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Designing a Bioinstrumentation Lab for All Learners

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Designing a Bioinstrumentation Lab for All Learners

Introduction

Combining the experiences of the instructor, teaching assistant, and students, we utilized participatory action research and the application of entrepreneurial mindset to improve the experience for all students in a difficult lab course. The biomedical instrumentation lab course is required for all undergraduate bioengineering majors and is a technical elective for several other engineering majors at a large public land grant university in the Midwest United States. The course content has been challenging for many students. Additionally, some students noted other challenges in the lab, e.g., reading labels on parts, lights, and lab bench layout. The goal of this project is to reduce these challenges with the content, space, and supplies.

In the first phase of the project, the research team used methods from Universal Design for Learning (UDL), human centered design, and entrepreneurial minded learning to evaluate the laboratory space and course materials and generate ideas for improvement. Several ideas were investigated further for feasibility. In the second phase of the project, a few of these ideas were implemented in the course and feedback was solicited from current students. This paper will discuss the brainstorming process and outcomes, changes made to the course and space, as well as some preliminary feedback.

Diversity, Equity, Inclusion, Belonging, and Access in Undergraduate Laboratory Courses

Diversity, equity, inclusion, belonging, and access (DEIBA) is an initiative that emphasizes the significance of constructing environments where individuals feel welcomed, respected, and presented with equal opportunities to succeed [1]. Lab environments have often lacked DEIBA, resulting in potential or inadvertent microaggressions, unconscious bias, and unequal opportunities for various individuals. Historically, students of previously privileged social groups do not recognize the value of learning about others' cultures or identities [1], allowing for an imbalance in scientific contribution. For example, not all STEM laboratory spaces are accessible to students with disabilities [2]. If DEIBA negligence continues, it will reinforce non-inclusive lab environments and contribute to overall homogeneity. Investigating contributing stress factors is crucial to proposing evidence-based strategies that implement DEIBA principles. By nurturing a more inclusive, positive, and rewarding learning environment, this research has the potential to improve students' experiences and enhance the quality and impact of scientific research.

While most students achieve the learning objectives in the bioinstrumentation lab course, anecdotal evidence suggests that the environment creates different levels of inclusion, belonging, and access which can increase stress for some students. This disconnect illustrates the motive to bridge the gap between attaining academic goals and promoting a positive learning environment for all.

Background on UDL, EM, and HCD Approaches Applied to Courses

Universal Design Learning (UDL) is a concept that aims to maximize learning by applying universal design to all aspects of instruction [1] and challenges the notion of separating the class instruction based on students' disability status, instead focusing on providing accessible education to all [2]. It recognizes the need to make systemic and structural changes to the framework of a particular course, making it more engaging for all students while not tailored to a specific individual [2]. UDL can be integrated into teaching in several ways, including encouraging peer-to-peer learning with informal/formal discussions, using different instruction methods such as interactive tools and visual aids, and being inclusive in assessment techniques like giving opportunities for do-overs [3].

Entrepreneurial Mindset (EM) is defined as "the inclination to discover, evaluate, and exploit opportunities" [4]. One can include EM in their instruction by focusing on integrating the three Cs of EML: *curiosity* about how something works and can be made better by challenging established protocols to consider multiple points of view [5], *creating value* out of something by asking questions and optimizing resources to see it as potentially applicable to helping the society [6], and *connecting* how different aspects of knowledge and general information are all related to one another [7].

Human-centered design (HCD) is an approach to problem-solving that applies design thinking to identify solutions to unmet needs of a population. HCD includes phases of understanding, synthesizing, ideation, prototyping, and implementation [8]. Throughout the phases, HCD emphasizes creativity and empathizing with people. Design thinking has also been applied in the design of courses [9], [10].

A common thread from UDL, EM, and HCD is collaboratively identifying solutions to meet the needs of many users. As such, methods from all three frameworks were applied throughout this project to identify potential improvements to the bioinstrumentation lab.

Background on Participatory Action Research

One common application of participatory action research (PAR) is developing knowledge and identifying opportunities for quality improvement. The PAR approach combines participants and experts in the research of social practices [12]. Generally, PAR includes cycles of reflection, planning, action, and observation. In education, PAR can be employed by instructors who wish to improve their teaching or courses by gathering evidence of teaching effectiveness and achievements of student learning outcomes to assess the changes implemented [13]. PAR combined with the design strategies mentioned above creates a space to bring together different participant perspectives to collaborate in the process of improving a course by applying successful problem-solving strategies.

