAB tactile oscilloscope software to request an audio reading of the seconds/division and uses the projected gridlines to make an informed estimate of the time constant, μ, characteristic to the low pass filter. The tactile oscilloscope can be further used to provide an audio reading of V_{RMS} for each channel so the student can populate an amplitude response plot.

The tactile oscilloscope proved crucial in teaching key behaviors, such as the effect of varying sampling frequency on discrete signals, the difference between an aliased and true signal, and familiarity with the time trace of a signal and its power spectra. Furthermore, the tactile oscilloscope's ability to display two signals simultaneously, as well as easily toggle between the two, enabled the student to observe the phase shift and change in amplitude for inputs or outputs simultaneously.

Fundamental laboratory accessibility was achieved with the tactile oscilloscope. However, there were distinct limitations when compared to the native functionality of the discrete Tektronix device. The tactile oscilloscope had a noticeable lag between the oscilloscope and the Graphiti. When the student made a change to the settings on the oscilloscope, the MATLAB script had to be manually prompted to request an update taking approximately 15 seconds to complete. After receiving serial information from the scope and rendering the screen in MATLAB, it then took an additional five seconds for the Graphiti to update with the change. This time-intensive process was a bottleneck in time-limited labs and it is unclear if there is a workable solution to improve this delay since it is related to the serial port download speed between the oscilloscope and the PC.

Additionally, the tactile oscilloscope's limited 60x40 pixel resolution resulted in confusion in the laboratory. For example, the student found it difficult at times to tell the difference between a sine wave and a triangle wave due to the lack of peak definition. The limited screen size resulted in a limited amount of information that could be shown at once, typically a maximum of two periods of a given waveform. Furthermore, obtaining an ideal viewing of the MATLAB rendered graph on the Graphiti required the visual support of the TA preventing the student from independent operation of the tactile oscilloscope.

When not using the tactile oscilloscope, accessibility was achieved through braille labeling of components or using the TA as a sighted aid. For example, breadboard circuit construction was conducted by the student using labeled components and a stylus to locate the appropriate circuit connection on the breadboard. However, due to the compactness of the terminals on the breadboard, it was easy to confuse adjacent connections which were conflicting by a single column. A breadboard with terminals spaced larger than the standard 0.1" spacing would help address this issue.

Throughout the course, laboratories were held to the same 3-hour time limit for all students and data collection requirements were kept the same. To accommodate laboratory delays due to the aforenoted tactile oscilloscope limitations, labs with large data sets were condensed into collection of key data points using accessible hardware and TAs provided the remaining data. Before each lab, instructors and TAs discussed which aspects of each were essential educational experiences and outcomes to ensure they could be delivered accessibly.

d. Accessibility for Lectures and Assignments

Outside of the laboratory, multiple plans were implemented to create accessible lecture and assignment content. Like many engineering courses, AME 341 requires the student to follow notes with equations and their derivations as well as circuit and system diagrams. Incorporating equations into accessible notes has a ready solution through the current version of Microsoft Equation Editor. Over the past decade, Microsoft has been implementing accessible functions into Word including an updated equation editor which presents equations in a way that can be read by commercial screen reader software (as opposed to inaccessible "objects"). MS Word is currently the most widely used word processor with reasonable accessibility tools and became the primary delivery mechanism for written content.

AME 341 lectures are taught via PowerPoint presentation skeletons which instructors mark-up with handwritten notes during lecture. PowerPoint skeletons were converted to accessible Word documents, and notes handwritten by the instructor were incorporated into the Word documents before their delivery in lecture. Creating these documents required adherence to multiple accessibility guidelines so that a screen reader could navigate the document beyond basic text. These guidelines are as follows:

i. It is important to structure the document with headings (designated as *heading fields* in MS Word), which helps readers understand how the document is organized. This special formatting collects all the headings in the document's Outline, which can be used by screen readers to efficiently navigate the document as most screen readers can jump between headings. Text can be changed to a heading in Word by highlighting the relevant text and selecting one of the heading styles from the *Styles* menu. Headings can be easily managed by opening the *Outline View*. In the case of AME 341, where PowerPoint lecture slides were converted into accessible Word documents, the slide title and slide number were used as the heading to facilitate navigating through the notes.
ii. When creating lists, it is important to make use of the *list* buttons in the Home ribbon. Without using this tool, screen readers may have difficulty recognizing the object as a list. To verify if a list (ordered or unordered) is properly created, ensure a new bullet appears automatically when creating new list entries.
iii. It is crucial to only create simple tables in MS Word. Complicated tables, with nested rows or columns or blank cells, can be difficult for assistive technologies to navigate. For tables with large amounts of data or complicated structures, it was best to use Microsoft Excel.