Methods

This project used participatory action research to apply frameworks, reflections, and design thinking to improve accessibility and belonging in a biomedical instrumentation laboratory course. The specific course context and methods used are described in this section.

Course Context

This course is a laboratory course that builds on students' previous learning of circuit theory and biomedical instrumentation. Each week consists of a 1-hour introduction lecture from the instructor and a 3-hour section in the laboratory space with the guidance of graduate teaching assistants and undergraduate students who previously took the course. Before the lecture each week, there is a pre-laboratory assignment where students are asked to solve equations to calculate circuit parameters and design the circuit in an online circuit simulator. Within the lab time, students follow step-by-step instructions that guide them through the construction and validation of their circuits. Following each lab section, students complete a post-laboratory assignment where they present their results in a lab worksheet and reflect on their in-lab experience. The post-laboratory assignment is graded as complete/incomplete, where an incomplete grade is returned to students with comments on how to revise and resubmit to earn a complete grade on the assignment [14].

Within the class, students learn how to build circuits, design and implement filters, utilize operational amplifiers, utilize electrical sensors to measure temperature, and build a working electrocardiogram (ECG). Building circuits requires a great deal of troubleshooting, which can be very difficult for students who are new to this discipline and can be discouraging. Teaching assistants are available to help guide the troubleshooting, but the class is built around the student's development of these skills independently. A lab practical at the end of the structured lab portion tests their ability to troubleshoot and construct circuits independently. The second part of the term is reserved for a cumulative project, called Design Your Own Experiment, where students implement the circuit theory and skills they have learned throughout the semester to design, build, and validate a biologically relevant instrument, such as an electromyogram (EMG), electrooculogram (EOG), or a pulse oximeter.

The composition of the class is very varied in level of experience, where the majority of the class is learning how to translate and build physical circuits for the first time (90% of the class), while some students are taking this as a technical elective and have a large background in the implementation of circuits (10%). This imbalance in experience makes this a difficult course for instructors to balance and for the less-experienced students to feel supported and on track. The pace of the course requires students to learn and troubleshoot quickly in order to complete the modules within their time in lab. The difficult learning curve necessary for this class can lead students to feel discouraged and that they don't belong in bioinstrumentation. As this is the majority of the students' first exposure to bioinstrumentation in their major, this disillusionment is a concerning problem that the professor sought to rectify by increasing inclusivity in the bioinstrumentation lab.

At the beginning of every semester, an introduction survey is distributed to the students as part of the typical classroom work. This survey previously included a space for students to provide their pronouns, describe in their own words what they hoped to learn in the course, and provide any planned absences or concerns about attendance. To better gauge how students felt about topics related to the course, the students were asked to assess themselves from "Not at all familiar" to "Extremely familiar" for eight course topics. These included: analyzing basic electrical circuits, reading an electrical circuit schematic, understanding frequency representation of a signal, understanding of basic filters, analyzing circuits with operational amplifiers, building circuits on a breadboard, MATLAB, and Simulink. After the survey results were anonymized, the survey responses were summarized for pronoun demographics and self-assessment ranking. The survey responses were quantified by number of responses for each rank on the scale of "Not at all familiar" to "Extremely familiar" (See Figure 1).

While some topics scored highly, for example, MATLAB use (a software most students have worked with in other classes) had 79.7% of students state that they were moderately to extremely familiar, others made the divide more apparent. Building circuits on breadboards and analyzing circuits with operational amplifiers had 53.1% and 64.1% of students respectively say they were slightly to not at all familiar with these concepts. In a free response section where students were asked what they hoped to learn, statements like “I hope to learn how to navigate circuits at least at a basic level” and “I have previously struggled with this topic, so I hope that this class will allow me to become well-versed in this subject” were reiterated in many responses. Out of the 64 responses (4 students did not respond), 24 of the students identified as he/him (35.3%), 39 identified as she/her (57.4%), and 1 student identified as they/them (1.5%). To respect the privacy of the one student who identified as they/them, their data will not be shown in the pronoun separated data. These survey results highlight a divide in experience, lack of confidence in areas of study, and that a majority of this class was made up of people historically excluded from STEM. For these reasons, we sought to increase inclusivity and accessibility in this course to improve student experience.

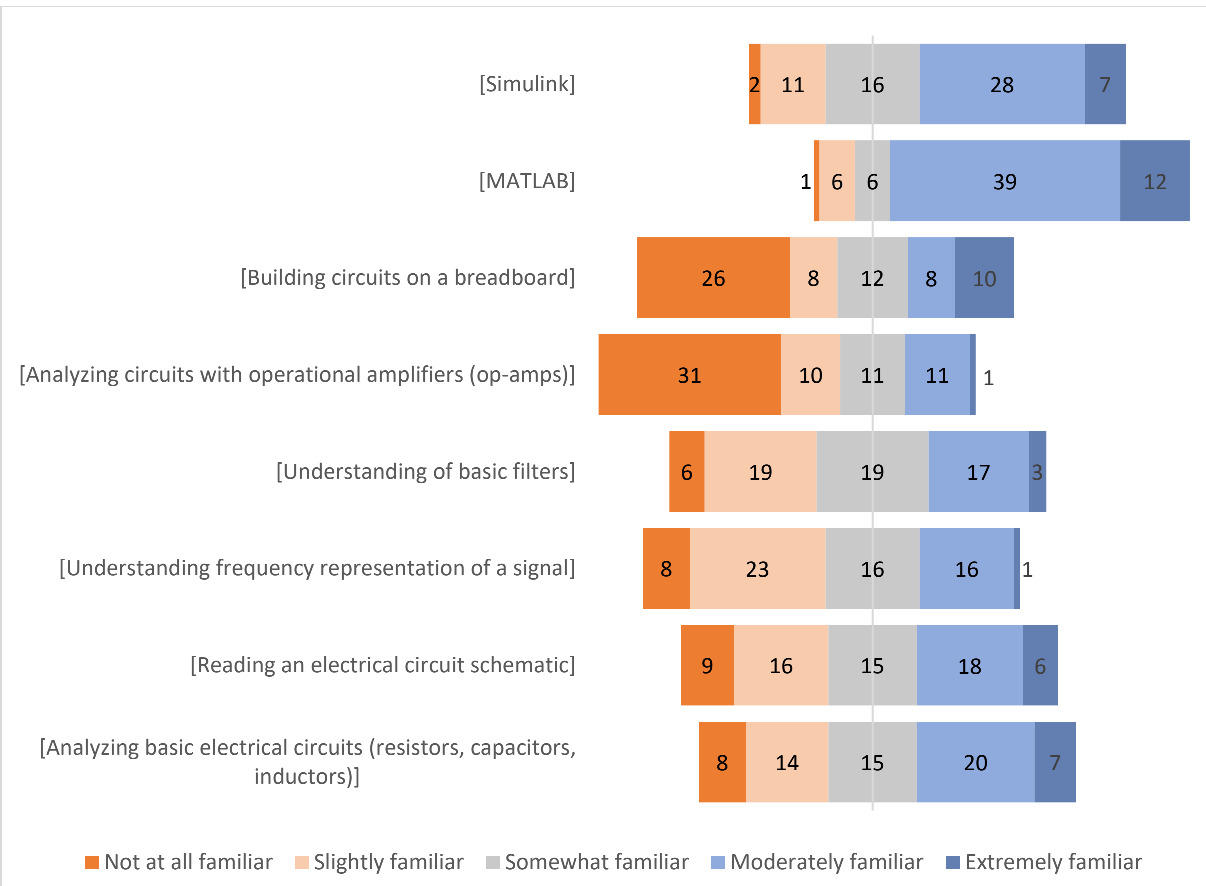

Figure 1 - Number of students based on self-ranking of familiarity with key course concepts.

The laboratory physical space consists of twelve complete lab stations arrayed in six evenly distributed clusters each with two chairs (See Figure 2). The lab stations and chairs are height adjustable, although the lab stations require at least two people to adjust properly. Each lab station has a desktop computer, an oscilloscope, a digital multimeter, a function generator, and a

DC power supply. The front of the classroom (east) contains a long panel of whiteboards where teaching assistants write helpful notes on how to accomplish each week's module. A projector screen descends in front of the whiteboard. Both the whiteboard and screen can be obscured by lab stations for the students located in the back of the room. At the north end of the classroom, students are provided with lockers to store their lab equipment (e.g., circuit board, resistors, wire kits). On top of the lockers, common resistors and capacitors are stored in stacked organization bins (See Figure 3). Just southwest of the lab center, a large pillar stands between benches and impedes movement in that section of the space.