The formatting of objects and images depends on the use of the document. For example, if constructing a document that is meant to be accessible to all students, it is best to enter alternate text for each image by clicking on the object, selecting *Format Picture*, navigating to *Alt Text* and entering information about the image in the Description field. While a description of the images sufficed for some pictures, given the nature of the material covered in AME 341 it was often necessary to illustrate diagrams. Circuit diagrams, free body diagrams, plots, and other critical illustrations were all drawn by hand by the TA using the Sensational Blackboard [10]. This accessibility device allows users to create indented drawings using standard paper and a ballpoint pen. The initial plan for the 341 course was to use the Graphiti to display the many diagrams digitally. However, the low-tech and low-cost ($50) Sensational Blackboard was able to produce better quality diagrams in less time. The following practical tips were found to make drawings easy to interpret

- Two parallel lines should be at least 0.5 cm apart
- All text should be at least 1 cm tall (In general, 1.5 cm tall lettering for capital letters and 1 cm tall lettering for lowercase or subscripts)
- Dashed lines should have dashes which are about 0.5 cm apart to differentiate them from a solid line
- Rounded lettering is easier to read (e.g. a Futura-like font)
- Adding serifs to both lettering and diagrams helps makes it clear where a line ends. This is especially important in denser diagrams or text.
- If drawing multiple diagrams on a single sheet of paper, make the distinction between the diagrams clear by folding the paper and creasing along the division
- When dotting, draw small circles.
- A 0.7 or larger ball point pen is necessary. Any thinner risks tearing the paper.

The Sensational Blackboard was used to draw all lecture and circuit diagrams necessary for lab. When a diagram was made for lecture and corresponded to a specific lecture slide, a comment was written into the lecture notes, and the hand-drawn diagram was titled with the slide and lecture number. Example diagrams drawn with the Sensational Blackboard are shown in Figure 3. These were given to the student one week in advance of lectures and labs along with Word versions of the lecture notes. The Sensational Blackboard also proved a crucial tool when working on assignments or in office hours, since it could be used to draw accessible diagrams in real time.