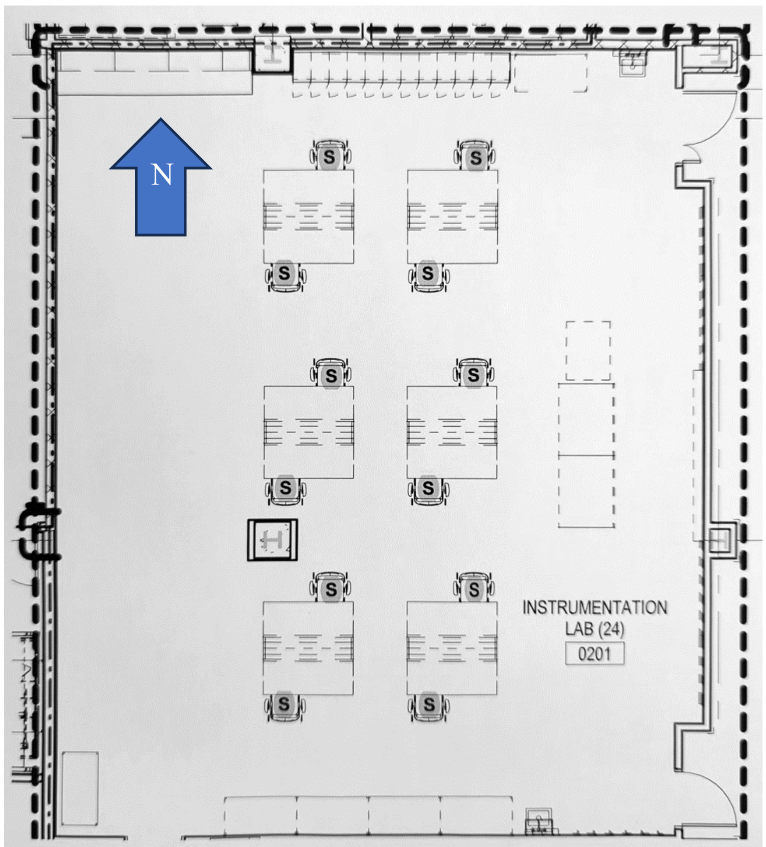

Figure 2 – Floorplan of existing lab space during COVID. North is up.

Figure 3 – Lockers and parts storage in the lab space.

Approach for Identifying Potential Improvements

Through an independent study course, a team was assembled with the shared goal of increasing impact and inclusivity of the bioinstrumentation lab course with a variety of different perspectives. The team consisted of the professor of the lab course, a former teaching assistant, a former student, and an outside perspective from a student in a different, but related, department. The principles of human-centered engineering design, universal design for learning, and the entrepreneurial mindset were utilized together to understand the barriers, synthesize findings, identify pathways to address the problems, develop solutions and implement these proposed changes to increase the students' feeling of belonging in the course. The principles of participatory action research guided the creation and makeup of the team, prioritizing direct experience and collaboration through dialog, ensuring that different perspectives were present and represented equally.

The team first focused on understanding the barriers faced by students, using a mindset of curiosity to inspire the team's investigation. The testimonies of the professor, former teaching assistant, and former student were all heard and used to generate a list of concerns from each perspective. The team then began a systematic review of the physical lab space, course website and online materials for accessibility and student inclusivity. The focus was on ensuring accessibility for all students and identifying changes that would improve the students' experience. Following this initial assessment, the team utilized several published resources designed to assess the inclusivity of a course to discuss which areas the course was already inclusive and what areas could be improved upon. Additionally, the team attended a course presented by the university's Center for Design that taught how to identify human-centered engineering design learning opportunities for engineering courses by mapping the course learning objectives to engineering design activities and the various spaces of Bloom's learning taxonomy. This helped to guide the emphasis on engineering design of the class and identify the areas for improvement to more completely address all levels of the taxonomy.

After this inspiration phase focused on understanding the problems facing students in this bioinstrumentation course, the team sought to integrate their findings and brainstorm solutions to address identified issues. A list of ideas was generated and assessed for their ease of implementation, potential impact, and feasibility. The ideas were separated into physical space changes, course material changes, and course structure changes. For each category, the team split the ideas amongst themselves to source materials, identify potential different solutions, and rate their feasibility. The feasibility rating took into consideration project limitations including a limited budget, time to develop materials, and not changing the course learning objectives as that would require approvals beyond the scope of the project. After this period of research, the team reconvened and decided which changes were the focus of implementation for the next term and what were longer term goals that required more time or resources to be effectively implemented. The shorter-term changes were divided between the team members to implement before the beginning of the next term.

Results

Analysis of student introductory survey responses indicated that emphasis of inclusivity and belonging might help address student disillusionment with bioinstrumentation. Students identifying as she/her (57.3% of the class) consistently ranked themselves as less familiar with the topics than those that identified as he/him (35.3% of the class) (See Figure 4). The largest difference in rating was 37.2% on understanding basic filters topic, with 53.8% of students identifying as she/her ranked themselves as having slight to no familiarity, while only 16.7% of those who identified as he/him answered the same. Another large difference was noted for the analyzing circuits with operational amplifiers topic, 74.4% of students identifying as she/her ranked themselves as having slight to no familiarity, while 45.8% of students identifying as he/him answered the same. The smallest difference, 2.2%, was for MATLAB, 10.3% of students identifying as she/her ranked themselves as having slight to no familiarity, while 12.5% of students identifying as he/him answered the same. This is also the only category where fewer students identifying as she/her ranked themselves slight to no familiarity than students identifying as he/him. While this survey did not collect demographic data outside of preferred pronouns, the trend between the two pronoun populations highlights that those who have historically been excluded from science are less sure of their abilities, even though the majority of students have had the same exposure to these concepts in previous courses.

This data led the research team to work through various inclusive course design frameworks in order to discuss challenges and potential improvements. This section will describe the team's learning and implemented changes from the specific methodologies outlined earlier. It will also analyze the impact on student attitudes over the semester.

The team analyzed the physical bioinstrumentation lab space by designating smaller areas of focus and working in the same order that a student would encounter the room during a typical lab session. Within each focused segment, the team identified strengths, weaknesses, opportunities for improvement, and threats to navigating and working within the lab (SWOT analysis). The team discovered that an important aspect of this process was to analyze the obvious. For instance, the lab doors in this specific building were particularly heavy, such that most students would have to put some amount of effort into pulling the door open. It was clear that students with mobility impairments, for instance wheelchair users, would face a potentially aggravating and discouraging challenge right at the outset of lab if they struggled opening the door to enter. This problem could be solved with a simple doorstop, but it serves as a good example of how simple challenges can set the tone for a feeling of belonging in a physical classroom space. In this vein, the team researched Americans with Disabilities Act (ADA) space allowance and reach range guidelines [15] to ensure that all students, especially those with mobility impairments, could independently navigate the lab space, maneuver around benches, and reach lab materials, computers, and benchtop equipment. This research inspired changes to equipment storage and the development of detailed protocols in case that specific students needed space accommodations, such as lowering the benchtops or moving equipment. With these protocols, course staff can quickly adapt the lab space to meet student needs, alleviating some of the burden on students to constantly advocate for themselves. Of course, improvements to lab space are not limited to mobility. Poor lighting, whiteboard visibility from each student bench, and reading small labels on electrical components can be a challenge to many students, including those with visual impairments or conditions that contribute to chronic migraines. Solutions to these challenges can depend on a specific lab's budget and needs, for this course the team utilized undershelf LED strip lighting at each lab bench and a magnifying glass with a light to read electrical components. The annotated photo in Figure 5 highlights the updates to the physical space that have already been completed.