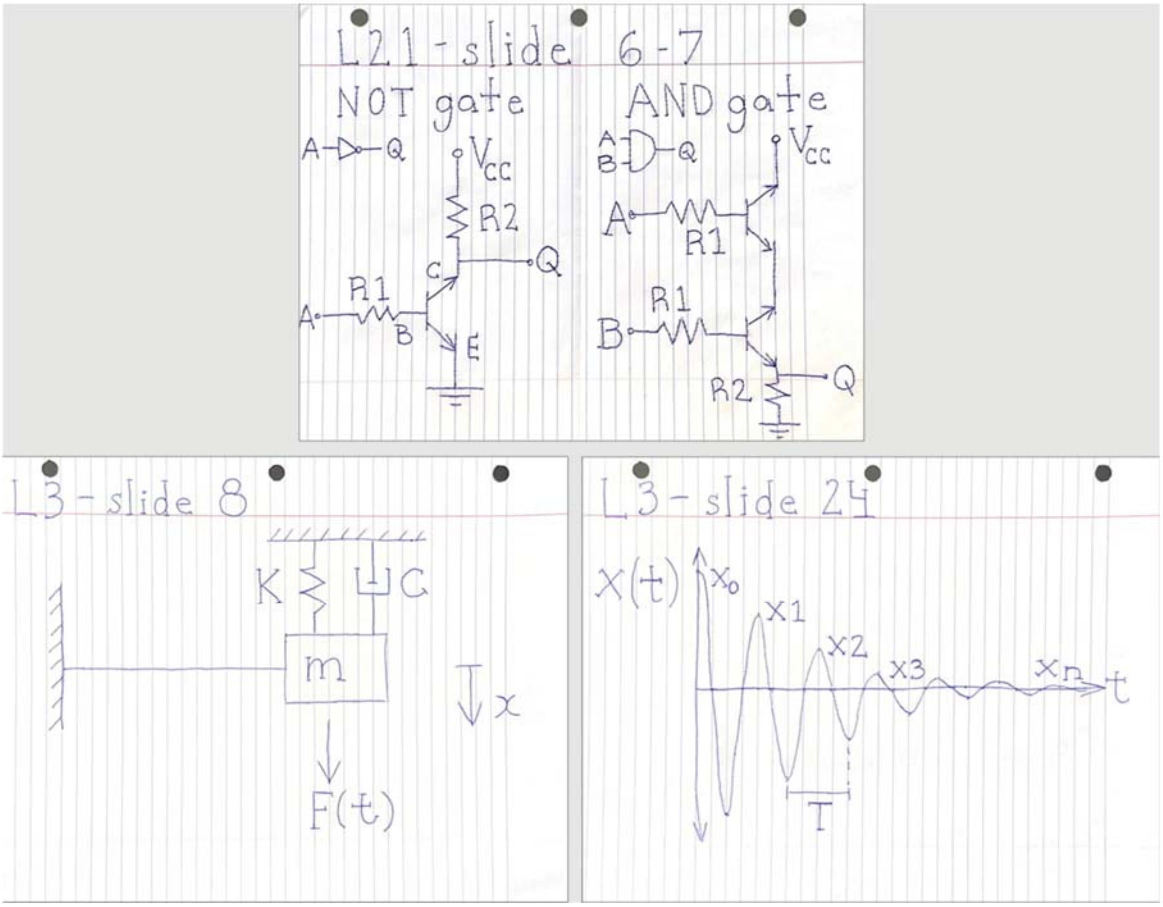

Figure 3. Examples of lecture and lab diagrams drawn with Sensational Blackboard. Drawing on this device using notebook paper and a ballpoint pen results in raised tactile diagrams.

Assignments for AME 341 require students to process data and create professional quality written reports with both graphics and text. Assignment requirements remained the same for all students and only small rubric changes were made for items without a clear path toward accessibility. The presentation of graphics in homework assignments remained required and was accomplished via MATLAB plot generation and feedback provided by sighted course aids. Excel was also used in the course for data analysis. Graph creation in Excel does not have a ready accessible solution therefore presentation of all results was conducted in MATLAB.

Written reports were successfully completed by the student throughout the semester and the general rule when grading assignments was to consider only formatting elements which offered accessible feedback. As an example, the numbering of equations in Word is often inconsistently read by a screen reader. Thus, errors in equation numbering were not considered in the accessible grading rubric. The general requirement for formatting and presentation was that data be organized in a way which would be clear to another engineer. Requirements for calculations, writing and technical knowledge were held to the same standard as all students.

III. AME 341b: Mechoptronics

a. Course Requirements and Equipment Overview

AME 341b "Mechoptronics" is the second semester of the laboratory sequence. Students are expected to implement the technical skills they developed in the previous semester to integrate hardware and software and create automated experimental platforms. The core equipment used for these experiments remains largely the same as the first semester, and accessibility techniques previously applied may be carried over. However, the mechatronics portion of the course curriculum relies on National Instruments LabView software and National Instruments hardware. Students write programs in NI LabView that send and receive digital and analog signals to a variety of sensors and actuators. NI LabView is inherently a visual programming language without an accessible command-line option. Thus, an alternative control method is necessary to adapt the existing laboratory curriculum.

Scientific communication is a continued focus in AME 341b and students are expected to create spreadsheets, presentations, and written research papers. These exercises are spread out over increasingly complex experiments with benchtop equipment such as vibrating beams, simple open-loop motor control, and physical property measurement of strain, pressure, and temperature. Bench-top experiments like those in AME 341a are adapted using tactile labeling, the tactile oscilloscope and TA assistance.

For the late-term experiments that rely on large, permanent installations such as the Wind Tunnel, alteration of the physical setup to increase accessibility presents a logistical challenge. In these cases, a reasonable approach to an equitable experience is to use the Graphiti tablet to tactilely represent the live data acquisition. The focus of the large experiments is to expose the students to large datasets that are pooled from an entire week's worth of lab time, which can then be easily processed with the same accessible tools as the rest of the class (MATLAB and MS Excel.)

b. Development of an Accessible Alternative to NI LabView

The first 10 weeks of the AME 341b curriculum are fully reliant on NI LabView to introduce computer-based hardware control. Fortunately, there are many options that are inherently more accessible to a visually impaired user than LabView. The question is thus which is the most appropriate solution for a third-year engineering student in our current (and future) curriculum. Accessibility-oriented languages and frameworks such as Quorum and Bootstrap do not have the same level of functionality as MATLAB or Python. As the focus of the course is on the scientific process of data acquisition and analysis, it would be an undue burden for the student to also be expected to learn an entirely new coding environment without classroom and curricular support. For this reason, MATLAB was chosen as the platform to replace LabView. MATLAB is used extensively in USC's course prerequisites and has the advantages of prebuilt toolboxes that interface with National Instruments Hardware. This environment has already been introduced for simple data collection in the first semester of 341a. In the second semester of the course, students create software to both read and write digital and analog data, which is straightforward to do with the same DAQ. Therefore, the educational goal of extending previous programming knowledge to new applications is maintained with a simple change in platform, without a loss in overall content.