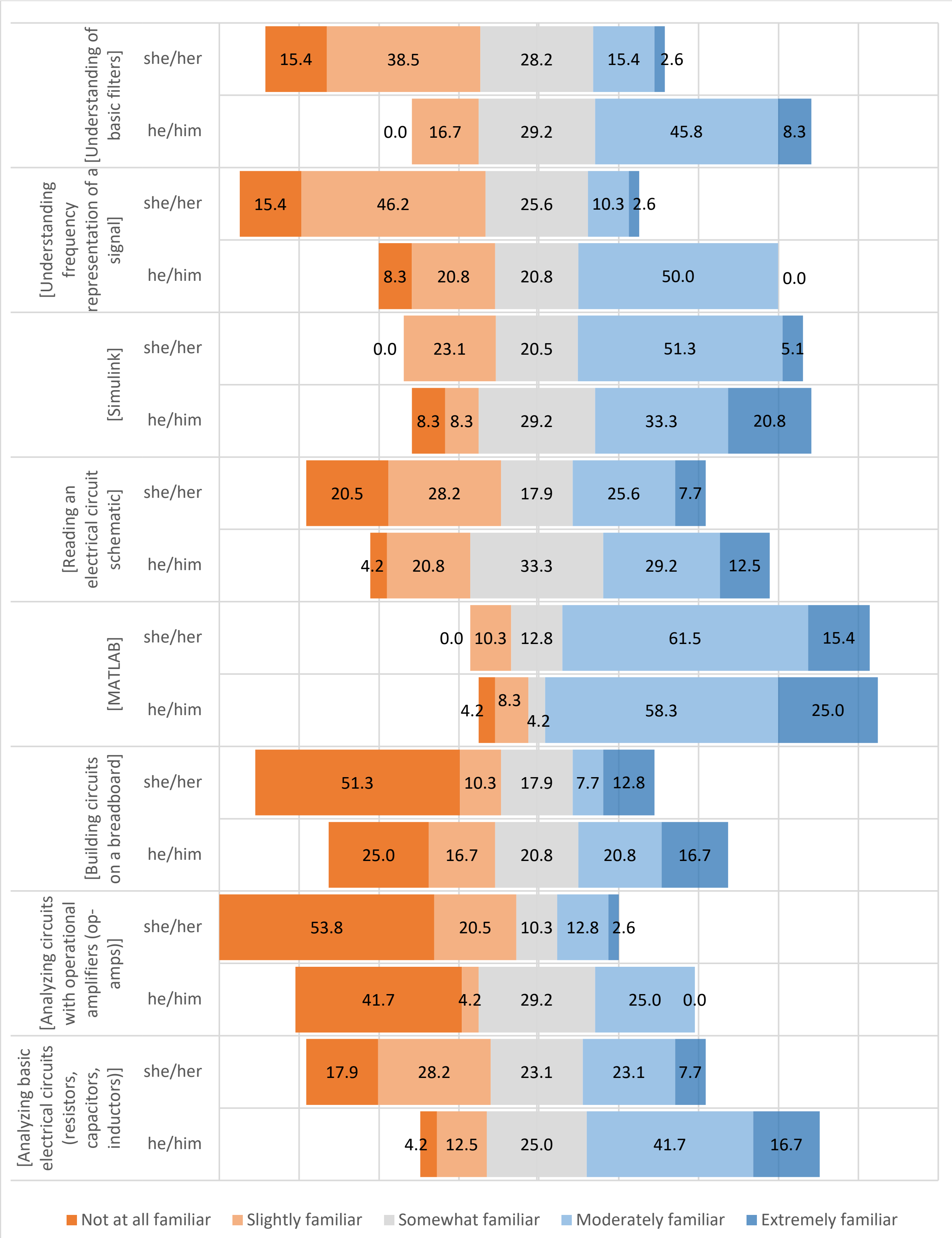

Figure 4 – Percentage of students self-rating of familiarity with course topics split by pronouns

In addition, it is important to analyze methods of delivering course content for accessibility issues. The team discussed and navigated through each aspect of the course's main page and electronic textbook to ensure that assignments and expectations were clearly communicated, and additional resources were easy for students to locate. It was also necessary to investigate screen readers and other online tools to ensure that documents such as lab protocols, assignments, and material and component documentation are accessible to those with disabilities.

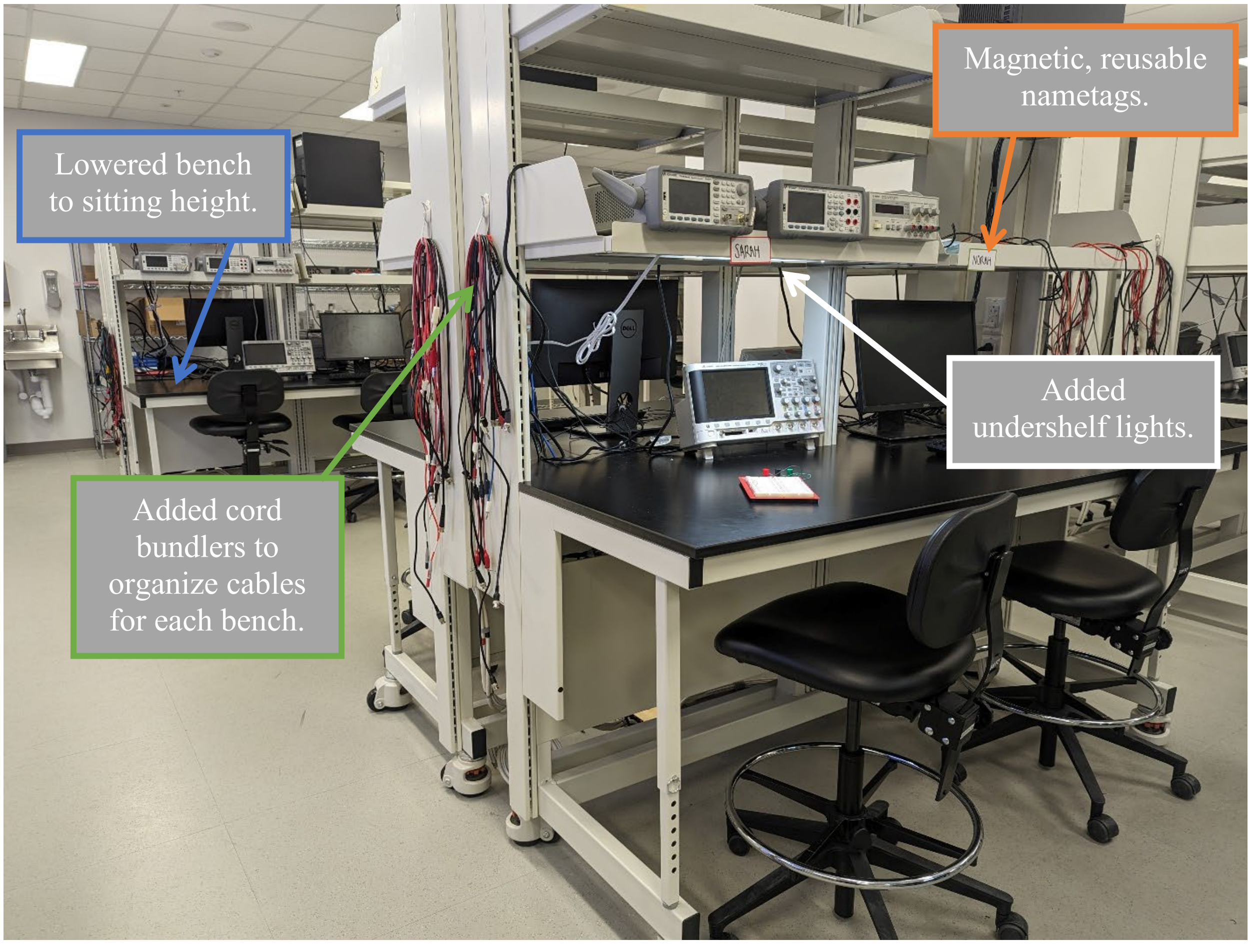

Figure 5 – Annotated picture of select updates to the lab space.

After analyzing the physical lab space and assignments separately, the team utilized the University of Michigan Center for Research on Learning and Teaching's 5 Elements framework and Equity-Focused Teaching Strategies Reflection to assess the course holistically. The goal of this reflection is to frame student diversity as an advantage for learning, encourage transparency between course staff and students, and build systems that accommodate empathetic and equitable learning [15]. The team worked through this reflection together, discussing the large range of equity-focused teaching practices to determine which were applicable to a lab setting, which were already being utilized, and where in the course a practice could be integrated. From this reflection, we identified improvements including training course staff to provide growth mindset-based feedback on assignments and lead a norm-setting discussion in the first lab to establish course expectations. In addition, template deliverables were provided on the course page in order to demonstrate an example of work that would be given a "complete" grade. This was done to provide grading transparency and help set expectations for student work. It was also suggested that interested students could be recruited as an advisory board to proactively gather feedback on the course and gauge the impact of introduced changes.

During further discussions on equitable teaching practices, post-lab reflections were identified as a method for students to relate course material to issues facing their communities and provide feedback on their learning experience. Students in past offerings of the course have been asked to fill out a 100-word reflection after completing each lab, which asked what aspects of the laboratory assignment met or did not meet student expectations, how it surprised, excited, or frustrated, what lessons were learned from the assignment, whether partners worked effectively together, and for any additional questions students still had.