There are still limitations to this solution; only MATLAB Online has screen reader capability and it is not compatible with hardware toolboxes. Thus, the workflow will likely still involve an aide as a go-between. Code typed in the online environment can be copied into a local MATLAB script and executed, but the expected debugging process would necessarily involve copying the command output into a word processor with accessibility tools each time code is executed. This would be unduly cumbersome in time and effort without a secondary person to assist. While not the most efficient solution, this avoids the need to teach an entirely new programming language to the student. For curricula that use Python or equivalents from an early stage, the work done for this class can be easily used as a framework and translated into the appropriate syntax.

IV. Test and Measurement Accessibility Limitations

The process of creating accessible laboratory courses has yielded several successful solutions. However, there is significant work required for truly independent accessibility in a test and measurement environment as evidenced by the reliance on the TA as a sighted aid for most laboratory tasks. The majority of common laboratory tools do not have accessibility considerations from their manufacturer. For the few laboratory instruments that do have accessible versions, they are often not available in a quality suitable for a professional environment. For example, braille calipers are commercially available, but their resolution is limited to 1/16 of an inch.

Accessibility also remains an issue for industry standard software such as NI LabView and MATLAB. Only the online version of MATLAB is configured for use with a screen reader and the desktop version of the software does not offer this accessibility. This leads to a severe restriction in the use of toolboxes, as the online version of MATLAB only supports a limited set. According to the MATLAB website, “Given the advances in accessibility for the web, we are focusing first on increasing the accessibility of MATLAB® Online™” [11]. This poses a barrier for the student to interface MATLAB with other programs and hardware and removes access to major functionality of the MATLAB program.

True accessibility in a classroom or professional laboratory setting requires that all equipment and software be accessible for a student with no or little usable vision. This can be achieved through auditory feedback, tactile feedback, braille, or a mixture of the three. Tactile feedback along with verbal or written descriptions should be used for graphics, while braille or auditory feedback, such as a screen reader, should be used for math and text. For measurement devices, auditory or braille feedback should be incorporated into the devices. Alternatively, if a device can output data in compatible formats, a screen reader could be used to read the data. If this is not possible, devices such as calipers or multimeters should have braille or auditory feedback. There are very few accessible measurement devices on the market, so more accessibility in this space would be welcome.

Ultimately all software should be made accessible with screen reading software. This includes labeling all buttons, links, and elements as well as including image descriptions and making sure the layout of the software is not confusing to a person using a screen reader. It is also necessary to check potential solutions against actual screen readers before offering accessibility solutions to students. Often a proposed software solution was created by an instructor only to realize that it was incompatible with either common or preferred screen reading software. The two most popular screen readers are NVDA and JAWS. It's necessary to cross check solutions against these tools and not assume functionality.

V. Outcomes & Conclusions

The Aerospace and Mechanical Engineering Department at USC has adapted our core Junior laboratory sequence (AME 341a & AME 341b) to be accessible for the visually impaired. A visually impaired student was able to meet all course requirements in the standard course curriculum and most importantly, the laboratory experience was maintained so that the student achieved the same desired educational outcomes and benefits of laboratory instruction as their sighted peers. Our student completed the course in the top 50% of the class for both AME 341a and AME 341b completing all assignments and assessments with all students evaluated under the same grading criteria.

Accessibility tools and techniques documented here can serve as a template for other universities adding accessibility to their engineering curriculums. Additionally, limitations encountered during this process highlight the need for increased accessibility from manufacturers of both engineering hardware and software.

This effort at USC was considered a success by both instructors and our student. Nevertheless, this work should be considered as a first step in the process of accessibility and not a ready solution. Educational continuity was maintained only through leveraging significant University resources and there still are fundamental engineering functions which do not offer accessible alternatives. The effort and labor required for adapting these courses could have been significantly reduced if the original course materials had been created with the accessibility guidelines discussed above. This would result in a gradual adoption process as opposed to a resource intensive push to convert an entire course in a short time scale. Similarly, the need to develop accessibility tools ahead of the academic year required high-effort focused projects at USC. If experimental accessibility accommodations were developed in a proactive as opposed to a reactive manner, they could be also created gradually using less institutional bandwidth. Industry produced accommodations for experimental accessibility in common hardware would also reduce requirements for academic institutions facing limited resources. Fully independent accessibility in a laboratory environment will require significant development from engineering equipment manufacturers and software providers who ultimately set industry standards.

VI. References

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