Based on past course experiences, team discussed and agreed that current reflection prompts may not adequately stimulate students to think about what they learned, concepts they still needed to review, and whether they needed to change group work or troubleshooting strategies to succeed in the next lab. The reflection also did not adequately prompt students to let the course staff know about questions they still had or concepts they still did not understand after each lab.

As a result, using the critical incident questionnaire [16] as a guide, the team adjusted reflections with the goal of better evaluating learning and comprehension in lab. Updated post-lab reflection questions asked students at what point in the lab assignment they were most engaged or distanced as a learner, what action from course staff and peers was most or least helpful, and what surprised, excited, or frustrated students. This reflection provides opportunities for students to reflect on team dynamics and how peers improved their learning process. In addition, each reflection included a few questions tailored to specific labs, to assess whether important concepts were understood. The reflection can also serve as a way to integrate DEIBA and design thinking in the course, students were asked to consider how bioinstrumentation might need to adapt to solve problems faced by diverse patient populations. Students have the option to answer any of the questions in the prompt, with the goal of improving the course staff's ability to gauge conceptual understanding and whether students feel engaged and capable of success in class.

Discussion

The project represents a significant step forward in creating inclusive educational environmental in STEM field. The project's approach, integrating the interdisciplinary approach, incorporating participatory action research, UDL, human-centered design, and entrepreneurial mindset, the lab's learning environment has been significantly enhanced overall, offers a comprehensive framework for addressing inclusivity in lab setting. The team employed various methods to evaluate and improve the lab space and course materials by taking on different lab users' roles.

By focusing on the physical accessibility of the lab, such as addressing the inconvenience of the lab door, lowering benchtop, and moving equipment while ensuring the ADA compliance, the team demonstrated that even minor modifications can have a substantial impact on fostering an inclusive and welcoming environment. The identified improvements are not limited to physical inaccessibility, but also including inadequate lighting and difficulties in reading small labels, disproportionately affected students with visual impairments. Addressing these issues through practical solutions like improving lighting, magnification equipment, and clearer, larger labels not only catered to the students but also enhanced the overall lab experience for all students.

This project serves as a model that can be replicated and adapted in different educational contexts. While UDL has been broadly applied to lecture courses in different universities, there are limited examples of UDL applied to a STEM lab course. Additionally, applying broader design thinking strategies such as human centered design and entrepreneurial mindset to the development of a course is also widespread. The methodology and the thinking process provide a blueprint for other institutions to enhance their learning environment. The inclusion of incorporating feedback from students, which was pivotal in understanding and addressing the diverse needs and perception within the lab. By including students and staff in the research process more perspectives were captured during the brainstorming and reflection activities than would have been captured through traditional feedback surveys. This process emphasized the necessity of creating a learning environment where every student feels a sense of belonging, is able to participate fully, and has a voice in the course design. For instance, the use of post-lab reflections and surveys provided insights into students' engagement, comprehension, and perceived challenges, enabling continuous improvement of the lab experience. While this data has been collected throughout the first semester of changes, there was not time to fully evaluate the changes before the publication deadline.

While the outcomes of these interventions are specific to bioinstrumentation lab, the underlying process of identifying and addressing challenges through different stakeholders' involvement is universally applicable. Other educational institutions could adopt similar methodologies to improve their own learning environments, regardless of the student population. Future research could explore the long-impact impact of such inclusive design changes on students' engagement and performance, potentially leading to better changes. By sharing the methodology and outcomes, the team hopes to inspire other educators to undertake similar initiatives, leading to a more inclusive and effective learning environment across various educational settings.

Conclusions and Future Work

In this project we created a team of various perspectives: instructor, teaching assistant, former students, and students who have taken similar courses. The team used frameworks from UDL and inclusive teaching to reflect upon different aspects of a biomedical instrumentation laboratory course to identify changes that could increase a sense of belonging and access for students in the course. Methods from human centered design and KEEN's entrepreneurial mindset were also applied to identify other opportunities for improvement. While this project was focused on a particular course, the methods utilized could be applied to other courses. In the next phase of the project, changes identified will be refined, implemented, and additional data will be gathered through course assignments, observations, and reflections.

Acknowledgements

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